Research Article

Effect of finishing technique on the occurrence and length of microcracks in resin-based materials

ADALBERTO B. DE VASCONCELLOS, DDS, MS, PHD, ALEX DELGADO, DDS, MS, RONALDO HIRATA, DDS, MS, PHD, RICHARD BLACKMON, BS, PHD, EDWARD J. SWIFT, JR., DMD, MS, HARALD O. HEYMANN, DDS, MED, AMY L. OLDENBURG, MS, PHD & ANDRÉ V. RITTER, DDS, MS, MBA

ABSTRACT: Purpose: To evaluate the presence and length of microcracks in resin-based materials finished with different techniques, using optical coherence tomography (OCT). **Methods:** Standardized Class V preparations (3×2×2mm) were made in the facial and lingual surfaces of 20 recently-extracted human third molars. 20 preparations were restored with a resin-based composite material (RBC; Filtek Supreme Ultra) and the other 20 with a resin-modified glass-ionomer material (RMGI; Ketac Nano). After final polymerization, specimens were further stratified by finishing system: aluminum oxide discs (Sof-Lex) or spiral fluted carbide bur series (H48L). By random allocation, each extracted tooth therefore received one RBC and one RMGI restoration, and equal numbers of restorations from each material were finished using each finishing system (n= 10). After 24 hours of storage in 100% humidity at room temperature, the specimens were evaluated at ×20 to ×600 under environmental SEM. Cross-sectional occlusal-cervical B-mode images were obtained in increments of 25 mm from the mesial margin to the distal margin of the restoration using a spectral-domain (SD) OCT system and analyzed using Image J software to identify and measure microcrack penetration into each restoration. The total length (mm) at the point of the deepest microcrack penetration in each specimen was recorded. Data were statistically analyzed using a t-test. **Results:** No microcracks were observed in the RBC samples. However, microcrack presence was identified in all of the RMGI specimens. The t-test showed a statistically significant difference ($P < 0.05$) in mean microcrack length values based on the finishing technique used for the RMGI samples. [SofLex: 0.67 (± 0.28) mm; carbide: 1.26 (± 0.30)] mm. Two-way ANOVA showed significant differences in the factors "finishing technique" and "restorative material" ($P < 0.001$). The interaction of these two factors was also statistically significant ($P < 0.001$). For the tested RMGI, Tukey post-hoc test revealed that the finishing with aluminum oxide groups resulted in statistically significant lower mean microcrack length when compared to spiral fluted carbide burs ($P < 0.001$). (*Am J Dent* 2016;29:294-300).

CLINICAL SIGNIFICANCE: Resin-modified glass-ionomer (RMGI) is more susceptible to microcrack presence than resin-based composites. Also, aluminum oxide discs produced lower values of mean microcrack length than spiral fluted carbide burs after the finishing procedure of RMGI restorations.

✉: Dr. A. Bastos de Vasconcellos, rua Doutor Sylvio Henrique Brauma 22, Centro, Nova Friburgo, RJ, Brazil. E-✉: adalbertovasconcellos@id.uff.br; prof.vasconcellos@hotmail.com

Introduction

Notwithstanding the remarkable advantages presented by resin-based materials in restorative dentistry, mostly due to their esthetic attributes and conservative nature, adhesive restorations are technique-sensitive and their success can be affected by many factors. Finishing and polishing of adhesive restorations are critical to generate desired anatomy, proper occlusion, and a smooth surface texture. A lack of proper finishing and polishing procedures can compromise marginal and surface integrity, therefore leading to staining of the restoration, gingival irritation and recurrent caries as rough surfaces lead to increased biofilm accumulation.[1-4] However, despite the unquestionable advantages of this clinical procedure, finishing has been linked to increased wear and microcrack formation in posterior resin-based composite (RBC) restorations.[5-7] In contrast, another study[8] showed that subsurface defects could be eventually found in both finished and unfinished surfaces. However, regardless of the discussion about a possible role of the finishing procedure in generating these imperfections, microcrack formation is directly related to water sorption and hydrolytic degradation, therefore representing a potential factor that could negatively affect the mechanical properties of RBCs.[9] Water sorption in resin-based restorative materials is regarded as a degradation process,[10] contributing to the loss of marginal integrity and surface properties.[11] A shortened lifespan of resin composites may occur due to the expanding and plasticizing of the resin component, silane hydrolysis and microcrack formation.[12]

Resin-modified glass-ionomers (RMGIs) represent another popular type of resin-based materials, featuring improved physical properties and esthetic qualities over conventional glass-ionomers by incorporating resin monomers.[13] RMGIs are essentially a conventional glass-ionomer with added resin, setting via both an acid-base reaction and a free radical polymerization process.[14] As a result of the hydrophilic functional groups present in their chemical composition, RMGIs are very sensitive to water sorption, showing a rapid uptake of high amounts of water, which can lead to lower flexural strength, lower elastic modulus and softer surfaces when compared to their behavior in a dry environment.[14] Furthermore, microcrack formation has been previously reported as the prevalent mechanism of long-term hydrolytic degradation in RMGIs.[15]

Even though several studies have been published reporting the effects of finishing and polishing procedures on the surface roughness of resin composites and RMGIs, not much has been

reported on internal defects caused by those procedures in resin-based restorations. Some studies[8,16] assessed subsurface defects in RBMs using scanning electronic microscopy (SEM), but only for a superficial (shallow) depth evaluation.

