Laboratory evaluation of an optical fiber illuminator on the adhesive bond strength of resin cements to high-translucency zirconia

Avaliação laboratorial de um iluminador de fibra óptica na resistência de adesão de cimentos resinosos à zircônia de alta translucidez

Carolina Gonzales **França**[1] | Tarcisio Jose de Arruda **Paes Junior**[1] | Lais Carolina Landim **Gomes**[2]

[1] Universidade Estadual Paulista Júlio de Mesquita Filho, Instituto de Ciência e Tecnologia, Departamento de Materiais Dentários e Prótese. São José dos Campos, SP, Brasil. Correspondence to: TJA Paes Junior. E-mail: <tarcisio.paes@unesp.br>.

[2] University of Saskatchewan, College of Dentistry. Saskatchewan, S7N 2Z4, Canada.

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ABSTRACT

Objective: To evaluate in vitro the bond strength of resin cements in high-translucency zirconia restorations as a function of the light-curing system and the type of resin cement. **Methods**: Forty-eight third molars received high-translucency zirconia (KatanaTM – Kota – Tokyo, Japan) and were randomly distributed into four groups (n=12) according to the light-curing system (indirect with commercial equipment or direct with the new optical fiber illuxminator) and resin cement type (light- or dual-cured). The optical fiber device conducts LED light to hard-to-reach areas. A micro shear bond strength test applied a 50 Kgf load at 0.5 mm/min until failure. Two-way ANOVA and Tukey's test (5% significance) analyzed results. **Results**: The highest bond strength occurred in the direct optical fiber system with dual-cure cement (p<0.05), also increasing bond strength for light-cured cement. **Conclusion**: Within the limitations of this laboratory study, the use of the optical fiber illumination system was associated with higher bond strength values of resin cements to high-translucency zirconia compared with the conventional system, depending on the type of cement used. These findings indicate that the device may favor adhesion in situations with limited light access; however, further studies are required to establish its clinical relevance.

Indexing terms: Dental curing lights. Polymerization. Resin cements.

RESUMO

Objetivo*: Avaliar in vitro a resistência de união de cimentos resinosos em restaurações de zircônia de alta translucidez em função do sistema de fotopolimerização e do tipo de cimento resinoso.* ***Métodos****: Quarenta e oito terceiros molares receberam restaurações indiretas de zircônia de alta translucidez (Katana™ – Kota – Tóquio, Japão) e foram distribuídos aleatoriamente em quatro grupos (n=12), de acordo com o sistema de fotopolimerização (indireto com equipamento comercial ou direto com o novo iluminador de fibra óptica) e o tipo de cimento resinoso (fotoativado ou dual). O dispositivo de fibra óptica conduz a luz LED até áreas de difícil acesso. Um teste de resistência de união por microcisalhamento foi realizado com carga de 50 Kgf a 0,5 mm/min até a falha. Resultados: Os resultados foram analisados por ANOVA dois fatores e teste de Tukey (nível de significância de 5%).* ***Resultados****: A maior resistência de união foi observada no sistema direto com fibra óptica associado ao cimento dual (p<0,05), com aumento também da resistência de união para o cimento fotoativado.* ***Conclusão****: Dentro das limitações deste estudo laboratorial, o uso do sistema de iluminação por fibra óptica esteve associado a maiores valores de resistência de união dos cimentos resinosos à zircônia de alta translucidez, quando comparado ao sistema convencional, dependendo do tipo de cimento utilizado. Esses achados indicam que o dispositivo pode favorecer a adesão em situações de acesso restrito à luz, embora estudos adicionais sejam necessários para estabelecer sua relevância clínica.*

