In vitro evaluation of apical microleakage in retrofillings with different resection angles

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ABSTRACT

Paraendodontic surgery is a procedure that aims to solve problems that could not be solved by, or when it is not possible to perform conventional endodontic treatment. The aim of this experimental study was to compare the apical microleakage of teeth sectioned at 45° or 90° to the long axis of the tooth and root-end filled with mineral trioxide aggregate (MTA) using stereomicroscopy. In this study, 26 maxillary central incisors were used. Cleaning and shaping were performed with use of the Oregon technique and the samples were randomly divided into two groups. In Group A (n=10) apical section was performed at an angle of 90°, making a retrocavity with an ultrasonic tip and retrofilling with MTA. In group B (n=10) the same procedures were performed, but the apical section was at a 45° angle. Then the samples were immersed in a dye (India ink), placed in an oven at 37° for 48 h before applying the clearing technique. Afterwards the teeth were assessed by stereomicroscope at 20x magnification to analyze dye leakage. Data were submitted to the Student's-t test with significance level p< 0.05. There was statistically significant difference between groups. Group B showed higher apical microleakage values compared with group A (P= 0.004), but both groups showed dye leakage. The results showed that the 90° apical section promoted lower dye microleakage values at the dentin-retrofilling material interface than the 45°-section and could be considered the most effective technique for apical preparation in paraendodontic surgery.

Received: March 2019; Accepted: October 2019.

Keywords: *Periapical diseases, retrograde obturation, mineral trioxide aggregate.*

Avaliação in vitro da microinfiltração apical de retrobturações com diferentes ângulos de ressecção

RESUMO

A cirurgia paraendodôntica é um procedimento que visa resolver problemas que não poderiam ser resolvidos, ou quando não é possível realizar o tratamento endodôntico convencional. O objetivo deste estudo experimental foi comparar a microinfiltração apical de dentes seccionados a 45° ou 90° em relação ao longo eixo do dente e extremidade radicular preenchida com agregado de trióxido mineral (MTA) utilizando estereomicroscopia. Neste estudo, 26 incisivos centrais superiores foram utilizados. Limpeza e modelagem foram realizadas com o uso da técnica de Oregon e as amostras foram divididas aleatoriamente em dois grupos. No Grupo A (n = 10) foi realizada seção apical em ângulo de 90°, realizando retrocavidade com ponta ultrassônica e retrobturação com MTA. No grupo B (n = 10), os mesmos procedimentos foram realizados, mas a seção apical estava em um ângulo de 45°. Em seguida, as amostras foram imersas em um corante (nanquim), colocadas em estufa a 37°C por 48 h, antes da aplicação da técnica de clareamento. Posteriormente, os dentes foram avaliados por estereomicroscópio, com aumento de 20x, para análise do vazamento de corante. Os dados foram submetidos ao teste t de Student, com nível de significância p <0,05. Houve diferença estatisticamente significante entre os grupos. O grupo B apresentou maiores valores de microinfiltração apical em comparação ao grupo A (P = 0,004), mas ambos os grupos apresentaram vazamento de corante. Os resultados mostraram que a seção apical de 90° promoveu menores valores de microinfiltração de corante na interface do material retrobturador dentinário do que a seção 45° e pode ser considerada a técnica mais efetiva para preparo apical em cirurgia paraendodôntica.

Palavras-chave: *Doenças da polpa dental, obturação retrógrada, MTA.*

INTRODUCTION

In spite of the controversy regarding success rates of conventional endodontic therapy, it is a fact that with the continuous improvement of instruments and techniques, high indexes are obtained, approximately 88%[1]. In case of failure, clinicians may and must decide for endodontic retreatment, that has 80% success rates, an evidence of its effectiveness[2].

When there is failure in retreatment or when this practice is contraindicated, surgical therapy may be a solution for teeth maintenance. Such procedure consists in exposing the apex of the root, in performing apical resection, apical retropreparation and then sealing with retrofilling material[3,4].

Apical sealing is the most important surgical success factor resulting from the use of retrofilling material, which can prevent bacterial activity and bacterial by-products inside the root canal and in periapical tissues[5,6]. Periapical infections may be resistant to antimicrobial therapy and only paraendodontic surgery can produce disinfection and enhance tissue repair[7]. Success indexes of paraendodontic surgeries performed according to modern concepts account for 88,4%[8] .

Materials have been developed through time and their properties have been improved. This has changed the materials of choice for retrofilling. Mineral Trioxide Aggregate (MTA) – developed at the University of Loma Linda in the early 1990's [9] -presents advantages vis a vis previously used materials, due to its sealing ability, marginal adaptation and biocompatibility[10-12]. MTA has been the most widely used retrofilling material, yet, it has some limitations, such as long setting time, difficulty in handling and maintaining the mixture consistency[13,14].

Retrocavity preparation may be performed after resection at an angle of 45° or 90° with respect to the long axis of the tooth. For many years, the 45° -angled section was used as it enabled the visual and manual access to the apical region[15]. This angling enhances the exposure of dentinal tubules, enabling higher microleakage levels and resulting in keeping the lingual/palatal root portion without the adequade treatment[16,17]. In the case of the 90° resection, it enables a better crown/root proportion as it preserves more dental structure and promotes less leakage[18,19].

