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Film thickness evaluation using different indirect restoration luting techniques – pilot study

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Resumo

Objetivo: Avaliar a espessura da interface restauração-cimento-dente, resultante da cimentação de restaurações indiretas em blocos de resina composta com preparações padronizadas, utilizando um cimento resinoso e uma resina composta termo-modificada, com ou sem aplicação de vibração ultrassónica.

Materiais e métodos: Cinco (5) blocos de resina composta fresada com o formato de um molar preparado para onlay e cinco (5) restaurações cerâmicas correspondentes foram emparelhados aleatoriamente e divididos em cinco (5) grupos (n = 1). Cada restauração foi cimentada com: cimento resinoso Variolink Esthetic LC (grupo 1A), cimento resinoso Variolink Esthetic LC com vibração ultrassónica (grupo 1B), resina composta termo-modificada (a 69°C) IPS Empress Direct (grupo 2A), resina composta termo-modificada (a 69°C) IPS Empress Direct com vibração ultrassónica (grupo 2B) e resina composta IPS Empress Direct com vibração ultrassónica à temperatura ambiente (22°C) (grupo 2C). Posteriormente, a espessura de película de cada grupo foi observada através de microscopia eletrónica de varrimento (MEV) e medida recorrendo ao software Adobe Photoshop CC.

Resultados: As amostras do grupo 1B apresentaram a película mais fina de cimento (77μm), ao passo que as amostras do grupo 2A exibiram a interface mais espessa (305μm). Os valores médios de espessura de película obtidos pelos grupos 2B e 2C foram 192μm e 146μm, respetivamente. O grupo 1A obteve um valor médio de espessura de interface de 92μm. Verificou-se deslizamento da restauração nas margens oclusais das amostras cimentadas com a resina composta IPS Empress Direct e uma interface mais adaptada nas margens do grupo 2C.

Conclusão: Apesar das limitações inerentes a este estudo, as amostras cimentadas com Variolink Esthetic LC, com ou sem vibração ultrassónica, apresentaram uma interface mais fina, comparativamente com os grupos cujo agente cimentante foi a resina composta IPS Empress Direct. A adição de vibração ultrassónica revelou promover a diminuição da espessura de película em ambos os materiais testados. Com o intuito de investigar o impacto do deslizamento da restauração durante a sua cimentação, mais estudos devem ser efetuados.

Palavras-chave: cimentação adesiva, espessura de película, cimento resinoso, resina composta, termo-modificação, vibração ultrassónica

Abstract

Aim: Evaluate the film thickness of the restoration-cement-tooth interface resulting from luting indirect restorations to laboratory standardized tooth preparations, using a resin cement and a thermo-modified composite resin and/or ultrasonic vibration.

Materials and methods: Five (5) composite resin blocks milled into the shape of a molar prepared for an onlay and five (5) ceramic restorations matching the tooth preparation were randomly coupled and divided into five groups (n = 1), where each restoration was cemented using: resin cement Variolink Esthetic LC (group 1A), resin cement Variolink Esthetic LC with ultrasonic vibration (group 1B), thermo-modified composite resin IPS Empress Direct at a 69°C (group 2A), thermo-modified composite resin IPS Empress Direct (at 69°C) with ultrasonic vibration (group 2B) and composite resin IPS Empress Direct with ultrasonic vibration at room temperature (22°C) (group 2C). The film thickness of the restoration-cement-tooth interface was observed by scanning electron microscopy (SEM) and measured using Adobe Photoshop CC software.

Results: The thinnest interface was verified in group 1B (77μm), whereas the highest thickness was observed in group 2A (305μm). Groups 2B and 2C obtained mean values of film thickness of 192μm and 146μm, respectively, and an average measurement of 92μm was verified in group 1A. SEM images demonstrated sliding of the restoration on the occlusal margins of the samples cemented with composite resin IPS Empress Direct, particularly evident in groups 2A and 2B. A more adapted cement layer in the margin was detected in sample 2C.