Optical coherence tomography (OCT) is an emerging diagnostic tool with potential for non-invasive and non-destructive cross-sectional imaging of dental tissues and adhesive restorations. OCT employs low-coherence interferometry to enable high-resolution, cross-sectional imaging of the internal microstructure in materials and biologic systems by measuring backscattered or reflected light.[17] Recent reports present OCT as a reliable imaging tool for the evaluation of marginal gaps in adhesive restorations,[18,19] caries lesions detection[20,21] and enamel crack evaluation.[22]

This study evaluated the microcrack presence and length in two types of RBCs finished with two different techniques, using a spectral-domain (SD) OCT system as a cross-sectional imaging diagnostic method. The hypotheses tested were that microcrack length in resin-based materials was influenced by: (1) the finishing technique; and (2) the restorative material. The study also used environmental scanning electronic microscopy (ESEM) to qualitatively perform a topographical microstructure evaluation of the samples' surfaces.

Materials and Methods

Specimen preparation and study design - Twenty freshly extracted, defect-free human third molars were collected and stored in 0.5% thymol for disinfection. The teeth were collected according to the rules for Protection of Human Research Subjects established by The Office of Human Research Ethics of the University of North Carolina at Chapel Hill. Two standardized Class V preparations (3 mm × 2 mm × 2 mm; mesiodistally, incisogingivally, and depth wise, respectively) were made in each tooth, one on the facial surface and one on the lingual surface for a total of 40 preparations. Each preparation was done using a new No. 271 carbide bur (H26M[a]) in a water-cooled high-speed handpiece, with the occlusal margin in enamel and the gingival margin in dentin.[23] The dimensions of all preparations were verified with a digital caliper.

Twenty preparations were restored with a resin composite (Filtek Supreme Ultra[b]), and the other 20 with RMGI (Ketac Nano[b]). Both materials were used following manufacturers' recommendations. For the RBC, the preparation was etched with 35% phosphoric acid gel (Scotchbond Etchant Plus[b]) for 15 seconds and then thoroughly rinsed with water for 15 seconds. An ethanol and water based dental adhesive (Adper Single Bond[b]) was applied on the hydrated dentin with a microbrush, rubbed for 15 seconds, slightly dried to evaporate the solvent, and then reapplied. It was light-polymerized for 20 seconds, and the RBC was inserted in two increments; the first increment was placed from the axial wall to the gingival margin and the second increment from the first increment to the occlusal margin. Each increment was light-activated with a light-curing unit (LED Demetron A.2[c]) for 20 seconds. The average of the curing intensity of the light-curing unit was 1,150 mW/cm^2.

The preparations restored with RMGIC were first coated with Ketac Nano Glass-Ionomer Primer[b] for 15 seconds to the prepared semi-dry enamel and dentin surfaces. It was slightly dried with air for 10 seconds and the primed surfaces were light-polymerized for 10 seconds. The RMGI was mixed and dispensed using the Quick Mix Capsule directly into the preparation, and the tip was kept immersed in the material to avoid air entrapment. The material was shaped anatomically using a Mini-3 placement instrument,[d] and then light-polymerized for 30 seconds.

Table 1. Finishing and polishing instruments specifications,

Groups	Instruments	Specifications (μm) particle size
Sof-Lex discs	Coarse	100 μm / 150 grit
	Medium	40 μm / 360 grit
	Fine	24 μm / 600 grit
	Extra Fine	8 μm / 1,200 grit
H48 fluted carbide finishing burs	Fine	12 flutes blade
	Extra Fine	20 flutes blade
	Ultra Fine	30 flutes blade

Specimen finishing and polishing - After polymerization, specimens were further stratified by finishing system. Aluminum oxide discs (Sof-Lex[b]) or spiral fluted carbide bur series (H48L[a]) were used to finish all RBC and RMGI restorations. By random allocation, each extracted tooth therefore received one RBC and one RMGI restoration, and equal numbers of restorations from each material were finished with each finishing/polishing system (n= 10). The finishing was done following the respective manufacturers' recommended sequence at a standardized force of approximately 0.15 N using a customized pressure/abrasion device.[23] The finishing sequence and the particle sizes (grits) are shown in Table 1 for each finishing system.

Environmental scanning electron microscope evaluation - After the finishing procedure, all specimens were stored in a moist environment for 24 hours to avoid dehydration. An environmental scanning electron microscope (ESEM) was used to qualitatively examine the topographical microstructure of specimen surfaces (Quanta 200 ESEM[e]). This microscope has the capability of imaging uncoated (low vacuum mode) and nearly wet (environmental mode) specimens, along with the conventional high vacuum SEM imaging. The instrument can be operated at variable pressure modes and hydrated specimens can be viewed without much preparation. It was used at the low vacuum mode with a 10.00 kV accelerating voltage, a working distance between 10-12 mm and a chamber pressure of 0.4 Torr. The specimens were observed first at ×20 magnification to see the entire restoration, and then the image was increased to ×80 and ×600.

Optical coherence tomography evaluation - After the ESEM evaluation, imaging of the samples was performed using a custom, ultrahigh-resolution SD-OCT system. The SD-OCT system was comprised of a Ti:Sapphire laser (Griffin[f]) with a central wavelength of 800 nm and bandwidth of 125 nm, resolution of 3 × 12 μm (axial vs. transverse, respectively), and a sample power between 10-15 mW. A previous study[24] described in detail the SD-OCT system used in this study. Each specimen was placed into the sample arm, and cross-sectional occlusal-cervical B-mode images were obtained in increments of 25 mm from the mesial margin to the distal margin of the restoration. The scanning beam was oriented at 90 degrees to

Table 2. Mean microcrack length and standard deviations (n= 10) in mm, and the statistical significance.