Retrocavities need to have at least a 3-mm depth for a more effective and a safer sealing action[16]. The use of spherical burs for making these retrocavities means that a root resection at 45° should be made for chamfering the root and having manual access, which tends to promote a higher periapical permeability[20,21]. However, by using angled ultrasound tips for the apical retropreparation, it was possible to get a more even and conservative preparation, when compared with the spherical burs [22] making it unnecessary to chamfer the root portion and permitting that a 90°-angle resection be made[20].

The purpose of this research was to evaluate apical microleakage in diaphonized and MTA-retrofilled teeth, by using 45° and 90° apical section angles, through the dyeing (India Ink) method analysed by stereo microscope.

MATERIALS AND METHODS

The research project was submitted to the Ethics Committee in Research with Humans of the University of Itaúna. The project was approved and protocol N° 421.819 was then assigned.

Twenty-six central superior, uniradicular incisors, with a completely formed apex, were used in the research study. The teeth were cleaned, sterilized in autoclave and previously submerged in saline solution, at the beginning of the procedures. Periapical X-Rays were made for evaluating the absence of calcifications, reabsorptions or of any previous endodontic treatment.

After selecting the teeth, access to their crowns was performed using the high rotation carbide bur 1557 (KG Sorensen, São Paulo, Brazil), and subsequently, the ceiling of the pulp chamber was removed, with the high rotation Endo-Z bur (Dentsply Maillefer, Ballaigues, Switzerland). The teeth were instrumented using the Oregon Technique, with manual K-type files. The patency was established by means of the K #10 file (Dentsply Maillefer, Ballaigues, Switzerland) and the length of the canal was determined through visualization of the K #15 file (Maillefer, Ballaigues, Switzerland) in the apical foramen. The length of the task was determined as being 1 mm beyond the apical foramen. Gates-Glidden #2 and #4 Burs (Maillefer, Ballaigues, Switzerland) were used for preparing the two coronal thirds of the dental roots; the apical third was standardized in all the teeth with a K-type #45 file (Maillefer, Ballaigues, Switzerland). During instrumentation, 2 ml of a NaOCL solution were used for canal irrigation. The final irrigation was done with 3 ml of Ethylenediaminetetraacetic acid (EDTA) 17% (Formula & Action, São Paulo, Brazil) for 60 s, followed by 2 ml of NaOCl 2,5%. Before the filling procedure, the canals were completely dried with absorbent paper cones (Dentisply Maillefer, Ballaigues, Switzerland). The filling procedure was done through the lateral condensation technique by using a digital spacer digital #25 (Odous de Deus, Belo Horizonte, Brazil), Endofill cement filling (Dentisply Maillefer,

Ballaigues, Switzerland) and gutta-percha cones #45 and accessory cones R1 (Dentisply Maillefer, Ballaigues, Switzerland). Three millimeters of the root crown portion were removed and, then, sealing was done by using IRM (Dentsply / Caulk, Milford, USA).

Subsequently, the samples were divided into two groups: A (n=10) and B (n=10). By using a millimetered ruler, in the apical third of the teeth a 3 mm standard marking was made at the points where the samples were resected. In Group A, the root-end was resected at an angle of 90° with the long axis of the tooth, by means of a high rotation multilaminated Zekrya bur (Dentsply-Maillefer, Ballaigues, Switzerland), with constant irrigation. The section was done from the mesial surface up to the end of the root distal surface. In Group B, the same procedures were applied, however, the apical resection was performed at a 45° cutting angle with the axis of the tooth.

After apicoectomy, the cavities were shaped with the Retro-D700 ultrasonic tip adapted to the ENAC ultrasonic device (Osada, Tokyo, Japan), by applying medium-power and under constant irrigation, with standardized 3 mm cavity depth and diameters. The samples were covered with two layers of enamel, except for the apical 3 mm portion. Six teeth were used as a negative control and all the surfaces of the dental structure were covered with two layers of enamel, showing the effectiveness of the enamel as a barrier to dye penetration. Retrofillings were irrigated with EDTA, 24%, during 3 minutes and then carefully rinsed with water for removal of excess of EDTA. The chosen retrofilling material was white MTA (Ângelus, Londrina, Brazil), handled according to the manufacturer's label and inserted into the cavities by using an MTA applicator (Ângelus, Londrina, Brazil). After the handling procedure, and according to the manufacturer's label, an initial 15-minute lapse was considered for letting the MTA set.

After these procedures, the teeth were submerged in Indian ink and placed in a microbiological oven at 37°C, and 100% Relative Humidity, during 48 hours. Subsequently, the samples were withdrawn from the oven and placed on surgical bandage to remove the excess of dye. Then, they were left at room temperature during 24 hours for dye fixation. Subsequently, the teeth were decalcified in hydrochloric acid, 5%, during 3 days, rinsed during 24 hours, and dehydrated in incremental alcohol solutions (70%, 80%, 90% and 100%, respectively) during 4 hours, a diaphonization technique previously described by Vertucci [23]. Then, the teeth were clarified using methyl salicylate, and remained like this until the analyses[24]. An examiner, trained and calibrated for identifying lineal dye penetration, performed the analyses of the samples.

