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Evaluation of light transmission and uniformity of hardening of resin cements as a function of simulated indirect restoration thickness

Avaliação da transmissão de luz e uniformidade do endurecimento de cimentos resinosos em função de simulações de restaurações indiretas com variadas espessuras

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ABSTRACT

Objective: This study evaluated how the thickness of a simulated indirect restoration influences the light transmission of curing units and the uniformity of dual-cure resin cement polymerization using two light sources. (VALO – ULTRADENT and RADII-CAL – SDI). **Material and Methods:** Sixty A2-shade resin composite discs (GrandioSo, VOCO GmbH), 12 mm in diameter, were fabricated and divided into three experimental groups by thickness: 1.5 mm, 2.5 mm, and 3.5 mm (n = 10 per group). For irradiance transmission, light passage through each disc was measured using a radiometer (ECEL RD-7). The same discs were used in an indirect restoration simulation (SRI), employing a 3D-printed mold with 0.3 mm lateral barriers to ensure uniform cement thickness. Dual-cure resin cement (Bifix QM Universal, VOCO GmbH) was applied, and light-curing was performed for 60 seconds with each light source. After 24 hours, Knoop microhardness was assessed in three regions of the cement: central, intermediate, and peripheral region. Light transmission was analyzed by two-way ANOVA, while cement microhardness was assessed by three-way ANOVA, followed by Tukey's post-hoc test (α=0.05). **Results:** Light transmission was undetectable through 3.5 mm specimens, indicating increased attenuation with thickness. VALO showed higher irradiance (67.6 ± 9.69 mW/cm^2) than RADII-CAL (57.3 ± 13.82 mW/cm^2). Cement microhardness decreased as restoration thickness increased, with the highest value at 1.5 mm using VALO (75.4 ± 8.43). Thickness also influenced hardening uniformity, with the highest regional value observed in the center of 1.5 mm specimens (81.5 ± 6.49). **Conclusion:** We can conclude that thickness directly influences the hardening of dual-cure resin cement, as it is affected by the light attenuation occurring through the indirect restorative material.

KEYWORDS

Cementation; Dental materials; Polymerization; Prosthodontics; Resin cements.

RESUMO

Objetivo: Este estudo avaliou como a espessura da restauração indireta simulada influencia a transmissão de luz das unidades de fotopolimerização e a uniformidade do endurecimento de um cimento resinoso dual com duas fontes de luz.(VALO – ULTRADENT e RADII-CAL – SDI). **Material e Métodos:** Sessenta discos de resina composta de cor A2 (GrandioSo, VOCO GmbH), com 12 mm de diâmetro, foram confeccionados e divididos em três grupos experimentais por espessura: 1,5 mm, 2,5 mm e 3,5 mm (n = 10 por grupo). Para transmissão de irradiância, a passagem de luz através de cada disco foi medida usando um radiômetro (ECEL RD-7). Os mesmos discos foram usados em uma simulação de restauração indireta (SRI), empregando um molde impresso em 3D com barreiras laterais de 0,3 mm para garantir espessura uniforme do cimento. Cimento resinoso dual (Bifix QM Universal, VOCO GmbH) foi utilizado e a fotopolimerização foi realizada por 60 segundos com cada fonte de luz. Após

24 horas, a microdureza Knoop foi avaliada em três regiões do cimento: região central, intermediária e periférica. A transmissão de luz foi analisada por ANOVA a dois fatores, enquanto a microdureza do cimento foi avaliada por ANOVA a três fatores vias, seguida pelo teste post-hoc de Tukey (α=0,05). **Resultados:** A transmissão de luz foi indetectável através de espécimes de 3,5 mm, indicando aumento da atenuação com a espessura. VALO apresentou maior irradiância (67,6 ± 9,69 mW/cm^2) do que RADII-CAL (57,3 ± 13,82 mW/cm^2). A microdureza do cimento diminuiu conforme a espessura da restauração aumentou, com o maior valor em 1,5 mm usando VALO (75,4 ± 8,43). A espessura também influenciou a uniformidade do endurecimento, com o maior valor regional observado no centro de espécimes de 1,5 mm (81,5 ± 6,49). **Conclusão:** Podemos concluir que a espessura influencia diretamente o endurecimento do cimento resinoso dual, pois é afetada pela atenuação da luz que ocorre através do material restaurador indireto.