Termos de indexação*: Cimento resinoso. Luz de cura dentária. Polimerização.*

INTRODUCTION

Dental ceramics are materials routinely used in aesthetic restorative procedures due to their excellent properties, such as high compressive strength, high translucency and fluorescence, chemical stability, low electrical conductivity, and a thermal expansion coefficient similar to dental structure [1] Adequate cementation and adhesion between the dental substrate and the ceramic are decisive factors to achieve successful prosthetic treatment with long-term restoration durability. Furthermore, the primary photoinitiator, camphorquinone, is the most commonly used in resin-based restorative materials, as it is sensitive to the visible spectrum of blue light (425–510 nm) [2]. Manufacturers use co-initiators to enhance the degree of conversion of resin cement in regions which are not directly exposed to light since it acts in the chemical conversion of cements [3]. However, even in dual-cure cements, the efficiency of photoactivation also depends on adequate exposure to ensure the correct conversion of monomers and thus improved physical properties [4-6]. The conversion of monomers into polymers is never complete, leaving considerable amounts of unreacted methacrylate groups or residual monomers within the material, and studies have reported a degree of conversion ranging from 35% to 80% [6-9].

An inadequate degree of conversion results in low wear resistance, microleakage, tissue inflammatory reactions [10], increased sorption and solubility, color instability, and a higher likelihood of failures and restoration loss [8,11-14]. This degradation can consequently lead to the restoration dislocating due to the marginal seal dissolving, resulting in fractures and/or secondary caries, along with the risk of a local inflammatory response in the pulp caused by residual monomers [15].

The distance between the light-curing equipment and the cement leads to reduced light dissipation from the restorative material thickness. The size and quantity of filler particles cause a gradual decrease in polymerization, known as the curing depth, which influences the structure of the formed polymer [16-21].

Therefore, polymerization in cervical proximal boxes is inadequate, as the light, which is already absorbed by the material, is also affected by the difficulty of reaching the region directly. Thus, the greater the restoration depth and thickness, the less light will penetrate, and consequently the monomer conversion will be lower [14,22-27].

Considering the current limitations in delivering LED light to areas of difficult access during the cementation of indirect restorations, this study aimed to develop an optical fiber–based illumination system to reach restricted regions and to evaluate its influence on the bond strength of resin cements to zirconia restorations under in vitro conditions.

METHODS

Specimen preparation

A total of 48 intact human third molars (Ethics Committee, Brazil Platform, CEP 58905222.0.0000.0077) were used and randomly assigned to 4 experimental groups (n=12) based on the type of photopolymerization system, and the type of resin cement applied (chart 1). The composition of each resin cement is described in chart 2. The sample size was determined based on a statistical power analysis applying the G*Power 3.1 software [28].

Chart 1. Description of groups according to the cement used and activation method.

Groups (n=12)	Photopolymerization Protocol	Photopolymerization Time
IPD	Indirect photopolymerization with light-curing equipment associated with dual-cured cement.	45 seconds (Occlusal) 6 mm of distance
IPL	Indirect photopolymerization with light-curing equipment associated with light-cured cement light.	45 seconds (Occlusal) 6 mm of distance
DPD	Direct photopolymerization with optical fiber illuminator associated with dual cured cement.	45 seconds (Occlusal) + 80 seconds in each third in the buccolingual direction on the proximal
DPL	Direct photopolymerization with optical fiber illuminator associated with light cured cement.	45 seconds (Occlusal) + 80 seconds in each third in the buccolingual direction on the proximal

Note: Distribution of experimental groups according to each activation system.

Chart 2. Composition of cement and their respective manufacturers.

Product	Manufacturer	Chemical Composition
AllcemVeener	FGM Dental group (Joinville, Santa Catarina/Brasil)	Methacrylic monomers, camphor quinone, co-initiators, stabilizers, pigments, silanized Barium-Aluminum-Silicate glass particles, and Silicon Dioxide.
Allcem Dual	FGM Dental group (Joinville, Santa Catarina/Brasil)	Base paste: Methacrylic monomers Bis(GMA), Bis(EMA), and TEGDMA, camphorquinone, co-initiators, Barium-Aluminum-Silicate glass microparticles, Silicon Dioxide nanoparticles, inorganic pigments, and preservatives. Catalyst paste: Methacrylic monomers, benzoyl peroxide, stabilizers, Barium-Aluminum-Silicate glass microparticles.