Conclusions: Despite the limitations of the present study, samples cemented with Variolink Esthetic LC, with or without ultrasonic vibration, exhibited a thinner film when compared to the IPS Empress Direct groups. The addition of ultrasonic vibration while luting indirect restorations proved advantageous in lowering film thickness in the two resin-based materials tested. Further studies are recommended to investigate the impact of restoration sliding during cementation procedures.

Keywords: adhesive cementation, film thickness, resin cement, composite resin, thermo-modification, ultrasonic vibration

Introduction

Restorative dentistry is constantly changing, driven in part by new clinical applications of existing dental materials and the introduction of new ones.[1] In the last decades, the increased demand for aesthetics has resulted in significant improvements in nonmetallic restorations, such as indirect resin composites and glass-ceramics. Nevertheless, the clinical performance of those restorative materials relies mainly on the luting/bonding procedure.[2]

Cementation is a crucial step in assuring retention, marginal seal, and durability of indirect restorations.[3] The adhesive technique is based on mechanical and chemical retention and comprises the application of an adhesive system and a resin luting agent. It provides additional reinforcement to restoration and dental tissue, resulting from the effective adhesion achieved at the cement–restoration and cement–tooth interfaces.[4]

The bond between a luting agent and the tooth structure (or core build-up material) is generally made possible by applying an adhesive system. Hence, a genuinely adhesive cementation procedure can only be achieved when clinicians combine resin-based cements with bonding systems.[1]

Accordingly, the success of indirect restorations depends primarily upon the luting agent, which must guarantee a durable bond between the restoration and the dental structure, ensuring retention and marginal integrity.[4] The desired features of a luting material are biocompatibility, low viscosity and film thickness, high micromechanical bonding to tooth and restorative material, high shear and tensile bond strengths, low solubility and radiopacity, color stability and ease of handling.[5-7] Conventional luting cements, such as zinc phosphate and glass-ionomer, are used for luting metallic restorations and posts, whereas resin-based cements are preferred for all-ceramic restorations (e.g., veneers, inlays, onlays and crowns).[1,4,8] The latter can be used either in resin cement or thermo-modified composite resin presentations.

Resin cements are based on bisphenol-a-glycidyl methacrylate (Bis-GMA) resin and other methacrylates modified from the restorative composite resins.[7] Since this class of luting materials has a setting reaction based on polymerization, they are classified according to their curing mechanisms into light-cured, chemically-cured, and dual-cured.[4,7,8] The first are indicated for translucent and thin (less than 2mm thickness) restorations due to the possibility of light transmission through the restoration and their clinical advantages are extended working time and color stability. The second is suggested to be used under opaque or thick restorations as these limit light transmission; despite their adequate polymerization in inaccessible areas to light, they should be used cautiously, as discoloration is possible due to their aromatic amine content. Dual-cured cements can be used in intermediate situations, however, they may present lower color stability.[4,8] Therefore, under ideal circumstances, light-activated resin cements demonstrate better performance than chemical or dual polymerization.[9]

Resin cements and thermo-modified composites differ in the amount of inorganic filler particles, which influences the material flowability: lower filler content promotes greater flowability at room temperature.[10] Concerning cementation, higher flowability of the luting agent promotes thinner film at the restoration-luting agent-tooth interface.[11,12] Restorative composite resins' filler component is higher than that of resin cements, thus increasing their viscosity. Thermo-modification is described in literature as a strategy to improve medium viscosity composite resins' usability as luting agents, as the temperature rises and spatial molecular disorganization promotes a greater flow.[12-14]

Nevertheless, there is scarce scientific evidence that compares the different materials and techniques regarding film thickness in accurate experimental models that simulate clinical situations.

The purpose of this pilot study is to evaluate film thickness on the restoration-luting agent-tooth interface resulting from luting indirect restorations to laboratory standardized tooth preparations, using a resin cement and a composite resin with thermo-modification and/or ultrasonic vibration. The null hypothesis is that all materials and all cementation techniques present similar film thickness.

Materials and methods

Study design:

One conventional resin cement and one restorative resin composite were selected considering their range in classifications, formulations and manufacturers. Their characteristics are presented in Table 1.