	Finishing system	
Resin-based material	Fluted carbide	Sof-Lex
Filtek Supreme Ultra	0.00 A	0.00 A
Ketac Nano	1.26 ± 0.30 B	0.67 ± 0.28 C

Different letters indicate statistically significant differences between groups (Tukey test, P< 0.001).

the buccal or lingual plane, depending on the location of the restoration. B-mode images were 3 mm wide (x) with a maximum imaging depth (z) of 1.34 mm, sampled into 1,000 × 1,024 pixels in x and z, respectively. A total of 121 B-scan images were obtained along each restoration such that the total dimensions sampled in volume were 3 mm × 3 mm × 1.34 mm. All B-mode images were contrasted and segmented to enhance features and remove artifacts.

The total length in millimeters at the point of deepest microcrack penetration in each restoration was identified by analyzing each one of the 121 B-scan images, then measured using a public domain software, Image J 1.48V.[g] Measurements represent lengths in the x and z plane only. Microcracks were identified by the observation of increased OCT signal intensity along a line within the dental material; in a previous report,[18] similar OCT structures were shown to be consistent with the presence of dental gaps. This occurs due to increased light scattering caused by refractive index inhomogeneity at the boundaries of a microcrack. Since the presence of air filling the microcrack is assumed, a higher signal intensity will appear as a bright line due to a higher OCT signal value at this interface caused by the lower refractive index of air (n= 1.0) in comparison to RBMs (n= 1.5-1.6). Because the OCT system records the depth dimension (z) as an optical depth, a correction for the refractive index of the material must first be performed. The physical depth in z is obtained by dividing the OCT-recorded optical depth by the refractive indexes of the RBMs. The refractive indexes of the RBMs tested in this study were experimentally determined using a technique previously reported.[25]

Statistical analysis - Mean and standard deviation values for microcrack length in millimeters (n= 10) were calculated at the 95% confidence level. Normality of data distribution was tested using Kolmogorov-Smirnov and Shapiro-Wilk tests. Because the data were normally distributed, a two-way ANOVA was performed to analyze the influence of the two factors (finishing technique and restorative material) on the mean values of the dependent variable under investigation (microcrack length). The level of significance was set at P< 0.05. Multiple comparisons were performed using the Tukey post-hoc test. All statistical tests were carried out using the software IBM SPSS Statistics for Macintosh, Version 22.0.[h]

Results

The mean microcrack lengths and standard deviations are summarized in Table 2. No microcracks were observed in the RBC samples. However, microcrack presence was identified in all of the RMGI specimens. Two-way ANOVA showed significant differences in the factors "finishing technique" and "restorative material" (P< 0.001). The interaction of these two factors was also statistically significant (P< 0.001). Tukey post-hoc test revealed a statistically significant difference (P< 0.001) in mean microcrack length values between all compared groups except among RBCs finished with different techniques (Table 2). For the tested RMGI, the finishing with aluminum oxide groups resulted in statistically significant lower mean microcrack length when compared to spiral fluted carbide burs (P< 0.001). Figures 1-4 show representative cross-sectional images obtained by the SD-OCT and ESEM images of the surfaces of the same specimens.

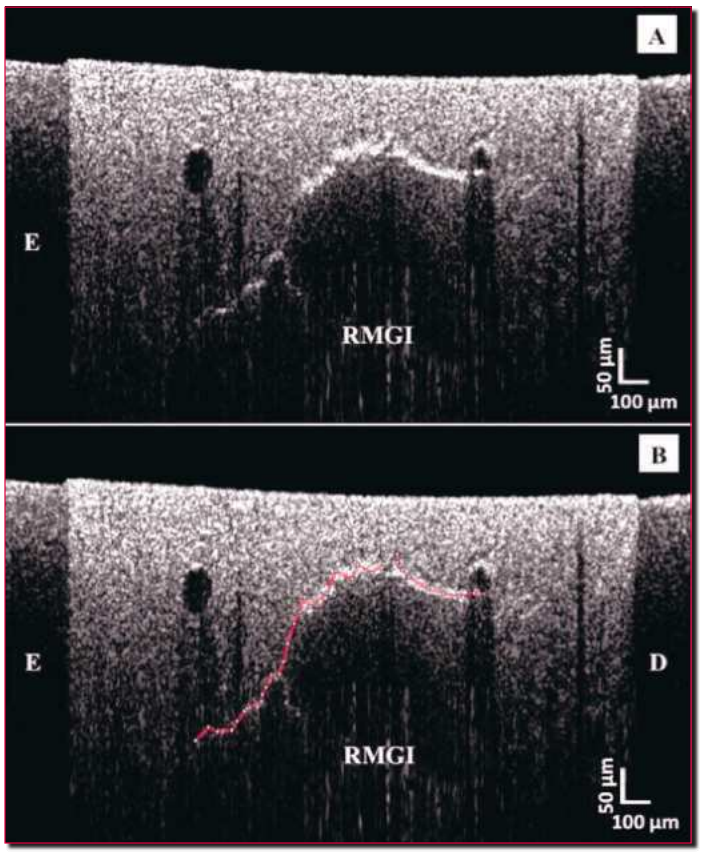

Fig. 1. SD-OCT images: (A) RMGI sample finished with fluted carbide; (B) Microcrack measurement in RMGI sample finished with fluted carbide.