Note: Composition of the resin cements used in the cementation of restorations.

Shear bond strength sample preparation

Translucent zirconia blocks (KATANA STML, Tokyo, Japan) were fixed onto a metal base in a cutting machine (ISOMET 1000, BUEHLER, USA) and sectioned perpendicular to the long axis (perpendicular to the y-axis) using a WFR BLDE 4” X 0.12” X 1/2” diamond disc (EXTEC-ERIOS, Juiz de Fora, Minas Gerais, Brazil) under constant water cooling, obtaining 48 slices of 2 mm thickness. Both sides of each disc were manually polished using water abrasive papers with grits 800 and 1200 (3M, Saint Paul, Minnesota, USA) on an Ecomet 250 polishing machine (Buehler, Lake Bluff, Illinois, USA) under water cooling until reaching 2 mm thickness and rounded angles were achieved.

After polishing, the zirconia samples were partially embedded in a PVC cylinder with a height of 3 cm in order to obtain support. The PVC cylinders with the zirconia slice positioned at the center of the cylinder were embedded with chemically activated acrylic resin (JET, Juiz de Fora, Minas Gerais, Brazil).

The 48 teeth were fixed onto a metal base in an ISOMET 1000 cutting machine (Buehler, Lake Bluff, Illinois, USA) and sectioned perpendicular to the long axis (perpendicular to the y-axis) using a WFR BLDE 4” X 0.12” X 1/2” diamond disc (EXTEC-ERIOS) under constant water cooling. The first cut was made 1 mm from the crown, removing the enamel portion, followed by a second cut to 3 mm in thickness. Both sides of each disc were manually polished using water abrasive papers with grits 800 and 1200 (3M, Saint Paul, Minnesota, USA) on an Ecomet 250 polishing machine (Buehler, Lake Bluff, Illinois, USA) under water cooling until the 3 mm thickness and rounded angles were achieved.

Optical fiber illuminator device system

The optical illuminator device was co-developed with Photonita Metrologia Óptica Ltda company (Florianópolis, Santa Catarina, Brazil). A metal device was used, which has an opening through which a 1 mm diameter, circular-section optical fiber cable passed through. The optical fiber conducted the LED light from the Radii Cal-SDI light-curing unit (SDI Limited, Bayswater, Victoria, Australia) at the respective power levels, aiming to more effectively activate the restoration area in the proximal preparation toward the cervical area, near the cementoenamel junction (CEJ). The design of the innovative optical illuminator device system (figure 1).

Figure 1. A) Complete fiber optic illuminating device being activated by a curing light. B) Fiber optic conducting the advised light from the curing light.

Calculation of the photopolymerization time for the new optical lighting system

The time needed for radiant exposure of 16J was calculated to determine the photopolymerization time for the new system. A power meter (Nova Handheld Laser Power Meter, OphirOptronics, Jerusalem, Israel) was used to measure the power of the LED Radii Cal device associated with the optical fiber illuminator system, reaching a value of 1.626 mW. The optical fiber area (0.00785 cm²) was considered to calculate the irradiance, resulting in 207.13 mW/cm², or 0.207 J/cm². The photopolymerization time was calculated using the following equation:

$$\text{Radiant Exposure (j)} = \text{Irradiance (J/cm}^2\text{)} \times \text{time (s)}$$

$$\text{Time (s)} = \text{Radiant Exposure (j)} / \text{Irradiance (J/cm}^2\text{)}$$

$$\text{Time (s)} = 16 \text{ (j)} / 0.207 \text{ (J/cm}^2\text{)}$$

$$\text{Time (s)} = 80 \text{ Seconds}$$

Thus, complementary photopolymerization was performed on the preparation notches of the proximal box for 80 seconds in each third in the buccal-lingual direction, followed by an indirect complimentary activation for 45 seconds at a distance of 6 mm per proximal without the use of the optical fiber lighting system. The photopolymerization of the resin cement without the optical fiber lighting system was performed according to the manufacturer's recommendations and photopolymerized for 45 seconds at a 6 mm distance per proximal. The photopolymerization was conducted in a dark room, protected from any external ambient light.