PALAVRAS-CHAVE

Cimentação; Materiais dentários; Polimerização; Prótese dentária; Cimentos resinosos.

INTRODUCTION

Restorative dentistry aims to restore function, esthetics, and structure of the lost dental tissue. In cases of significant tooth structure loss, indirect restorations are the most recommended therapeutic approach. These restorations can be fabricated from various materials, considering satisfactory mechanical properties to withstand the oral environment, while also mimicking the optical characteristics of natural teeth. In this context, resin composite is often used due to its adequate resistance, realistic optical properties, and affordable cost [1].

Regardless of the material chosen for the restoration itself, successful indirect restorations require a reliable bonding interface with the remaining tooth structure to ensure adequate marginal sealing and retention. Dual-cure resin cements are considered the gold standard for this purpose due to their high hardness, color stability, and extended working time, which facilitate clinical handling and allow for chemical polymerization in areas with limited light exposure [2].

To overcome this problem in limited areas with light exposure, dual-curing resin cement can be used. Dual-cure resin cement combines two activation processes: light-curing and chemical curing. Chemical-curing light-curing is crucial in areas where the curing light does not reach, enhancing the mechanical and physical properties, such as bond strength, wear resistance, and compressive strength, while also extending the working time for the clinician. Both activation modes initiate the same chain reaction, which continues until the free radicals are consumed or the viscosity of the material increases to the point where light-curing is hindered by radical diffusion limitations, showing how complementary the two modes are [3,4].

The effectiveness of this bonding, however, depends heavily on the degree of conversion achieved by the resin cement. Although dual-cure systems are designed to compensate for reduced light exposure, the chemical pathway alone may not provide sufficient monomer conversion in deeper or highly opaque regions [5,6].

This limitation is especially important when resin composites are used as restorative materials. These materials consist of an organic resin matrix, typically based on monomers like bis-GMA, UDMA, or TEGDMA, and a filler phase made of inorganic particles such as silica or zirconia. The volume, size, and distribution of these fillers directly affect the optical properties by influencing light transmission and scattering within the material [7]. As composite thickness increases, the amount of light able to reach the underlying resin cement decreases significantly, which can lead to reduced hardness and lower light-curing efficiency [8,9].

Although the effect of thickness on the light-curing of the cementing agent is known [10,11], the use of thick restorations in ceramics has been reported in the literature. Alternative methods, such as heated resin, which has low viscosity and reduced light-curing shrinkage, resulting in better marginal adaptation, support this trend [12]. Even though studies have reported indirect restorations up to 4 mm thick, there are accounts of even thicker restorations, such as endocrowns, measuring around 7.5 mm [13].

Clinicians using this technique with thick restorations and dual-cure cements often rely on the chemical cure component and sometimes relate successful cementation to hardening the clinically visible cement margin. However, it is unclear whether hardening of the cement at the restoration margin confers homogeneity throughout the cement region. This distribution is important because proper light-curing at the margins of the cement line is considered a clinical success indicator of the technique [14].

However, literature still lacks studies evaluating the microhardness in regions other than the margin of the light-cured cement. Inadequate light-curing of dual-cure cements due to poor light transmission may compromise key physical properties, such as flexural strength, elastic modulus, bond strength, and biocompatibility, ultimately putting at risk the long-term clinical success of the restoration [15]. While addressing already established and confirmed topics in literature may offer an opportunity to better understand the subject and reassess previously accepted practices and concepts that are being overlooked in the current trend, particularly regarding the use of very thick indirect restorations.