Discussion

Crack tolerance is a property that was recently reported as one of the highest priorities for an ideal direct restorative material.[26] This statement is supported by evidence that most mechanical failures of materials are related to crack initiation at defects, crack propagation, and crack termination.[27] For resin-based materials, microcrack formation has been positively correlated with the development of water sorption and hydrolysis, therefore probably playing an important role in the degradation process of RBCs and RMGIs.[9,12,15]

The hypotheses tested in the present study were accepted, as the mean microcrack length values in RBMs were significantly influenced by both finishing technique and restorative material factors. In the present study, two-way ANOVA revealed that RMGI was more susceptible to microcrack presence than RBC. As to the finishing technique, even though statistically significant differences in microcrack length were found for the RMGI groups based on this factor, no microcracks were observed in RBC specimens regardless of the tested finishing

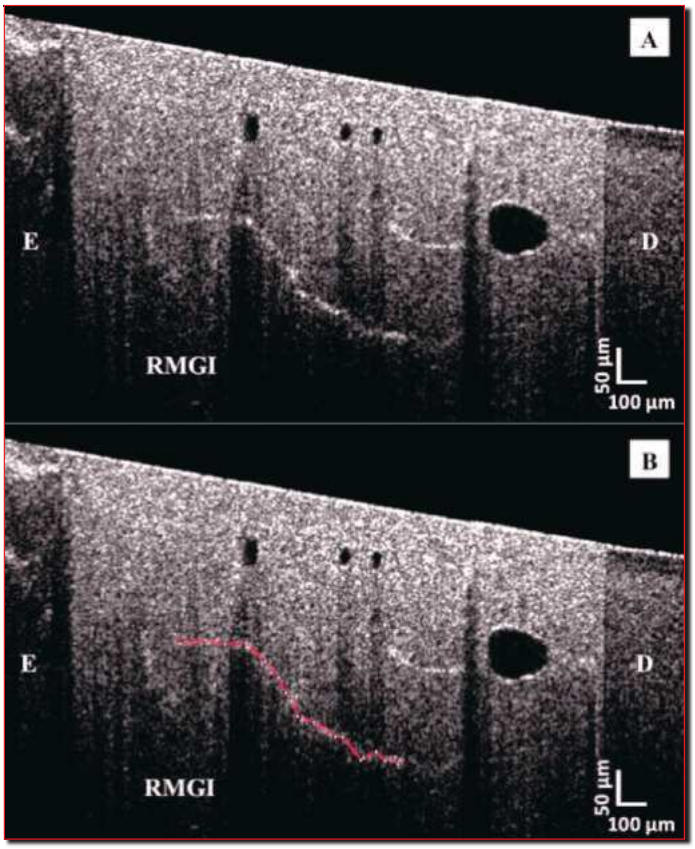

Fig. 2. SD-OCT images: (A) RMGI sample finished with Sof-Lex; (B) Microcrack measurement in RMGI sample finished with Sof-Lex.

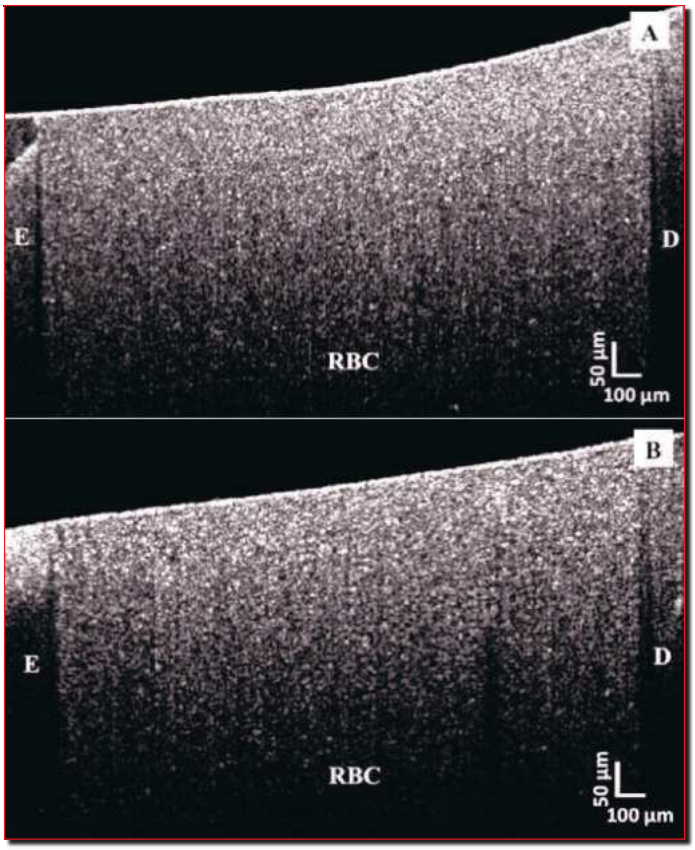

Fig. 3. SD-OCT images: (A) RBC sample finished with fluted carbide; (B) RBC sample finished with Sof-Lex.

system. The finding of no correlation between finishing with rotary instruments and the presence of a defective subsurface region in RBCs was supported in a previous report.[8] However, it is noteworthy that the cited authors conducted the experiment using a combination of staining technique and scanning electron microscope (SEM) evaluation that showed a capacity to identify defects and small cracks in a shallow micrometric depth just below the specimen surface.[16] In the present study, the microcrack presence in resin-based materials was investigated by using a SD-OCT system as a cross-sectional imaging diagnostic method. OCT provides micron-scale resolution for microstructural imaging up to 2-3 mm in depth,[24] and this technique has been reported[22,28] as a promising tool for determining the presence and extent of enamel cracks, as well as a reliable instrument for in vivo visualization of internal defects and large porosity in resin-based materials. In fact, the SD-OCT system used in the present study was quite effective for the identification of internal microcracks throughout the samples.