Specimen cementation protocol

The cementation step was performed according to the manufacturer's recommendations for the resin cement (FGM – Dental Group – Santa Catarina – Brazil) using the Allcem Veneer APS (light-cured) and Allcem Dual dual-body cements. The zirconia slices were subjected to sandblasting with aluminum oxide and then washed in an ultrasonic bath for 5 minutes with deionized water to eliminate debris. The universal primer Monobond (Ivoclar, Liechtenstein) was then applied with the microbrush for 60 seconds. The dentin structure was treated by applying 37% phosphoric acid (Condac 37, FGM Dental Group) for 15 seconds, followed by thorough rinsing with water. Then, the adhesive system (Ambar, FGM Dental Group) was applied actively with the microbrush, and excess material was removed. Next, a dark barrier was placed to block light interference, and photoactivation was performed using or not using the new fiber optic photoactivation system as described in chart 1 (figure 2A).

Micro-shear adhesive bond strength test

After cementation, the samples were stored in an incubator at 37°C, protected from light. For the mechanical test, the cylinders were mounted on a universal mechanical testing machine (EMIC DL 1000, EMIC, Brazil). The micro-shear test was performed using a knife-shaped blade and a 50 Kgf load cell at a speed of 0.5 mm/min until sample failure occurred (figure 2B). The adhesive strength (MPa) was calculated using the formula R = C/A, where C = rupture load (N), and A = bonded interfacial area (mm²). The adhesive strength values were subjected to statistical analysis.

Statistical analysis

The values obtained in the tests were subjected to the respective statistical analyses suitable for each test. A normality test (Shapiro-Wilk) was first conducted, and based on the parametric distribution, a two-way ANOVA was performed with a comparison of two independent variables: (Photopolymeralization System x Cement), followed by Tukey's multiple comparison test, with a significance level of 5%.