To address the issues described above, this study aims to evaluate the influence of the thickness of simulated indirect restorations (SRI) on the light transmission of light curing unit (LCU) and the homogeneity of hardening of the dual-cure resin cement, comparing LCUs with different powers.

Therefore, the following null hypotheses were formulated:

- H1: The thickness of the indirect resin composite restoration does not influence the light transmission of the light-curing unit.
- H2: The thickness of the indirect resin composite restoration does not influence the hardening of dual-cure resin cement.

MATERIAL AND METHODS

Study design

This study used 60 discs in shade A2 of resin composites by GrandioSo (VOCO GmbH–Cuxhaven, Niedersachsen, Germany), with a diameter of 12 mm and variable thicknesses according to the experimental groups. The groups were divided based on the thickness of the fabricated specimens into: one group with 10 specimens of 1.5 mm, another with 10 specimens of 2.5 mm, and a third group with 10 specimens of 3.5 mm in thickness. The specimens were fabricated using a circular mold produced via 3D printing, employing Voxel and CHITUBOX software. Following the printing of the molds, resin composite increments of up to 1 mm were inserted and light-cured for 20 seconds until the required thickness was achieved, according to the proposed design (Figure 1).

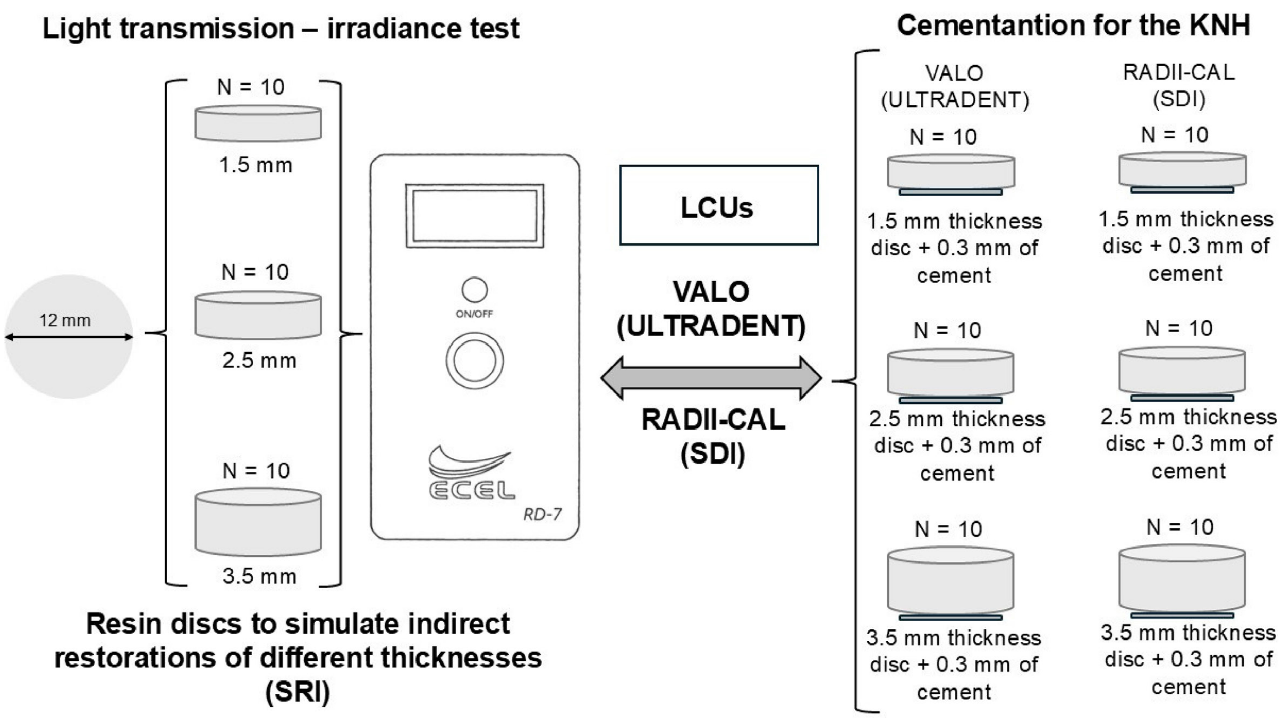

Figure 1 - Schematic figure for the division of experimental groups according to specimen thickness and the light-curing unit.