Then, the teeth were photographed and evaluated in a stereosmicroscope (Leica Microsystems, Heerbrugg, Switzerland) with a 20X magnification, for observing the dye penetration process along the root-end surfaces. The lineal distance of the dye penetration was measured using the Image J software. This was transferred to a Microsoft Office Excel sheet and, then, to SigmaPlot program (Systat Software Inc. version 8.0, San Jose, CA, USA). The measurements of the lineal dye microleakage in both groups were analysed using a Student's-t test, with a $p<0.05$ significance level.

RESULTS

The measurements of the lineal dye microleakage of both groups are exhibited in Fig. 1 and illustrated in Fig. 2. The statistical Analysis showed a significant difference between Groups A and B ($p=0.004$). Both sections showed apical microleakage, yet, the group resected at 90° showed less leakage than the group with a 45° section in relation to the long axis of the tooth.

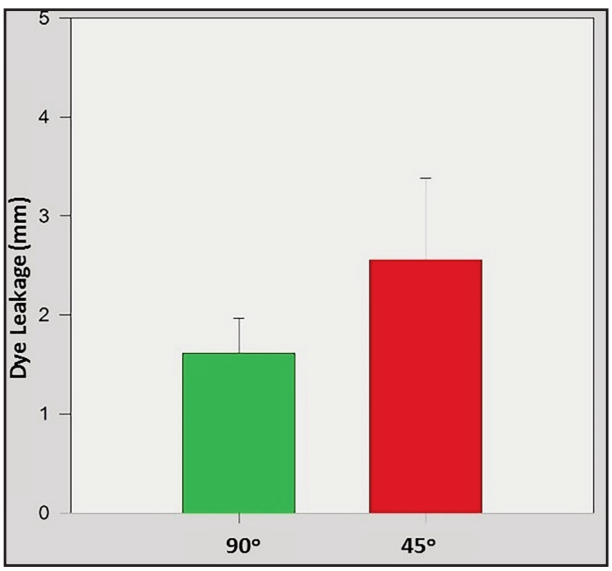

Fig. 1: Measures (arithmetical means) of microleakage in Group A (green column) and Group B (red column) in millimeters (mm). The vertical lines stand for standard deviations.

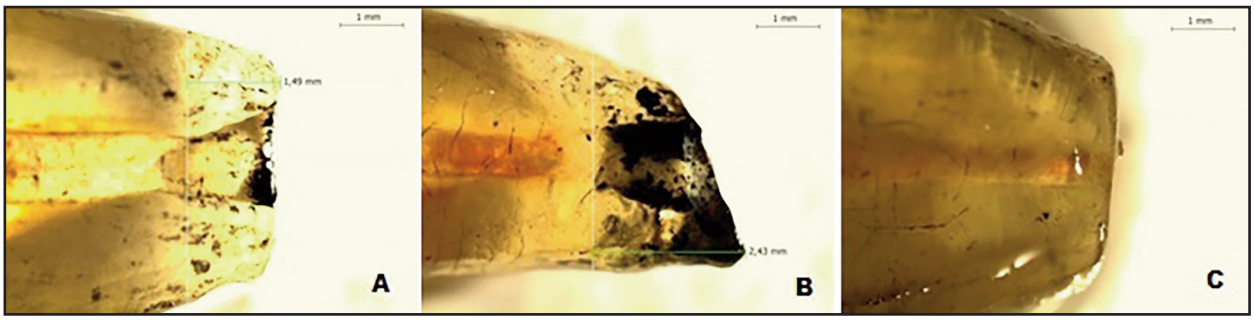

Fig. 2: Stereomicroscope with an original 20X magnification showing Indian ink penetration in the analysis groups and absence of leakage in the control group: A) Group A; B) Group B; C) Control Group.

DISCUSSION

In spite of the limitations of *in vitro* research studies, such studies are very valuable for developing endodontic techniques and materials, leading to relevant information for clinical practice[25].

Analysis using diaphonization permits the direct visualization of the internal anatomy of the root canal system and enables measuring lineal dye leakage in the interface dentin/retrofilling material. Diaphonization, which was used in previous Endodontia research studies, is a user-friendly method, with good sensitivity levels and no need for sophisticated methods and equipment. The dye used has a penetration capability similar to that of endodontic bacteria. This permits associating the outcomes of this *in vitro* study with those of the clinical study[24-26].

The relation between apical section angling and microleakage has been approached in several research studies, through different methodologies[3-7,9]. In this research, diaphonization was the analytical method chosen as it enables the internal visualization of retrofilled teeth and of the apical third dyed by penetration of Indian ink. By means of diaphonization, it was possible to have a 3D view of all the surfaces of the tooth and, consequently, to have a good access for determining the penetration of the dye[27,28]. In literature, there are studies in which the chosen methodology was vertical dental resection for analysis of microleakage, yet, this technique restricts the visual access to retrocavity peripheral areas and deteriorates the adequate evaluation of dye penetration, not simulating a real clinical situation[18,29].