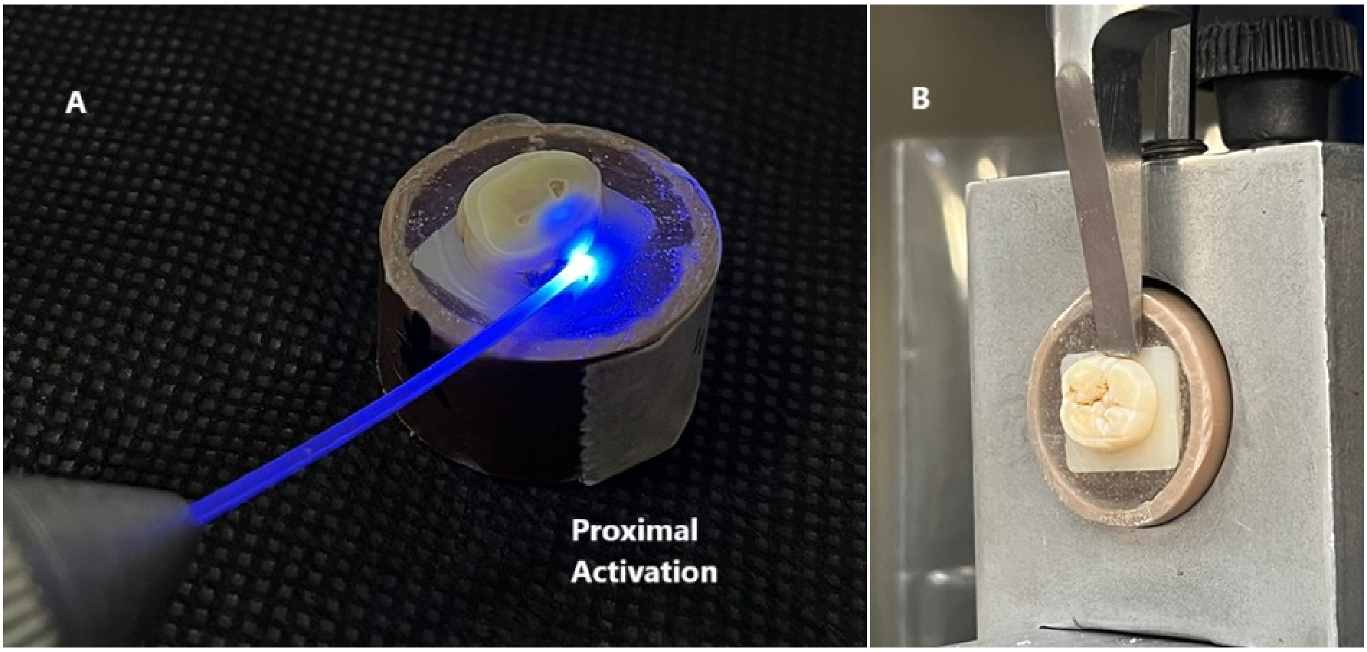

Figure 2. A) Sample being photopolymerized in the proximal region with the fiber optic illuminating device. B) Sample in the microshear test in EMIC.

RESULTS

Two-way ANOVA showed that both the photoactivation system and the type of resin cement significantly influenced micro-shear bond strength values ($p<0.05$). The highest bond strength values related to the photoactivation system were obtained with direct photoactivation using the optical fiber device combined with the dual-cured resin cement ($p<0.05$).

For the light-cured resin cement, a significant increase in bond strength was observed when the optical fiber photoactivation system was used, resulting in values comparable to those obtained with the dual-cured cement under indirect photoactivation (table 1 and figure 3).

Considering the type of cement, the dual-cured resin cement showed significantly higher bond strength values than the light-cured resin cement, regardless of the photoactivation system ($p< 0.05$).

Table 1. Statistical description of the resistance in Mpa of the samples.

Photoactivation system	Cement	N	Bond strength (MPa) – mean ± SD
Direct fiber photoactivation	Dual	12	11.00 ± 2.87
Direct fiber photoactivation	Light-cured	12	6.98 ± 4.23
Indirect photoactivation	Dual	12	7.38 ± 3.65
Indirect photoactivation	Light-cured	12	4.57 ± 3.39

Note: Descriptive statistical analysis. Bond strength values are expressed as mean ± standard deviation (MPa). SD: Standard Deviation.