Light transmission – irradiance test

To quantify the amount of light transmitted through the indirect restorations, the ECEL RD-7 radiometer (Ribeirão Preto, São Paulo, Brazil) was used, with sensitivity in the 400–500 nm range and output reading in mW/cm². The output of the light-curing devices was measured on the radiometer before being combined with the specimens to determine the irradiance of each device. Each sample was measured three times by placing it over the radiometer, considering the diameter of the light-curing tip. The specimens were made with a diameter of 12 mm for this reason.

Simulation of cementation and microhardness of cement

To simulate the cementation of indirect restorations, the same discs used in the analysis of the light transmission of the light-curing were used as a resin barrier, to simulate the different thicknesses of an indirect restoration made of composite resin (simulated indirect restoration - SRI). A printed matrix (fabricated using designs created in the software Voxeldance Tango 2.11 and sliced for printing with Chitubox) with 0.3 mm thick lateral barriers was used to standardize the cement thickness (Figure 2). The discs (SRI) were attached to the matrix, and the dual-cure resin cement Bifix QM Universal (VOCO GmbH – Cuxhaven, Niedersachsen, Germany), was used with self-mixing syringes and dispensed into the specimen, which was pressed onto a glass plate, ensuring homogeneous spreading throughout the SRI. The material composition is on Table I.

Light-curing was performed using two distinct light-curing units with different power outputs: Radii-cal (SDI - Itasca, Illinois, USA) with a power output of 1200 mW/cm², and VALO (Ultradent Products - South Jordan, Utah, USA) with a power output of 1600 mW/cm². Both light-curing units followed a light-curing protocol for the cement through the various thicknesses of the SRIs. The cement was light cured in three distinct regions, simulating cementation within the oral cavity, considering 3 directions (top surface, anterior side, and posterior side). Each direction was light cured for 20 seconds, totaling 60 seconds. After cement polymerization, the samples were stored in sealed, light-protected containers at a controlled temperature for 24 hours to allow for adequate chemical setting of the material.

The Knoop microhardness (KHN) of the resin cement was assessed using a microhardness tester (FM-700; Future-Tech Corp., Tokyo, Japan) under the following conditions: a load of 25 N applied for 10 seconds. Each specimen underwent nine indentations, distributed as follows: three at the peripheral region, three at the center, and three between these two regions, ensuring a representative average value for each analyzed area (Figure 3).

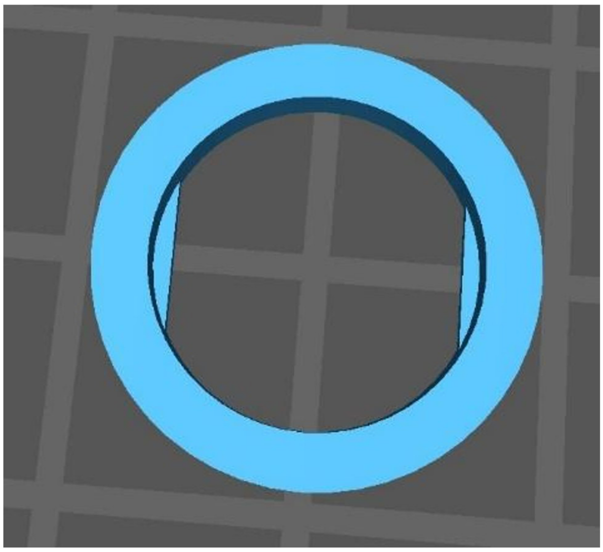

Figure 2 - Printed matrix used to standardize cement thickness to 0.3 mm.