Although no microcracks were observed in the RBC samples, the SD-OCT images in the present investigation revealed microcracks in all RMGI samples. These findings were consistent with a previous study[15] conducted under confocal fluorescence microscopy to investigate the role of microcrack formation in the degradation mechanism for RMGIs. These authors stated that a network of cracks in the RMGI specimens was found prior to any finishing procedure that was performed in their experiment. Additionally, that study included discussion about the key role played by the slow formation of cracks as the prevalent mechanism of long-term hydrolytic degradation in RMGIs.

One possible explanation for the microcrack formation in RMGIs could be related to polymerization shrinkage stresses.[15,29] The development of setting stresses in RMGIs starts immediately upon light activation, reaching stress values of 2.5 MPa after 1 minute of irradiation.[30] Despite the potential contribution of shrinkage stress to formation of microcracks, it is worth noting that both OCT and ESEM images (Figs. 1 and 4A) showed that most microcracks originated from internal or external microvoids in the RMGI specimens. This finding of a possible correlation between microcrack and void was supported by a previous report as well.[15]

In the present study, a careful observation of the ESEM image (Fig. 4A) showed that most microcracks present on the surface of the RMGI sample started from voids. This evidence was also supported by the SD-OCT images (Figs. 1A-B) of the same sample shown in Fig. 4A, because the cross-sectional OCT imaging clearly reveals the penetration of the microcrack into the RMGI cement beginning from the void located on the surface. Although the present samples were not fatigued, it is worthy to note that cracks associated with fatigue failure frequently nucleate on the surface of a component at some point of stress concentration. Possible crack nucleation sites include any notch or geometrical discontinuity that can act as a stress raiser and fatigue crack initiation site.[31]

The occurrence of voids in glass-ionomer cements (GICs) and RMGICs has been reported.[32,33] These studies found that the method of mixing could influence the mechanical properties of GICs, depending on the extent of porosity present in the material. The authors confirmed the occurrence of small air bubbles in all specimens, showing a distribution throughout the