Room temperature was set at 22°C and 69°C was considered the clinical desired temperature for luting with preheated composite resin.

The effect of ultrasound energy application on film thickness was also tested, using an ultrasonic tip after restoration seating and removal of major excesses.

After cementation, film thickness was evaluated through scanning electron microscope (SEM) and measured using Adobe Photoshop CC software.

Table 1. Characteristics of the tested luting agents.

Resin-based luting agent	Manufacturer	Type	Composition		Particles		Lot number	Expiration date
			Resin monomers	Filler wt% (vol%)	Shape	Mean size (range)		
Variolink Esthetic LC	Ivoclar Vivadent, Schaan, Liechtenstein	Light-cured resin cement	UDMA, DDMA	(38)	Irregular	0.1µm (0.04µm-0.2µm)	Z00965	09/2022
IPS Empress Direct	Ivoclar Vivadent, Schaan, Liechtenstein	Nanohybrid composite resin	Bis-GMA, UDMA, TCDDMA	75-79 (52-59)	Irregular	550nm (40nm-3µm)	Z00SJW	12/2023

UDMA, urethane dimethacrylate; DDMA, 1,10-decandiol dimethacrylate; Bis-GMA, bisphenol-A glycidyl dimethacrylate; TCDDMA, tricyclodocane dimethanol dimethacrylate.

Sample standardization and preparation:

A standard onlay preparation was performed by a calibrated operator in a tooth model and scanned using an intraoral scanner (iTero Element 5D, Amsterdam, The Netherlands). The resulting preparation digitalization was individualized and milled in five (5) composite resin blocks (IPS Empress Direct, Ivoclar Vivadent, Schaan, Liechtenstein) of 6x10mm under water-cooling. Five restorations designed to match the tooth preparation (mimicking the anatomy of a molar) were fabricated by injection molding, resorting to lithium disilicate ceramic blocks (IPS e.max, Ivoclar Vivadent, Schaan, Liechtenstein). The composite resin and the ceramic blocks were used as experimental models to evaluate distinct adhesive cementation techniques and luting agents.

Experimental protocol:

The tooth models and restorations were randomly coupled and divided into five groups (n = 1). Each restoration was cemented following the protocol undermentioned:

Group 1A: samples cemented with resin cement Variolink Esthetic LC (Ivoclar Vivadent, Schaan, Liechtenstein) at room temperature (22ºC).

Group 1B: samples cemented with resin cement Variolink Esthetic LC at room temperature (22ºC) with the addition of ultrasonic vibration.

Group 2A: samples cemented with thermo-modified composite resin IPS Empress® Direct (Ivoclar Vivadent, Schaan, Liechtenstein) at 69ºC.

Group 2B: samples cemented with thermo-modified composite resin IPS Empress® Direct at 69ºC with the addition of ultrasonic vibration.

Group 2C: samples cemented with thermo-modified composite resin IPS Empress® Direct at room temperature (22ºC) with the addition of ultrasonic vibration.

Luting protocol:

Resin blocks and respective ceramic restorations were identified and numbered.

The luting protocol was executed one group at a time, as follows.

IPS Empress Direct composite resin was preheated to 69ºC for 30 minutes using a composite heating device (Hot Set, Technolife, Rio de Janeiro, Brazil, 20W), aiming to achieve and stabilize temperature before testing. Ceramic restorations were also left inside the heater after silanization to lower heat dissipation in the luting procedure.

Regardless of the group, all resin blocks were submitted to sandblasting with 30µm aluminum oxide particles to obtain a surface with uniform roughness and allow the penetration of the bonding agent.

Hydrofluoric acid at 5% was used to etch the ceramic's internal surface for 20 seconds, followed by thorough rinsing with water for one minute. The resulting surface was cleaned by actively applying and rubbing phosphoric acid at 37,5% (Gel etchant, Kerr Corporation, CA, USA) for one minute and rinsing with water to clear any acidic remnants. A strong air stream was used to dry the restoration, followed by the application of universal ceramic primer (Monobond Plus, Ivoclar Vivadent, Schaan, Liechtenstein, lot Z01P1R), which was left to dry.