Table I - Composition of materials

Material/Shade/Lot	Type	Manufacturer	Composition*
GrandioSo A2 2342688	Resin composite	VOCO GmbH, Cuxhaven, Germany	Barium aluminon borosilicate glass, silicon dioxide, bisphenol-A-glycidyl methacrylate, triethyleneglycol dimethacrylate, Bis(2-ethylhexyl) phthalate, initiators, stabilisers, pigments.
Bifix QM Universal 2342688	Dual-curing composite-based luting system	VOCO GmbH, Cuxhaven, Germany	Barium aluminon borosilicate glass, HEDMA, BisGMA, fluorosilicate glass, fumed silica, initiators, stabilisers, pigments

*Composition provided by the manufacturers.

Statistical analysis

For light transmission analysis, following confirmation of data normality, a two-way ANOVA test was employed, considering the thickness of SRIs and the type of light-curing unit. For analysis of the cement microhardness values, a three-way ANOVA test was utilized, considering the thickness of the SRIs, the type of light-curing unit, and three distinct regions of the cement (peripheral region, center, and intermediate region). Following this, Tukey post-hoc test was used for multiple comparisons, with a significant level of 5%.

RESULTS

Light transmission – irradiance test

In accordance with the proposed objective, the irradiance test data were collected and subjected to normality and homoscedasticity tests, indicating $p<0.05$. Descriptive statistics, considering the irradiance measured by the light-curing units studied and the different thicknesses, are reported as mean and standard deviation values in Table I. It was observed that the radiometer device was not able to detect the irradiance of the light-curing units through the 3.5 mm specimens, as shown in Table II.

Statistical differences were found in the interaction between the factors ($p < 0.05$). Differences in the transmission of light were observed between thicknesses, with irradiance decreasing as restoration thickness increased. Regarding the type of light-curing unit, VALO showed higher transmission of light compared to RADII-CAL at thicknesses of 1.5 mm ($p < 0.001$) and 2.5 mm ($p < 0.001$). Both light-curing units exhibited similar behavior at the 3.5 mm thickness ($p = 1.000$) (Figure 4).

Knoop microhardness of cement

In the data analysis, a statistically significant difference was observed for the light-curing unit factor ($p < 0.001$), thickness ($p < 0.001$), cement region ($p < 0.001$), and in the interactions of factors, such as: Light-curing unit*Thickness ($p < 0.001$), Thickness*Cement region ($p < 0.001$).

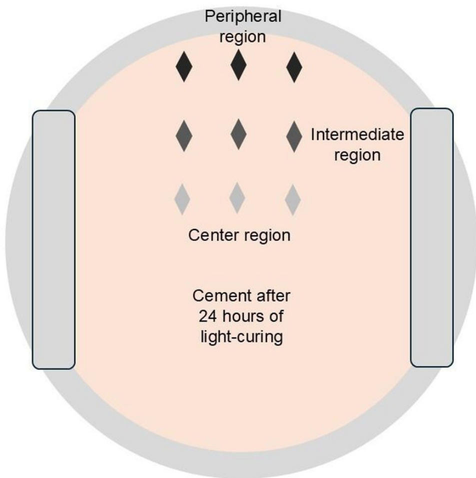

Figure 3 - Demarcation of regions in light-cured cement.