American Journal of Dentistry, Vol. 29, No. 5, October, 2016

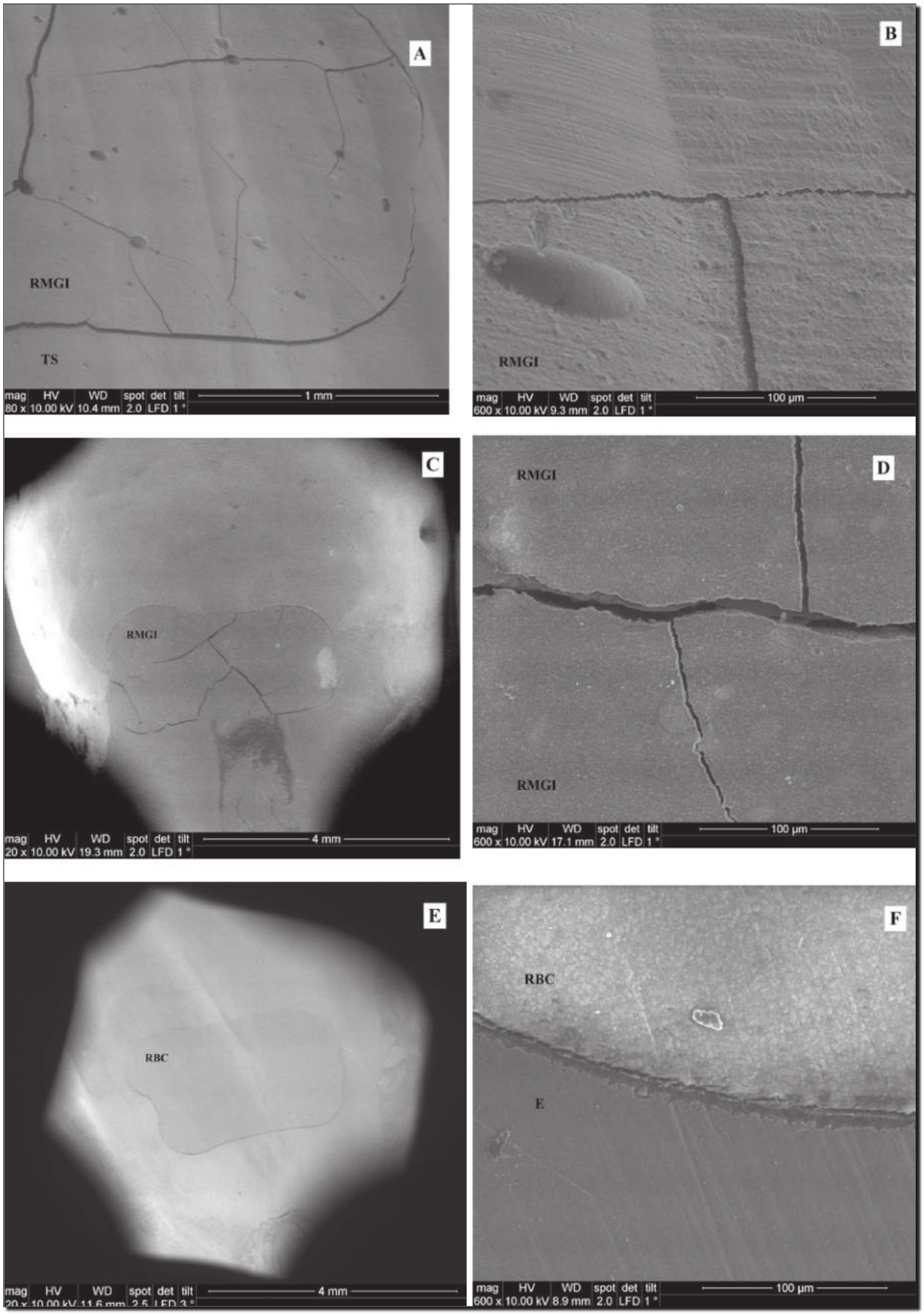

Fig. 4. ESEM images: (A) RMGI sample finished with fluted-carbide at ×80 magnification. (B) RMGI sample finished with fluted-carbide at ×600; (C) RMGI sample finished with Sof-Lex at ×20 magnification; (D) RMGI sample finished with Sof-Lex at ×600 magnification; (E) RBC sample finished with Sof-Lex at ×20 magnification; (F) RBC sample finished with Sof-Lex at ×600 magnification. Abbreviations: RMGI, resin-modified glass-ionomer; RBC, resin-based composite; TS, tooth structure; E, enamel; D, dentin.

whole mass of the GIC. They found a correlation between failures at lower stress with the presence of large bubbles. Despite the influence of the material viscosity and the method of mixing on the porosity formation, those defects seem to be inherent to any kind of viscous material that sets through a mixing process, which invariably results in air inclusions along the mixture. Considering that RMGI consists of GIC components with incorporated hydrophilic monomers, despite the improvement in its handling and working characteristics, it was not completely unexpected to find microcracks in the present study.

The possibility of a desiccation effect on microcrack formation in RMGI specimens during OCT/ESEM imaging is not of concern due to the maintenance of sample hydration during imaging. ESEM has the capability of imaging uncoated (low vacuum mode) and nearly wet (environmental mode) specimens, along with the conventional high vacuum SEM imaging. The instrument can be operated at variable pressure modes and hydrated specimens can be viewed without much sample preparation, thus preserving the integrity of the viewed surfaces. This characteristic represents a large advantage over traditional SEM analyses, where samples can attain artifacts simply due to dehydration effects encountered during preparation of the samples. Accordingly, a previous report stated that the observation of artifactual cracks within fractured RMGIs was quite usual under SEM where the samples are examined in a high vacuum and desiccated environment. However, the authors reported that cracks identified by ESEM were not artifacts caused by dehydration shrinkage, but probably due to "intrinsic setting shrinkage" or a "self-desiccation" process.[29]

Despite the consideration that most mechanical failures of materials relate to crack initiation at defects, crack propagation and crack termination,[27] there is still some controversy regarding possible benefits from water sorption in RMGIs, specifically related to a stress-relief behavior or a mechanism of "self-repair" that could partially compensate for the initial polymerization shrinkage stresses, therefore minimizing a further fracturing process.[30,34] In theory, that hypothesis could support the recommendation for exposing RMGI restorations to water before reaching critical stress levels in order to avoid the occurrence of early failures.[30] On the other hand, previous studies[14,34] reported that RMGIs were highly sensitive to water sorption, which therefore leads to lower values of flexural strength and elastic modulus. This RMGI water uptake, which acts as a surface plasticizer when those restorations are kept in contact with water or saliva,[14,34] is due to its chemical composition, characterized by the hydrophilic nature of a network basically formed by poly hydroxyethyl methacrylate (HEMA), copolymers of grafted HEMA and polyacid salts.[34] Additionally, as previously noted, the mixing procedure may produce air voids that accelerate the water sorption and solubility of these cements, since those defects increase the surface exposed to water/saliva, possibly leading to areas of unpolymerized material.[35]

Therefore, given their higher values of water sorption, as well as due to the reported correlation between their water uptake and microcrack formation, inferior mechanical properties and hydrolytic degradation, RMGIs should be avoided for restorations in occlusal load-bearing areas. In contrast, published studies of long-term clinical trials[36,37] have reported the superior clinical performance of RMGI restorations in non-carious cervical lesions when compared to RBC restorations. The microcrack presence observed under SD-OCT imaging in the present study may represent one of the possible explanations for this higher clinical performance of RMGIs in non-carious cervical lesions, because those defects could represent a stress-breaking effect during lateral cuspal movements or due to a vertical deformation of the tooth previously reported as "barreling effect."[38]

In the present study, statistical analysis showed a significant difference ($P < 0.001$) in mean microcrack length based on the finishing technique employed for the RMGI samples. Aluminum oxide discs produced lower values of mean microcrack length than spiral fluted carbide burs after the finishing procedure of RMGI restorations. Despite the lack of reports evaluating the influence of different finishing techniques on microcrack generation in RMGIs, several studies have supported that Sof-Lex disks produce the smoothest RMGI surface among all available finishing systems.[39-43] A possible explanation for this finding is that aluminum oxide discs seem to permit finishing of RMGIs without dislodging the glass particles.[40,42] Because both OCT and ESEM images (Figs. 1 and 4A) showed microcracks originating from external microvoids in the RMGI specimens, the finding of shorter microcracks after using aluminum oxide discs is understandable since this finishing technique can lead to fewer voids generated by the displacement of glass particles.