Subsequently, Adhese® Universal (Ivoclar Vivadent, Schaan, Liechtenstein) adhesive was actively applied in all resin and ceramic blocks with a microbrush. An air stream was used to evaporate solvents, thus obtaining a shiny and immobile layer, without polymerizing.

A standard volume of the luting agent – Variolink Esthetic LC in groups 1A and 1B; IPS Empress Direct at 69ºC in groups 2A and 2B and 22ºC in group 2C – was dispensed on the internal surface of the respective ceramic restoration.

In groups 1B, 2B and 2C, ultrasound energy was applied using an ultrasonic tip CM4 (CVDentus®, São Paulo, Brazil) assembled in an ultrasound handpiece (CVDentus®, São Paulo, Brazil), which operated at 30% power without irrigation. The ultrasonic tip was used with smooth movements from the center to the periphery of the sample.

All restorations were seated by applying a controlled pressure of 23N for three periods of 20 seconds, interspersing with excess removal between each period of force application. Seating pressure was continuously measured using a patented prototype (publication number WO/2020/167153) developed explicitly for clinical luting procedures. The applied force (N) value resulted from a calibration process of the device load sensor according to previous measurements rendered by a calibrated operator.

After removing the remaining excesses with OptraSculpt (Ivoclar Vivadent, Schaan, Liechtenstein), samples were polymerized seven times for 20 seconds each with a LED light-curing unit (Bluephase® Style 20i, Ivoclar Vivadent, Schaan, Liechtenstein, 1200 mW/cm^2). Finally, glycerin-based aqueous gel (Liquid Strip, Ivoclar Vivadent, Schaan, Liechtenstein) was applied over the sample margins and light-cured again seven times for 10 seconds each.

Scanning electron microscopy (SEM):

Each sample was longitudinally sectioned with a vestibular-lingual direction parallel to the tooth's long axis, in two halves. The section was performed with a low-speed (300 rpm at 0.050 mm/s) diamond disc (Accutom-5; Struers, Ballerup, Denmark) under continuous water cooling.

Subsequently, one half of each five samples was polished with 2500 grit abrasive sandpaper and set up on aluminum stubs using a double-sided carbon tape for observation on a compact variable-pressure scanning electron microscope (Hitachi FlexSEM 1000; Hitachi, Tokyo, Japan) with an accelerating voltage of 10.0kV and a low vacuum of 30Pa. UVD (Ultra Variable-Pressure) and BSE (Backscattered Electron) detectors were simultaneously used to optimize signal detection. The magnification implemented was x1000, x500 or x470.

For each specimen, five photomicrographs were taken in distinct segments of the luting interface, specifically:

a. cervical margin
b. vestibular wall
c. vestibular angle
d. central fossa
e. occlusal margin

Measurement of the luting agent film thickness:

To measure the thickness of the ceramic-cement-resin interface, Adobe Photoshop CC software was used.

After opening each image, calibration was performed using the image's scale bar. A linear measurement was taken at three different points in each image: one at the center and two at each extremity. Regarding cervical and occlusal margins, linear measurements were taken in the area immediately before any overflowed luting agent.

The average values of each group were obtained with resort to the measurements taken in the five captured microphotographs.

Results

Microscopic analysis:

A representative microphotograph of each group can be observed in figures 1 to 5. Images obtained from the occlusal margin of the samples cemented with resin composite are represented in figures 6 to 8.

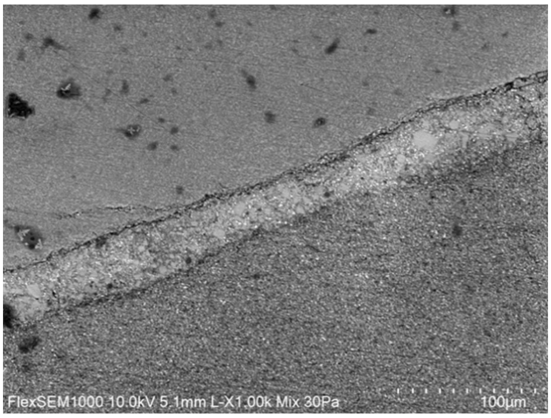

Figure 1. Representative microphotograph of group 1A, segment d, at 1000x magnification.