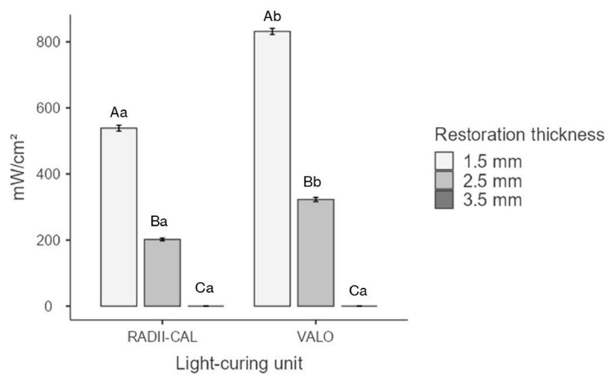

Figure 4 - Bar graph showing the transmission of different light-curing units across varying restoration thicknesses. Distinct lettering signifies statistically significant differences. Uppercase letters denote comparisons between thicknesses, while lowercase letters indicate comparisons between light-curing units.

Table II - Descriptive data of mean and standard deviation of light transmission (mW/cm²) from light-curing units through restorative simulations

		Light-curing device			
		VALO		RADII-CAL	
		Mean	SD	Mean	SD
Thickness	1.5mm	832	41.1	539	40.6
	2.5mm	323	27.7	202	18.1
	3.5mm	0	0.0	0	0.0

No statistically significant differences were found for the Light-curing unit*Cement region interaction (p = 0.282) and the Light-curing unit*Thickness*Cement regions interaction (p = 0.544).

Regarding the light-curing unit factor, VALO (67.6 ± 9.69) exhibited higher values than RADII-CAL (57.3 ± 13.82). Concerning the thickness factor, microhardness decreased with increasing thickness, as indicated by the mean and standard deviation found at 1.5 mm (72.6 ± 9.83), 2.5 mm (62.5 ± 6.39), and 3.5 mm (52.3 ± 12.79). For the cement region factor, the microhardness observed in the peripheral region (60.9 ± 9.42) of the specimens was higher than that found in the intermediate region (58.3 ± 12.96), and the central region (68.3 ± 14.09) of the cement exhibited higher microhardness than both the peripheral region and the intermediate region.

Regarding the interaction between the light-curing unit and thickness, when evaluating the performance of VALO, some differences were observed. The microhardness of the cements was different between the 1.5 mm (75.4 ± 8.43) and 2.5 mm thicknesses, with the 1.5 mm thickness exhibiting higher microhardness. Upon comparing the 1.5 mm thickness with the 3.5 mm thickness (63.2 ± 8.48), statistically significant differences were also found ($p < 0.001$), with the smaller thickness showing superior microhardness. Conversely, the performance observed at the 2.5 mm thickness (64.2 ± 7.07) was similar to that at the 3.5 mm thickness (p = 0.980).

Evaluating the performance of RADII-CAL in this same interaction (light-curing unit*thickness), all comparisons showed statistically significant differences. The microhardness at the 1.5 mm thickness (69.8 ± 10.43) was higher than at the 2.5 mm thickness (60.8 ± 5.22 - $p < 0.001$) and higher than at the 3.5 mm thickness (41.4 ± 3.81 - $p < 0.001$). Furthermore, in comparison between the 2.5 and 3.5 mm thicknesses ($p < 0.001$), the 2.5 mm thickness exhibited higher microhardness than the 3.5 mm thickness ($p < 0.001$).

When evaluating the different light-curing units at the same thickness, in the interaction between them, VALO exhibited superior performance compared to RADII-CAL at thicknesses of 1.5 mm (p = 0.03) and 3.5 mm (p = 0.001), showing similar behavior at the 2.5 mm thickness (p = 0.154) (Table III).

Regarding the interaction between thicknesses and cement regions, statistically significant differences were also observed. When considering the same cement region across different thicknesses, similar behavior was only found in the comparison of the peripheral region between the 1.5 mm and 2.5 mm specimens ($p > 0.05$). All other conditions exhibited statistically significant differences (Table IV).

Within different regions, considering the same thickness, a statistically significant difference was observed among the three studied regions of the 1.5 mm specimens ($p < 0.001$), with the center > intermediate > peripheral region.