Further investigation should be conducted focusing on the evaluation of microcrack presence and length in resin-based materials under thermomechanical fatigue loading.

In conclusion, within the limitations of this in vitro experiment, the present study showed that RMGI was more susceptible to microcrack presence than RBC. Also, aluminum oxide discs produced lower values of mean microcrack length than spiral fluted carbide burs after the finishing procedure of RMGI restorations.

a. Brasseler USA, Savannah, GA, USA.
b. 3M ESPE, St Paul, MN, USA.
c. Kerr Corporation, Orange, CA, USA.
d. Hu-Friedy, Chicago, IL, USA.
e. FEI Company, Hillsboro, OR, USA.
f. KMLabs, Boulder, CO, USA
g. National Institutes of Health, Bethesda, MD, USA.
h. IBM Corp., Armonk, NY, USA.

Acknowledgements: To 3M ESPE and Brasseler USA for the donation of the materials, as well as Mr. Wallace Ambrose and the Chapel Hill Analytical and Nanofabrication Laboratory Institute for Advanced Materials (CHANL) for all the support given on conducting the ESEM imaging of this project. Dr. Vasconcellos was supported by the "Science without Borders" scholarship program from Brazil for a post-doctoral fellow position in the Department of Operative Dentistry at UNC/Chapel Hill, North Carolina, USA.

Disclosure statement: The authors declared no conflict of interest.

Dr. Vasconcellos is Associate Professor, Operative Dentistry, School of Dentistry, Fluminense Federal University, Nova Friburgo, RJ, Brazil, and Visiting Scholar, University of North Carolina at Chapel Hill, School of Dentistry, Department of Operative Dentistry, Chapel Hill, North Carolina, USA. Dr. Delgado is Clinical Assistant Professor, Division of Operative Dentistry, Department of Restorative Dental Sciences, College of Dentistry, University of Florida, Gainesville, Florida, USA. Dr. Hirata is Assistant Professor, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York, New York, USA. Dr. Blackmon is Postdoctoral Research Associate, and Dr. Oldenburg is Associate Professor Department of Physics and Astronomy, University of North Carolina at Chapel

Hill, Chapel Hill, North Carolina, USA and Biomedical Research Imaging Center, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA. Dr. Swift is Professor and Associate Dean for Education, Dr. Heymann is Professor, and Dr. Ritter is Professor and Chair, Department of Operative Dentistry, School of Dentistry, University of North Carolina, Chapel Hill, North Carolina, USA.