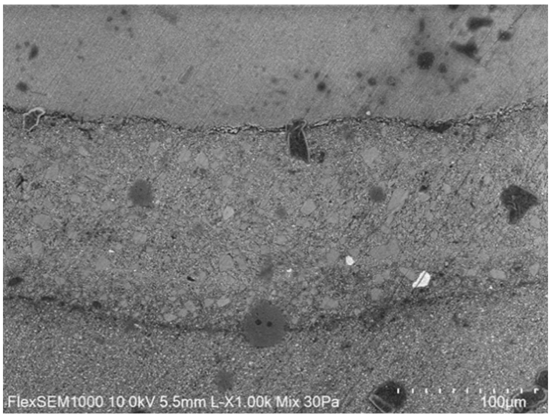

Figure 2. Representative microphotograph of group 1B, segment d, at 1000x magnification.

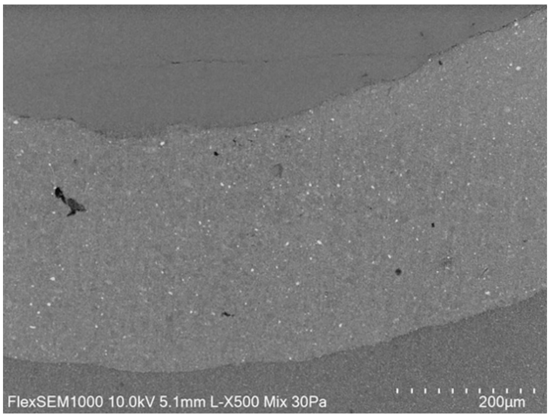

Figure 3. Representative microphotograph of group 2A, segment d, at 500x magnification.

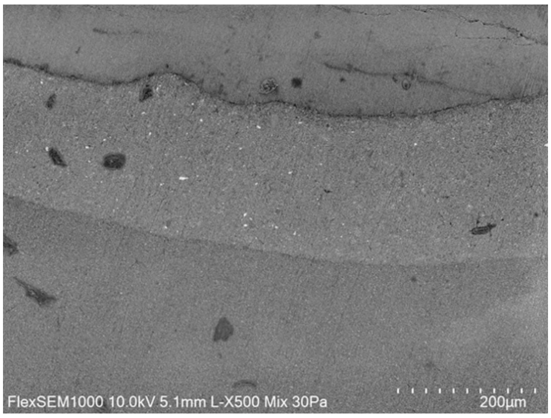

Figure 4. Representative microphotograph of group 2B, segment d, at 500x magnification.

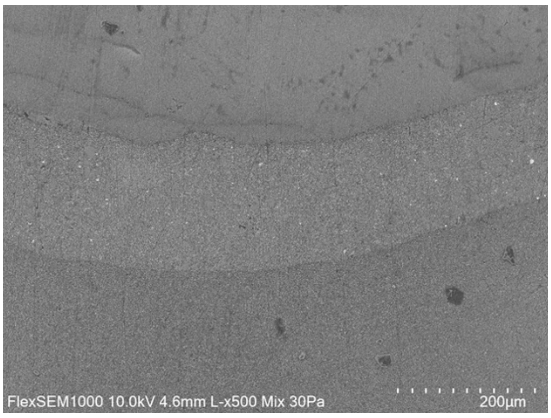

Figure 5. Representative microphotograph of group 2C, segment d, at 500x magnification.

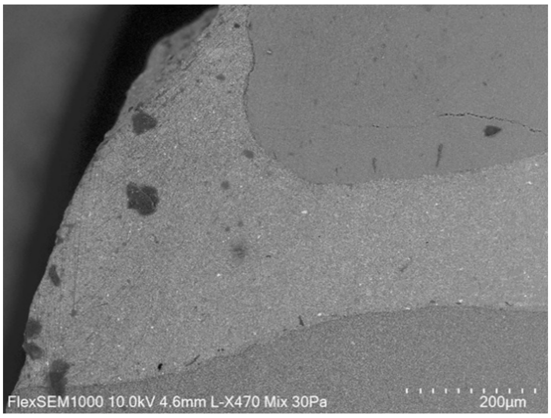

Figure 6. Representative microphotograph of group 2A, segment e, at 470x magnification.