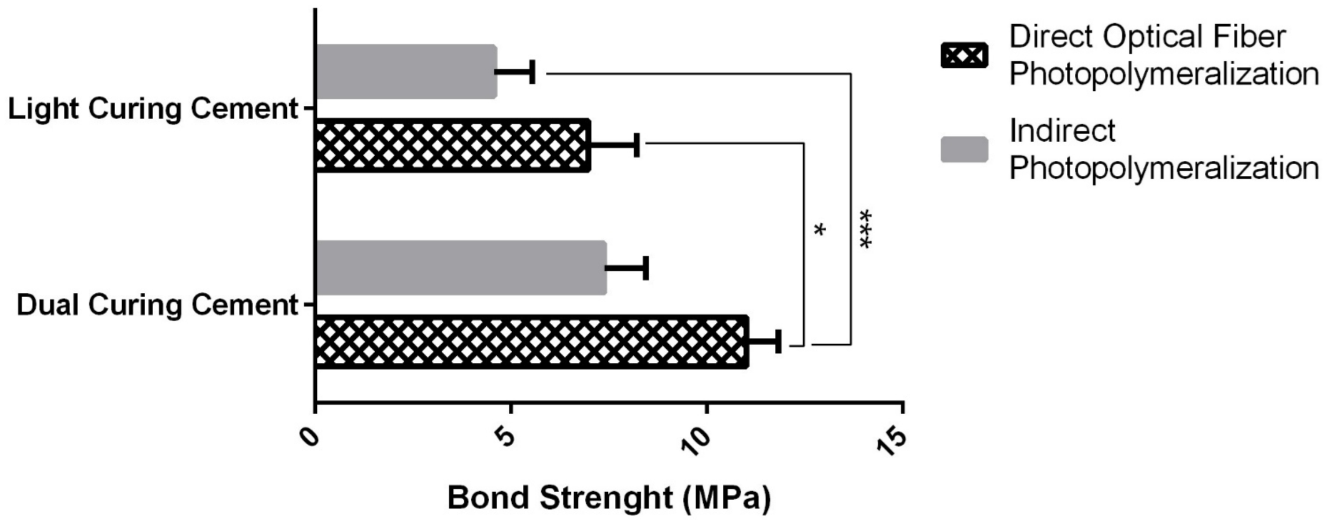

Figure 3. Micro-shear bond strength (MPa) of resin cements according to the photoactivation system.

DISCUSSION

The success of a restoration is directly related to adequate photopolymerization. This study presented a fiber optic illuminator system, which proved to be an effective alternative to improve photopolymerization, as both types of tested cements showed a significant increase in bond strength due to better LED light conduction to areas with difficult access in the posterior region.

The literature shows that proper monomer conversion is related to the good performance of the photopolymerizer [29]. In addition, Sulaiman et al. [30] and Farah et al. [31] observed that light exposure through zirconia is affected by its opacity, so that the thicker the material, the lower the irradiance received. In this context, the increase in bond strength observed in both groups when using the new photopolymerization system suggests greater monomer-to-polymer conversion due to improved light penetration.

In order to better conduct light, the research group developed the fiber optic illuminator device, designed to deliver light to areas with difficult access. In the study by Inagati et al. [32], this system showed higher monomer-to-polymer conversion in the apical third of the root canal, a region widely reported in the literature as difficult to reach with light [33]. In the present study, the device also resulted in higher bond strength in both groups subjected to direct photopolymerization, expanding the potential clinical applications of the system. These findings corroborate the study by Ho et al. [34], which demonstrated that groups exposed to higher light intensity, even in more distant regions, showed a higher degree of conversion.

Another relevant point is that the comparison between light-cured and dual-cured cements has limitations, as dual-cured cement naturally shows higher strength due to chemical settings. However, analyzing cement that sets exclusively by light allows for better evaluation of the photopolymerization system's effectiveness. In addition, the light-cured cement group with direct activation showed bond strength (6.98 MPa) similar to that of the dual-cured cement group with indirect activation (7.38 MPa). This finding has clinical relevance, as it allows considering the use of exclusively light-cured cements for restoration cementation, providing more treatment options for the prosthodontist in daily practice.

This study presents limitations inherent to the in vitro model. The simulation of proximal preparation does not fully reproduce the natural barrier represented by the adjacent tooth, which may influence light distribution and bond strength. Furthermore, as this is a pilot study, the primary objective was to evaluate bond strength under these conditions. The device, however, is part of an ongoing sequence of studies, including different types of restorations, other photopolymerizers, and additional analyses such as degree of conversion, fracture tests, aging, and microscopy. As this is the first study to propose the use of a new alternative photopolymerization system for indirect zirconia restorations, further mechanical and aging evaluations should be performed to better understand its behavior, in association with different ceramic restoration materials or resin cements, aiming to enable its potential clinical application in the future.

CONCLUSION

Within the limitations of this laboratory study, the preliminary findings suggest that the use of a direct optical fiber–based lighting system was associated with higher adhesive bond strength values, likely due to improved light delivery in areas of limited access, for both resin cement types. These results indicate that this approach may represent a potential alternative for light delivery in posterior or hard-to-reach regions; however, further studies are required to confirm its clinical applicability.

Collaborators

CG França, conceptualization, data curation, formal analysis, investigation, methodology, and writing – original draft. TJA Paes Junior, funding acquisition, project administration, resources, supervision, validation, visualization, and writing – review e editing. LCL Gomes, resources, formal analysis, project administration, validation, and writing – review e editing.

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