References

1. Jefferies SR. The art and science of abrasive finishing and polishing in restorative dentistry. *Dent Clin North Am* 1998;42:613-627.
2. Jefferies SR. Abrasive finishing and polishing in restorative dentistry: A state-of-the-art review. *Dent Clin of North Am* 2007;51:379-397.
3. Craig RG, Powers JM, Sakaguchi RL. *Craig's restorative dental materials*. St. Louis: Mosby Elsevier, 2006.
4. Yap AU, Ang HQ, Chong KC. Influence of finishing time on marginal sealing ability of new generation composite bonding systems. *J Oral Rehabil* 1998;25:871-876.
5. Leinfelder KF, Wilder AD Jr, Teixeira LC. Wear rates of posterior composite resins. *J Am Dent Assoc* 1986;112:829-833.
6. Ratanapridakul K, Leinfelder KF, Thomas J. Effect of finishing on the in vivo wear rate of a posterior composite resin. *J Am Dent Assoc* 1989;118:333-335.
7. Söderholm KJ, Richards ND. Wear resistance of composites: A solved problem? *Gen Dent* 1998;46:256-263.
8. Ferracane JL, Condon JR, Mitchem JC. Evaluation of subsurface defects created during the finishing of composites. *J Dent Res* 1992;71:1628-1632.
9. Soderholm KJ, Zigan M, Ragan M, Fischlschweiger W, Bergman M. Hydrolytic degradation of dental composites. *J Dent Res* 1984;63:1248-1254.
10. Huang C, Tay FR, Cheung GSP, Kei LH, Wei SHY, Pashley DH. Hygroscopic expansion of a compomer and a composite on artificial gap reduction. *J Dent* 2002;30:11-19.
11. Yap AU. Resin-modified ionomer cements: A comparison of water sorption characteristics. *Biomaterials* 1996;17:1897-1919.
12. Small IC, Watson TF, Chadwick AV, Sidhu SK. Water sorption in resin modified glass-ionomer cements: An in vitro comparison with other materials. *Biomaterials* 1998;19:545-550.
13. Percq A, Dubois D, Nicholson JW. Water transport in resin-modified glass ionomer dental cement. *J Biomater Appl* 2008;23:263-273.
14. Cattani-Lorente MA, Dupuis V, Payan J, Moya F, Meyer JM. Effect of water on the physical properties of resin-modified glass ionomer cements. *Dent Mater* 1999;15:71-78.
15. Fano L, Fano V, Ma W, Wang X, Zhu F. Hydrolytic degradation and cracks in resin-modified glass ionomer cements. *J Biomed Mater Res B Appl Biomater* 2004;69:87-93.
16. Turssi CP, Ferracane JL, Serra MC. Abrasive wear of resin composites as related to finishing and polishing procedures. *Dent Mater* 2005;21:641-648.
17. Huang D, Swanson EA, Lin CP, Schuman JS, Stinson WG, Chang W, Hee MR, Flotte T, Gregory K, Puliafito CA, Fujimoto JG. Optical coherence tomography. *Science* 1991;22:1178-1181.
18. Bakhsh TA, Sadr A, Shimada Y, Tagami J, Sumi Y. Non-invasive quantification of resin-dentin interfacial gaps using optical coherence tomography validation against confocal microscopy. *Dent Mater* 2011;27:915-925.
19. Monteiro GQ, Montes MA, Gomes AS, Mota CC, Campello SL, Freitas AZ. Marginal analysis of resin composite restorative systems using optical coherence tomography. *Dent Mater* 2011;27:213-223.
20. Jones RS, Darling CL, Featherstone JD, Fried D. Imaging artificial caries on the occlusal surfaces with polarization-sensitive optical coherence tomography. *Caries Res* 2006;40:81-89.
21. Shimada Y, Sadr A, Burrow MF, Tagami J, Ozawa N, Sumi Y. Validation of swept-source optical coherence tomography (SS-OCT) for the diagnosis of occlusal caries. *J Dent* 2010;38:655-665.
22. Imai K, Shimada Y, Sadr A, Sumi Y, Tagami J. Noninvasive cross-sectional visualization of enamel cracks by optical coherence tomography in vitro. *J Endod* 2012;38:1269-1274.
23. Delgado AJ, Ritter AV, Donovan TE, Ziemiecki T, Heymann HO. Effect of finishing techniques on the marginal integrity of resin-based composite and resin-modified glass ionomer restoration. *J Esthetic Restor Dent* 2015;27:184-193.
24. Chhetri RK, Phillips ZF, Troester MA, Oldenburg AL. Longitudinal study of mammary epithelial and fibroblast co-cultures using optical coherence tomography reveals morphological hallmarks of pre-malignancy. *PLoS One* 2012;7:e49148.
25. Tearney GJ, Brezinski ME, Southern JF, Bouma BE, Hee MR, Fujimoto JG. Determination of the refractive index of highly scattering human tissue by optical coherence tomography. *Opt Lett* 1995;20:2258-2260.
26. Rekow ED, Bayne SC, Steele JG. What constitutes an ideal dental restorative material? *Adv Dent Res* 2013;25:18-23.
27. Bayne SC. Correlation of clinical performance with in vitro tests of restorative dental materials that use polymer-based matrices. *Dent Mater* 2012; 28:52-71.
28. Ishibashi K, Ozawa N, Tagami J, Sumi Y. Swept-source optical coherence tomography as a new tool to evaluate defects of resin-based composite restorations. *J Dent* 2011;39:543-548.
29. Yiu CK, Tay FR, King NM, Pashley DH, Carvalho RM, Carrilho MR. Interaction of resin-modified glass ionomer cements with moist dentine. *J Dent* 2004;32:521-530.
30. Feilzer AJ, Kakaboura AI, de Gee AJ, Davidson CL. The influence of water sorption on the development of setting shrinkage stress in traditional and resin-modified glass ionomer cements. *Dent Mater* 1995;11:186-190.
31. Callister WD, Rethwisch DG. *Materials science and engineering: An introduction*. Hoboken: John Wiley & Sons Inc., 2010.
32. Nomoto R, McCabe JF. Effect of mixing methods on the compressive strength of glass ionomer cements. *J Dent* 2001;29:205-210.
33. Nomoto R, Komoriyama M, McCabe JF, Hirano S. Effect of mixing method on the porosity of encapsulated glass. *Dent Mater* 2004; 20:972-978.
34. Kanchanavasita W, Anstice HM, Pearson GJ. Water sorption characteristics of resin-modified glass ionomer cements. *Biomaterials* 1997;18:343-349.
35. Toledano M, Osorio R, Osorio E, Fuentes V, Prati C, Garcia-Godoy F. Sorption and solubility of resin-based restorative dental materials. *J Dent* 2003;31:43-50.
36. Fagundes TC, Barata TJ, Bresciani E, Santiago S, Franco EB, Lauris JR, Navarro MF. Seven-year clinical performance of resin composite versus resin-modified glass ionomer restorations in noncarious cervical lesions. *Oper Dent* 2014;39:578-587.
37. van Dijken JW, Pallesen U. Long-term dentin retention of etch-and-rinse and self-etch adhesives and a resin-modified glass ionomer cement in non-carious cervical lesions. *Dent Mater* 2008;24:915-922.
38. Heymann HO, Sturdevant JR, Bayne SC, Wilder AD, Sluder TB, Brunson WD. Examining tooth flexure effect on cervical restorations: A two-year clinical study. *J Am Dent Assoc* 1991;122:41-47.
39. Wilder AD Jr, Swift EJ Jr, May KN Jr, Thompson JY, McDougal RA. Effect of finishing technique on the microleakage and surface texture of resin-modified glass ionomer restorative materials. *J Dent* 2000; 28:367-373.
40. Tate WH, Powers JM. Surface roughness of composites and hybrid ionomers. *Oper Dent* 1996;21:53-58.
41. St. Germain HA, Meiers JC. Surface roughness of light-activated glass-ionomer cement restorative materials after finishing. *Oper Dent* 1996;21:103-109.
42. Pedrini D, Candido MS, Rodrigues AL. Analysis of surface roughness of glass-ionomer cements and compomer. *J Oral Rehabil* 2003;30:714-719.
43. Barbosa SH, Zanata RL, Navarro MF, Nunes OB. Effect of different finishing and polishing techniques on the surface roughness of microfilled, hybrid and packable composite resins. *Braz Dent J* 2005;16:39-44.