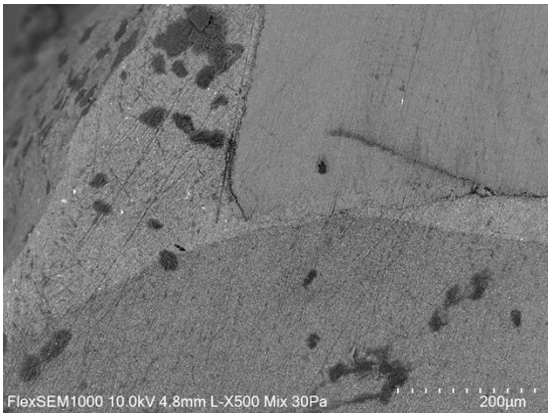

Figure 7. Representative microphotograph of group 2B, segment e, at 500x magnification.

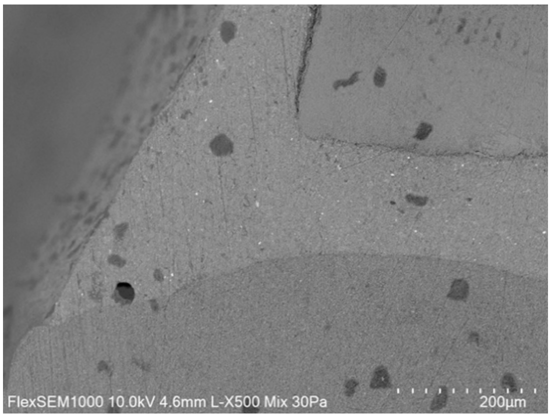

Figure 8. Representative microphotograph of group 2C, segment e, at 500x magnification.

Measurement of the luting agent film thickness:

Table 2. Mean values of the film thickness in micrometers for each tested group.

	1A	1B	2A	2B	2C
	n=5				
Segment a	131	60	387	276	148
Segment b	84	61	233	95	114
Segment c	19	27	318	342	118
Segment d	81	134	360	210	182
Segment e	144	105	227	39	169
Mean values	92	77	305	192	146

Discussion

Adhesive cementation of indirect restorations is of utmost importance for clinicians who intend to provide the best treatments to their patients. In parallel, the research invested to address this aspect has brought substantial knowledge regarding the luting agent, as it is widely known that the proper selection and manipulation of the latter significantly affects the longevity of the restoration.[7]

Film thickness should be thoroughly considered as a deciding factor for indirect restoration's success, as a thicker interface can lead to restoration failure.[15,16] The phenomenon of water sorption upon exposure to the oral cavity (also recognized as hygroscopic expansion of the cement) diminishes the flexural strength and the modulus of elasticity of resins, which may be critical in the thick areas of the cement. Thus, there will be unsupported areas and the restoration will not withstand high occlusal loads. Furthermore, contraction of the cement may generate compressive stress that propitiates crack propagation[15] and polymerization shrinkage may produce residual tensile stress that contributes to premature debonding.[15,16] These conditions will culminate in restoration fracture.[11,15-17] To counteract these adverse effects, it is advisable to obtain a cement film as thin as possible,[17] ideally between 5 and 25μm, not exceeding 50μm according to ISO Standard No. 4049.[18] The values obtained in the present study ranged between 77 and 305μm, therefore none of the materials complied with the ISO 4049 Standard.