Periapical surgeries are additional therapeutic procedures for teeth maintenance that may and must be applied in cases of failure of treatment and/or of endodontic retreatment, provided they are well prescribed and performed[8, 20].

With the development of dental materials, more desirable properties have been obtained for different clinical scenarios. Among such materials, MTA should be pointed out. MTA is undergoing extensive research and has shown to have physical and chemical features that make it appropriate for retrofilling, specially because it is biocompatible and helpful in tissue repair processes[9-13]. It is considered that this favorable biological response of MTA results in hydroxyapatite formation, useful in post-surgical bone repair[28].

The manufacture of ultrasonic angled tips has turned apical bevelling unnecessary as these tips allow clinicians to perform more uniform retropreparation, with parallel walls that make it easier to insert and adapt the filling material. Besides, it minimizes major leakage episodes associated with the augmented exposure of tubules caused by the 45° resection, as shown in this research study[17,18,30,31].

Lin et al. compared two retropreparation techniques - with ultrasonic tips and with the traditional spherical bur technique - using stereomicroscopy for evaluating the quality of the shape and size of a given retropreparation. The outcomes of such research study showed that the preparations with ultrasonic tip were more conservative and that there was a smaller number of root perforations than in the preparations with the spherical drills[19].

CONCLUSION

Irrespective of the technique used for performing apical resection, there was presence of microleakage. Nevertheless, the 90° section with the long axis of the tooth produced lower microleakage values when compared with the 45° section.

ACKNOWLEDGEMENTS
The stereomicroscopy procedures used in this research were performed by Marcus Paulo Alves de Oliveira (Doctor in Applied Biology, graduated from the Federal University of Lavras, Minas Gerais, Brazil).

FUNDING
None

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Effect of flowable composite or glass ionomer liners on shrinkage stress of a composite resin

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ABSTRACT

The aim of this study was to evaluate the effect of flowable composite or glass ionomer liners on the shrinkage stress of a restorative composite resin. Fifteen previously sandblasted metal boxes were attached to a universal mechanical testing machine (INSTRON 1011, Instron Corporation). Five of these boxes were filled with Filtek Z350 XT (FXT) Universal Restorative A2 (3M ESPE) (Group 1 or Control). Two further groups of 5 boxes were prepared by interposing a layer of Vitrebond Light Cure Glass Ionomer 3M ESPE (VGI) (Group 2 or G.I.) or Filtek Z350 XT Flowable Restorative A2 3M ESPE (FFR) (Group 3 or Flowable) between the box and the composite resin, completing with the same volume of composite as in Group 1. Upon activating light-curing, the filled boxes mounted on the testing machine were videoed for 60 seconds (40 s photoactivation and 20 s post-curing), timed with a digital chronometer. Force values were recorded in newtons and converted into stress according to contact surface. Stress values were recorded every 10 s. Results were analyzed using repeated measures ANOVA. Mean and standard deviation in kPa (stress) recorded for each group were: Control group: 126.2 (30.8); G.I.: 48.4 (18); Flowable: 27.9 (19.5). Statistical analysis showed significant differences between the control group and the rest ($p<0.01$), with no significant difference between groups with glass ionomer liners and flowable resin liners (G.I. and Flowable). Under the experimental conditions of this study, it can be concluded that polymerization shrinkage stress can be reduced by the presence of a liner between the preparation and the restorative material.

Received: May 2019: Accepted: October 2019.

Keywords: *Composite resins, dental curing lights, glass ionomer, liner.*

Efecto de recubrimientos con resinas de baja viscosidad o ionómero vitreo sobre la tensión por contracción de una resina compuesta

RESUMEN

El objetivo de este trabajo fue evaluar el efecto de la colocación de una capa de Composite flow o Ionómero vítreo sobre la tensión de contracción de un composite para restauración. Se utilizaron 15 cajas metálicas previamente arenadas y conectadas a la máquina universal para ensayos mecánicos (INSTRON 1011, Instron Corporation). Cinco de estas cajas (G1) se rellenaron con Filtek Z350 XT (FXT) Universal Restorative A2 3M ESPE. Al iniciar la activación de la unidad de curado se comenzaba a registrar con una cámara de video y un cronómetro digital desde el comienzo de la activación de la lámpara hasta 60 s después, registrando los valores post curado durante 20 s. Los valores de fuerza generados por la polimerización fueron registrados en newton de cada 10 s para los 15 ensayos. Los valores fueron convertidos en tensión de contracción según la superficie de contacto. Se realizaron además dos grupos de cajas (5 en cada una) en los cuales se colocaron una capa inicial de Vitrebond Light Cure Glass Ionomer 3M ESPE (VGI) (G2 o IV) y Filtek Z350 XT Flowable Restorative A2 3M ESPE (FFR) (G3 o Flow) y se completó con el mismo volumen de composite de las del GI. Los resultados obtenidos fueron analizados por medio de ANOVA para mediciones repetidas. La media y la desviación estándar en kPa (tensión o estrés de contracción) registrado para cada grupo fueron: Grupo control: 126.2 (30.8); IV: 48.4(18); Flow: 27.9(19.5). El análisis estadístico mostró diferencias estadísticamente significativas entre el grupo control y el resto ($p=0.00$), pero no hubo diferencias significativas entre la presencia de Ionómero vítreo o Composite Flow (IV y Flow). En las condiciones experimentales de este trabajo puede concluirse que la tensión de contracción generada durante la polimerización puede ser disminuida por la presencia de algún material interpuesto entre la preparación y el composite restaurador.