Accordingly, film thickness is intimately related to viscosity of the luting agent. This property determines the degree of molecular mobility of a resin-based material[19] and it is influenced by its composition, shape, size, as well as its inorganic portion.[20] Higher filler content increases material's intrinsic viscosity, thus hampering the flow of the resin and its adaptation to the preparation, which may lead to extensive films and even cracks in the surface.[20]

Resin cements have a flowability that confers them an adequate film thickness in the luting procedure due to their low filler content.[5] On the other hand, as composite resins contain a greater amount of inorganic particles and thus are more viscous, thermo-modification is considered a viable technique to improve this characteristic. Preheated composites exhibit increased monomer mobility because of higher thermal agitation, which leads to a lower viscosity.[21] Some studies vouch for the use of preheated restorative materials as luting agents for indirect restorations.[12,13,19,22-24]

Maintaining the acquired flowability of composite resins during cementation is a challenge as heat dissipation occurs rapidly after thermo-modification is ceased and the cement is applied to the tooth structure. It has been estimated that temperature decreases 50% after 2 minutes and 90% after 5 minutes after preheating is ceased. Therefore, the material should be placed and adapted in minimal time to attain potential advantages above that of room temperature, especially for reducing film thickness.[25]

Even though thermo-modification intends to temporarily reduce viscosity and increase flowability of restorative composite resin materials, thicker interfaces compared to resin cements are observed. In this research project, preheated composite resin IPS Empress Direct hardly showed interface thickness values in the range of the resin cement. The mean measurements were 305μm and 192μm for groups 2A and 2B, respectively. This results from the higher filler content that propitiates increased filler-to-filler interactions and interfacial friction between fillers and resin matrix, affecting flowability.[26]

These findings are in line with previous studies comparing the film thickness of resin cements and restorative composite resins, thermo-modified or not.[24,27] *Coelho et al*. researched the effect of three thermo-modified restorative composite resins and a photoactivated resin cement on the performance of bonded ceramic disks simulating veneers. All resin-based agents tested were able to strengthen the ceramic structure and the resin cement RelyX Veneer yielded lower mean film thickness (59μm) than Filtek Z100 (106μm), IPS Empress Direct (165μm) and Estelite Omega (196μm).[27] *Sampaio et al*. compared two resin cements (RelyX Veneer and Variolink Esthetic LC) and two composites (Filtek Supreme Ultra and IPS Empress Direct), on various cementation techniques using plastic teeth. The 3-dimensional (3D) microcomputed tomography method detected film thickness and volume alterations between materials. Results indicated that light-polymerized cements presented less thickness than restorative composite resins, regardless of preheating. Also, the increased volume of material and greater thickness observed in groups luted with composite resins was expected to increase shrinkage when light-cured in a single moment.[24]

On the other hand, an option to improve the rheological behavior of resin-based materials, aiming to minimize film thickness in adhesive cementation, is the use of ultrasonic energy.[13,28,29] In 2005, *Schmidlin et al*. demonstrated that ultrasonic vibration affects the thixotropic properties of the luting agents, leading to a decrease in their viscosity. Therefore, an adequate adaptation of the densely filled resin composites onto the dental substrate is obtained. Besides, they proved that ultrasound-aided inlay insertion results in faster seating and reduced pressure on the restoration.[29]

Another relevant study that corroborates the beneficial effects of adding ultrasonic vibration to the luting procedure was performed by Cantoro *et al.,* who aimed to assess the influence of cement manipulation and ultrasound application on the bonding potential of resin cements dentin. Fifty-six standardized class II cavities were prepared in extracted third molars and half of the composite resin restorations were cemented under a static seating pressure, whereas the other half were luted under vibration. The researchers observed a thinner cement layer with higher adaptation and lower porosity in samples cemented with ultrasonic energy. The improved flow of resin cement under ultrasonic vibration may explain the gain in inlay retention compared to the application under static pressure. Hence, they assumed that the ultrasonic technique was effective in improving microtensile bond strength and providing a faster and more controlled seating of the restorations.[28]

In 2020, Marcondes *et al.* researched the viscosity and thermal kinetics of ten distinct preheated restorative resin composites and two resin cements, as well as the effect of ultrasonic energy on film thickness. Results obtained showed a thinner film with resin cements (which complied with the ISO 4049 standard) compared to thermo-modified composite resins. The researchers assumed that clinicians have between 10 to 15 seconds of ideal working time with preheated composites resin when temperature and viscosity are still optimal. Besides, application of ultrasounds reduced film thickness between 21% and 49%. Five of the resin composites tested had film thicknesses below or approximately 50μm after using ultrasonic vibration. Nevertheless, the samples used were flat and smooth glass plates, whereas the cementation interface may not be.[26]

Considering the present study results, it was demonstrated that samples cemented with Variolink Esthetic LC with ultrasonic vibration (group 1B) obtained the lowest mean value of film thickness (77μm). Among the composite resin groups, when ultrasound energy was used without thermo-modification (group 2C), the mean film thickness value was 146μm. A mean value of 192μm was obtained with samples submitted to thermo-modification and ultrasonic vibration (group 2B). The samples cemented with only ultrasound energy provided a thinner interface than that achieved by the two techniques ensemble. Analyzing these results and the distribution of film thickness in each sample of groups 2B and 2C, the latest presents higher homogeneity along the luted surface, which may explain the lower average value, which also leads to the supposition that luting with heated composite resin may promote an initial sliding of the restoration with possible mismatch in certain areas, thus leading to uneven film thickness values throughout the sample.

It is worth emphasizing that, contrary to Coelho *et al.* study,[27] the experimental models used to perform this study's cementation procedure, specifically ceramic onlays and prepared resin blocks, intended to simulate what occurs in clinical environment. Thus, it is reasonable to assume that cavity design may influence the flow of the luting agent and values greater than 50μm may be obtained. Finally, considering the relevant thin film observed with ultrasound energy even at room temperature, the working time may not be a significant issue when preheated composite resin is used as luting agent. Provided that ultrasound is applied afterwards, clinicians can take their time for proper excess removal before final seating and light-curing.

Another concern related to the clinical scenario is the procedure of seating the restoration. In order to improve the adaptation of the cement and avoid possible restoration displacement arising from the viscoelastic response of the composite resin in the event pressure is removed, indirect restorations should be maintained under slight pressure during seating. To perform this luting procedure, a calibrated operator used a patented prototype to apply a controlled pressure of 23N on the restoration seating process. Even though all care was taken, sliding of the sample could occur due to the cavity's geometry and luting agent used. From the interpretation of the SEM images, a sliding effect occurred on the occlusal margins of the samples cemented with IPS Empress Direct composite resin, as an overflow of cement through the margin along with larger agglomerates of fillers are observed in figure 6. In microphotograph 7, a constriction area is detected, which corroborates the theory that luting with heated composite resin may cause excessive sliding of the restorations and uneven film thicknesses along the luting surface. On the other hand, as previously discussed, the sample with ultrasound-aided-cementation showed a more adapted cement layer in the margin (figure 8).

The null hypothesis that all materials and all cementation techniques have similar film thickness is rejected by the findings of this study, since different outcomes for each luting material were observed.

Limitations of the study

Resorting to distinct resin-based agents and techniques in adhesive cementation with 3D tooth preparation/restoration simulation models, the present study aimed to evaluate the thickness of the restoration-cementing agent-tooth interface.

A shortcoming of this research project was the use of only one resin cement and one composite resin in the luting procedure. Also, a reduced number of samples were tested per group, as this was a pilot study. Sample sliding during the cementation influenced the cement adaptation, yet this phenomenon can occur clinically.

Future studies should focus on determining differences in the behavior of these luting agents with dentin and enamel substrates and different types of tooth preparations. Besides, the use of technological equipment capable of yield images with higher resolution, such as micro-computed tomography (µCT), is highly recommended.

Finally, it should be emphasized that *in vitro* studies are unable to simulate all the conditions present in the oral cavity. Hence more clinical studies are required.

Conclusion

Taking into account the limitations of this *in vitro* study, the following conclusions can be drawn:

- Samples cemented with Variolink Esthetic LC, with or without ultrasonic vibration, exhibited a lower film thickness when compared to the IPS Empress Direct groups.
- Thermo-modified composite resin has potential benefits but should be used with knowledge of its limitations.
- The addition of ultrasonic vibration while luting indirect restorations proved advantageous to lower film thickness in the two resin-based materials tested.
- Further studies are needed to provide data on the impact of restoration sliding during cementation procedures.

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