Palabras clave: *Resinas compuestas, dispositivos para fotocurado, ionómero vítreo, recubrimiento.*

INTRODUCTION

Composite materials are being increasingly used in dentistry. Over the years, their composition and properties have changed to meet esthetic and mechanical requirements[1-3]. However, the greatest current challenge is still how to manage shrinkage stress, which depends on multiple factors such as polymerization shrinkage and the material's elastic modulus, which are directly related to the organic matrix and the quantity and type of filler; the speed

of conversion and degree of conversion [4,5] related to polymerization activation mode, and the type and quantity of initiators. These factors are directly affected by the composition of the material. [6,7]

Composites consist of an organic matrix, usually dimethyl acrylate, reinforced with ceramic fillers treated superficially with a vinyl-silane agent to adhere to the organic matrix and agents that promote the polymerization reaction. The base monomer, usually bis-GMA or some other diacrylate, has high molecular weight and, due to its high viscosity is mixed with other dimethyl acrylates of lower molecular weight (TEGDMA, UDMA) as diluents. It can be cured by chemical, physical or dual activation.[8,9] The composite sets as a result of polymerization, when the monomer chains crosslink to produce a final thermoset structure. During this process, the intermolecular distance between monomers is reduced, causing shrinkage. Linear and volumetric shrinkage of restoration composites have ranges of 0.5% to 2.0% and 1.0% to 4.0%, respectively. Shrinkage stress is 0.5 MPa to 8 MPa, depending on variables such as inorganic filler, monomer characteristics, material insertion technique, photoactivation methods and design of the preparation[10]. During polymerization gel point, the composite's elastic modulus increases such that the dissipation or deformation capacity is reduced to compensate the shrinkage. The adhesion to the tooth wall and the shrinkage of a composite restoration generate shrinkage stress, which is transmitted to the adhesive interface or dental substrate, generating clinical problems such as marginal gap, tooth fissures and/or fractures, secondary caries, postoperative sensitivity, marginal pigmentation, etc.[11-13]

The activation mode, as well as the types and concentrations of initiators, regulate the degree of conversion and kinetics of the reaction[14]. The higher the degree of conversion, the greater the shrinkage and the elastic modulus, both of which contribute to producing greater stress. Faster polymerization rates mean that the monomers move faster than the critical conversion, causing rapid setting and at the same time reducing flowability. A higher speed of reaction is associated to faster growth in the module before and after the gel point, and translates into faster development of stress compared to what would be produced by using a slower curing regime. [15,16]

There are several techniques to reduce shrinkage stress, such as using fillers or liners with low elastic modulus, incremental placement of composite resins, low intensity during the initiation of photopolymerization and modification of the composition of the material. Placing a liner material with lower elastic modulus such as a flowable composite or hybrid glass ionomer enables the size of the preparation, as well as shrinkage, to be reduced. Since both these materials are more flexible, shrinkage stress transmitted to the adhesive interface and/or the tooth is reduced. However, the results of studies on flowable composite as a liner are controversial. The elastic modulus of flowable composites varies, and can sometimes be higher than that of the composites themselves. The flowable composites with lower elastic modulus reduce shrinkage stress and better results were achieved even in some resins without ceramic filler.

Several authors have shown that using a filler reduces microleakage and increases adhesion and resistance values. Aggarwal et al.[17] studied marginal adaptation of composite resins with flowable composite and glass ionomer liners on third lower molars with different adhesive systems. Leevailoj et al. [18] evaluated marginal microleakage in class II restorations with high-viscosity composites (packable) with and without flowable composite liners in natural teeth. Montes et al. [19], evaluated bond strength of restorations with flowable composite with adhesives with or without ceramic fillers in bovine teeth. However, other studies report that using fillers has no beneficial effect on the margin of the material and the dentin due to the low content of filler and high polymerization shrinkage, e.g., the papers by Braga, Choi, Kwon and Caldenaro[20-23].

There are many studies on glass ionomer related to reduction of shrinkage stress. Bryant et al. [24] evaluated shrinkage of different types of glass ionomers and composite resins, finding that the shrinkage of glass ionomers is comparable to that of composites: about 2% to 3% in the long term without contact with moisture. Chutinan et al. [25] evaluated glass ionomers under conditions of moisture, reporting that as from 56 days, glass ionomers undergo expansion. Feilzer et al. [26] evaluated the influence of water sorption on shrinkage stress in resin-modified glass ionomer cements. Although the material initially shrinks after the setting reaction, subsequent hygroscopic

expansion of the glass ionomer due to conditions of moisture and according to time positions it better compared to flowable composites, in agreement with the conclusions reported by Kemp-Scholte[27] and Tolidis[28]. Competition between addition polymerization and the acid-base reaction of the resin-modified glass ionomers may affect the dimensional change of the material and its capacity to dissipate shrinkage stress, as suggested in the papers by Berzins, Kakaboura and Young[29-31].

In order to contribute to knowledge on this topic, the aim of this study was to assess the effect of using a layer of flowable composite or hybrid glass ionomer on shrinkage stress of a composite for restoration.

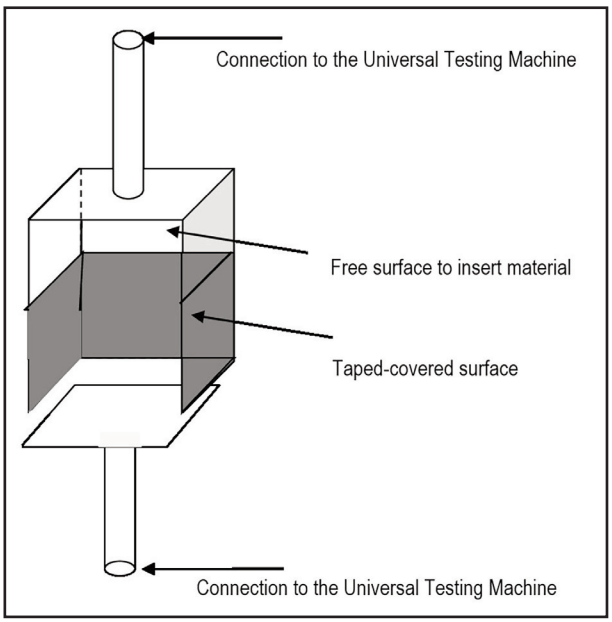

Fig. 1: Open box system used to evaluate shrinkage stress.

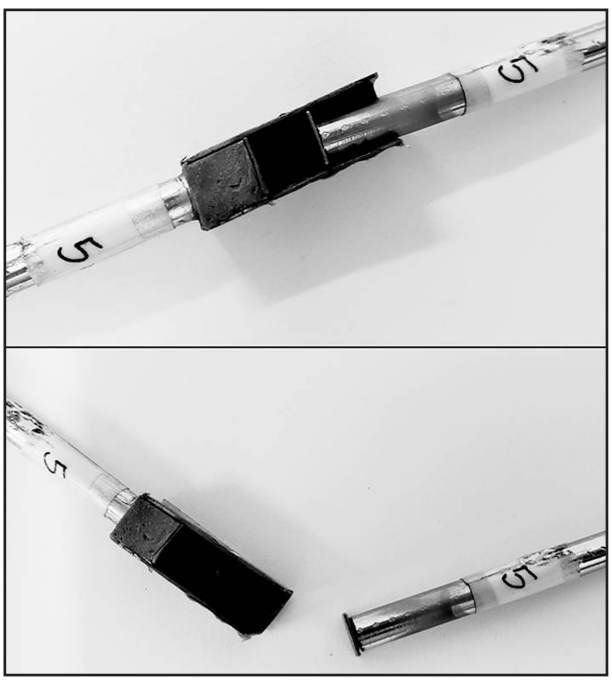

Fig. 2: Devices used to evaluate shrinkage stress; assembled (top) and disassembled (bottom). The two ends were connected to the universal mechanical testing machine.

MATERIALS AND METHODS

We used a nanofilled composite (FXT) (Filtek Z350 XT A2 from 3M), a resin-modified glass ionomer (VGI) (Vitrebond Light Cure Glass Ionomer from 3M) and a Flowable Composite (FFR) (Filtek Z350 XT Flowable Restorative A2 from 3M ESPE). The light-curing unit was a tungsten quartz lamp (XL-3000, 3M/ESPE).

We made metal boxes in which 4 of the sides were attached to each other. The top side was welded to a metal rod 4 mm in diameter. The bottom side was not attached to the rest of the box, but welded to another metal rod 4 mm in diameter (see Figures 1 and 2). Its edges were polished to enable it to slide freely through the box. The back surface was divided into two areas: one of 9 mm^2 on which to place the material, and the rest covered in paper tape. Composite was inserted through the open side. The opposite side was called floor, and its surface area was 20.25 mm^2. The metal rods were used to connect the pieces to a universal mechanical testing machine (INSTRON 1011, Instron Corporation, Japan).

Before using the boxes, we sandblasted them with aluminum oxide 50 μm in diameter using a Bio-Art microblaster for 10 s from a distance of 2 cm with air pressure 7 bar (102.5 psi). Then we washed them with distilled water in a Teslab® tb02 ultrasonic cleaner for 1 min at a power of 80 W and a frequency of 40 kHz, and dried them with air from a triple syringe.

We prepared three groups of 5 metal boxes: Group 1 (control group), filled with FXT; Group 2 (G.I.) lined with a resin-modified glass ionomer VGI and filled with FXT; and Group 3 (or Flowable) lined with FFR and filled with FXT.

For all three groups, each box was filled with 67.8 mg of composite, weighed with an OHAUS® Analytical Standard precision balance. The contact surface area was 56.25 mm^2 in all three groups. In Group 2, the Centrix system was used to line the boxes with a layer 1 mm thick of VGI, which was

cured according to the manufacturer's instructions. Immediately, the composite Filtek Z350 XT A2 (3M) was applied in a horizontal layer 2 mm thick, in contact with all five sides of the box, and cured for 40 s. The same was done for FFR. All assays were performed by a single operator.

The boxes were mounted on the testing machine such that the free-moving side was attached to the 0.5 kN load cell – adjusted in a 50N full scale – (the base of the free area was situated towards the floor of the box), while the rest of the box was attached to the base of the machine. The force values generated by polymerization were recorded every 10 s in newtons and converted to stress values (in kilopascals) according to contact surface area. Each procedure was recorded with a video camera and a digital chronometer from the beginning of composite activation with the lamp for 60 s (40 s photoactivation and 20 s post-curing).

The videos were used to record force values every 10 s for the fifteen tests performed. The results and the values converted to stress were analyzed statistically by ANOVA for repeated measurements and Tukey's test.

RESULTS

Table 1 shows mean and standard deviation (kPa) for the maximum stress values recorded for each group and evaluation time. Figure 3 shows mean stress values recorded for each group according to time. The ANOVA test, in linear and quadratic

Table 1: Mean and standard deviation (kPa) of maximum stress value recorded per group and time.

Time		10 s	20 s	30 s	40 s	50 s	60 s
Control	MEAN	27.4	78.0	94.1	99.5	118.0	126.2
	SD	28.1	18.6	21.6	24.1	28.5	30.8
G.I.	MEAN	20.4	28.7	29.6	30.1	42.7	48.4
	SD	9.2	14.3	16.8	19.1	20.0	18.0
Flowable	MEAN	-8.4	-1.1	2.4	3.4	19.8	27.9
	SD	4.8	7.3	10.3	11.5	17.0	19.5

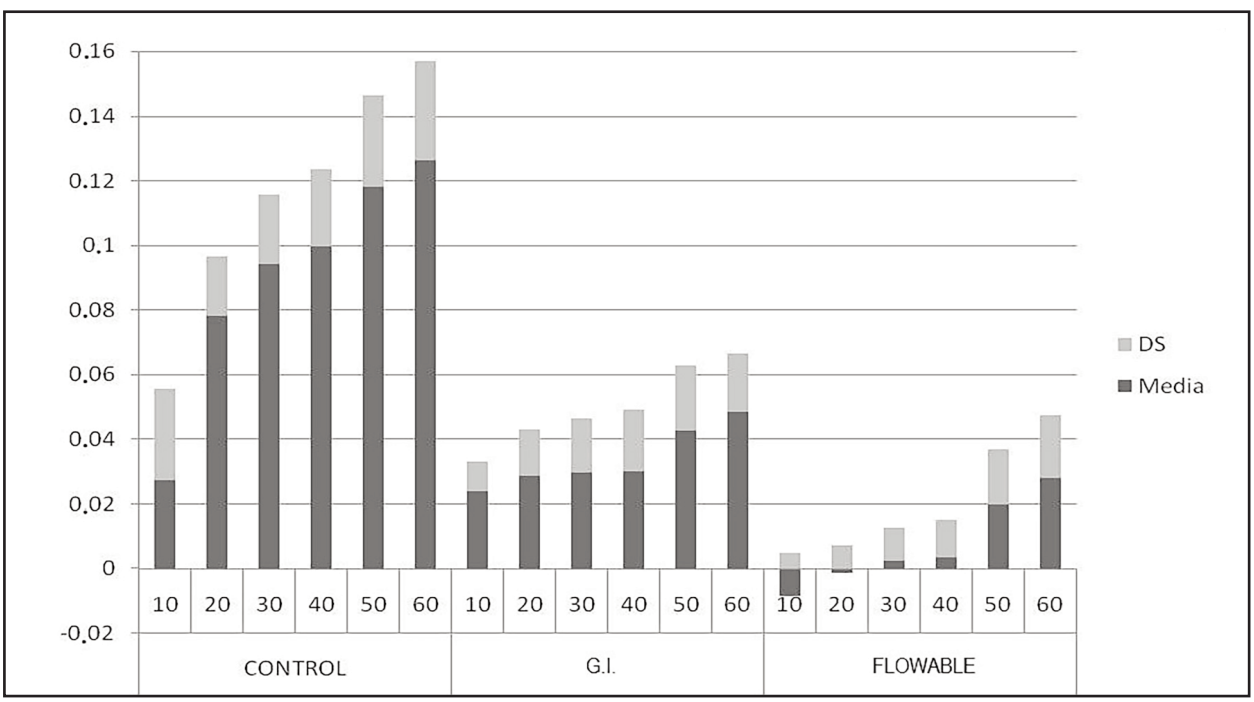

Fig. 3: Mean (kPa) per time and group (Control, GI and Flowable). Time: 1=10s, 2=20s, 3=30s, 4=40s, 5=50s and 6=60s.

function, showed statistically significant differences ($p<0.05$) according to material. Comparison of means using Tukey's test showed statistically significant differences between the control group (restorative material only) and the other two groups ($p<0.01$), but there was no significant difference between glass ionomer and flowable composite (Groups 2 and 3). Analysis of confidence intervals established that there was no statistically significant difference at the first evaluation time (10 seconds), but in the Control Group, shrinkage stress increased significantly as from 20 s compared to the groups with flowable composite or glass ionomer liners, with no difference between the latter two. This behavior is clearly visible in Figure 3, which shows that Groups 2 and 3 behave similarly, while in the Control Group, the stress generated increases progressively.

DISCUSSION

This study evaluated stress from the time of polymerization until 20 s post-curing, for the composite and for composite with a liner. It did not evaluate the individual behavior of each base or liner material, although their elastic modulus and stress are known to increase hours and even days after they have completely set[1].

It has been suggested that placing a liner with lower elastic modulus between the composite restoration and the substrate, used together with other precautions, may reduce the shrinkage stress[18,19]. Flowable composites and resin-modified glass ionomer are used as liners, but their use is still controversial according to results published to date. Because resin-modified glass ionomers (RMGIs) have fewer monomers that polymerize and therefore less shrinkage than composites, their use has long been suggested for reducing stress [14,24-26]. Kemp-Scholte & Davidson report that polymerization shrinkage stress was relieved by 20% to 50% as a result of the various flexible liner materials such as glass ionomer [27]. Tolidis K et al. also report that RMGIs liners reduce shrinkage stress. RMGIs set more gradually and slowly than resins, up to 48 h later, with better stress dissipation[28]. Bryant & Mahler report that at 30 min, the volumetric shrinkage of both conventional and hybrid ionomers is very similar to that of composites [24]. If shrinkage is similar, it may be deduced that stress would be similar, although our study found significant differences with and without liners, but no significant difference in stress relief for glass ionomer compared to flowable composite.

The competition between the acid-base reaction and addition polymerization can modify final structure and stress-dissipating ability. The two types of setting inhibit each other, i.e., if addition polymerization is activated, the rate and extent of the acid-base reaction is inhibited. Similarly, the polymerization reaction is affected by the polar nature of the ionomer medium, and as ionomer opacity increases as a result of acid-base neutralization, physical activation by light is attenuated[29]. It has been shown that the efficiency of curing decreases when it is applied after 20 min,[30] even though this situation is clinically quite unlikely to occur. But if activation is delayed by 3 min and 15 s, there will only be 85% polymerization compared to immediate activation.

RMGIs are susceptible to water uptake and release [27]. The movement of water may occur while the material sets under sealed conditions as a base or liner. Two chemical reactions have been reported. One is the intrinsic use of water during initial setting and the other is extrinsic water sorption by the acid-base reaction [31]. In the model applied herein, where RMGIs are used as bases or liners in metal boxes, there is no extrinsic water effect, and therefore the material shrinks. This could explain why no difference was found between glass ionomer and flowable composite.

According to Braga RR, Ferracane JL & Hilton TJ[20], flowable resins produce similar stress levels to composites. Most flowable composites do not produce significant stress reduction when used under composites [20] and there are even studies that report an increase in stress with flowable composite or RMGI liners[21-23]. Volumetric shrinkage and elastic modulus are inversely related and depend on the material's ceramic filler. Composites with high ceramic load have less organic matrix, and therefore less shrinkage due to the formation of crosslinked polymer chains, but in turn, they prevent elastic deformation for dissipating stress due to the high rigidity of the ceramic filler. A flowable composite follows these theories, but is a more fluid material due to the addition of monomers of smaller molecular size, and would theoretically have greater volumetric shrinkage. In turn, there are flowable composites with high ceramic loads which dissipate less stress due to

their high elastic modulus. Thus, they do not dissipate stress due to the change in mechanical properties of the material. It would be helpful to know to what extent the final stress is caused by the quantity and size of organic molecules and the elastic modulus of the composite when it has set.

The current study used metal boxes in a moisture-free environment. The boxes were sandblasted to increase micromechanical adhesion of the materials by applying a model similar to the one used by Pires-de-Souza et al. [32], with the difference that they used glass rods instead of metal boxes, mounted in the same way to the testing machine to record data. It should be noted that the substrate and adhesion are unlike the clinical situation. However, the design enables the behavior of materials and combinations to be evaluated, beyond the variables involved in the clinical situation. It would be interesting to ascertain the influence of the stress caused by each of them and the effect of the final resulting stress with the composite until the material hardens completely.

CONCLUSION

Under the experimental conditions in this study, it may be concluded that shrinkage stress generated during polymerization may be reduced by a liner placed between the preparation and the restorative composite.

FUNDING

This paper was funded by Grant 20020160100037BA of Scientific Program 2017 of the Secretariat of Science and Technology of Buenos Aires University.

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