Table III - Comparisons of mean and standard deviation of Knoop Microhardness among light-curing unit and thickness

		Light-curing unit	
		VALO	**RADII-CAL**
Thickness	1.5mm	75.4 ± 8.43^{Aa*}	69.8 ± 10.43^{Ab}
	2.5mm	64.2 ± 7.07^{Ba}	60.8 ± 5.22^{Ba}
	3.5mm	63.2 ± 8.48^{Ba}	41.4 ± 3.8^{Cb}

*Different letters indicate statistically significant differences. Uppercase letters compare rows within the same column; lowercase compare columns within the same row (Tukey's Test – α=5%).

Table IV - Comparative analysis between the cement region and the thickness factors

		Region of cement		
		Peripheral region	**Intermediate region**	**Center region**
Thickness	1.5mm	64.7 ± 7.56^{Aa*}	71.7 ± 7.09^{Ab}	81.5 ± 6.49^{Ac}
	2.5mm	63.5 ± 4.3^{Aa}	56.2 ± 3.16^{Bb}	68.0 ± 4.86^{Ba}
	3.5mm	54.5 ± 11.62^{Ba}	47.0 ± 11.52^{Cb}	55.5 ± 13.95^{Ca}

*Different letters indicate statistically significant differences. Uppercase letters – comparisons rows within the same column; lowercase letters – comparisons columns within the same row (Tukey's Test – α=5%).

At the 2.5 mm thickness, the center and peripheral region remained superior to the intermediate region ($p < 0.001$), and the peripheral region was similar to the center ($p > 0.05$). The behavior observed at the 2.5 mm thickness was repeated at the 3.5 mm thickness.

DISCUSSION

The results of this study confirm the direct influence of the thickness of indirect resin composite restorations on the transmission of the light and, consequently, on the homogeneity of cement hardening. Therefore, the null hypotheses were rejected. These findings corroborate existing literature, which demonstrates a significant reduction in transmitted light intensity as restorative material thickness increases [16].

The relationship between restorative material thickness and the reduction in light transmitted by light curing units is well documented. For instance, it was reported that at a thickness of 4 mm or greater, resin cement hardness decreases by more than 50%, indicating that light transmission through thick materials is insufficient for complete polymerization [5]. This finding is consistent with the present study, where a decrease in microhardness was observed as thickness increased.

A decrease in light transmitted was observed across all tested thicknesses, with a more pronounced reduction as the resin material became thicker. This result aligns with previous studies, which indicate that in restorations exceeding 2 mm in thickness, the transmitted light energy may be insufficient to ensure optimal polymerization of resin cement [17]. Furthermore, other studies suggest that when the restorative material exceeds 3 mm in thickness, the cement hardness may be compromised, indicating non-homogeneous polymerization [15].

Light transmission through composite resin is greatly affected by the material thickness, mainly due to its composition and microstructure. As thickness increases, light experiences more attenuation because of optical phenomena like absorption and scattering within the composite matrix [18]. This is explained by how light interacts with filler particles and the organic matrix, where density, size, and refractive index directly influence the material ability to transmit light [19,20]. In thicker layers, the longer optical path raises the chance of light being absorbed or deflected by microdefects, opaque fillers, or interfaces with mismatched refractive indices [21]. These mechanisms decrease the amount of light reaching deeper layers, affecting the effectiveness of the light-curing process.

Light irradiance is directly proportional to the amount of light transmitted through the composite resin and is a crucial factor for effective photopolymerization. The physical basis of this relationship lies in the connection between light energy and exposure intensity per unit area. Higher incident irradiance delivers more photons to activate the photoinitiators within the resin matrix, if the light can pass through the material [22]. However, as shown in this study, successful polymerization can still occur even under low transmitted irradiance conditions due to the specific optical and chemical properties of the materials, particularly in dual-cure cements, which combine light-activated and chemical curing mechanisms [23].

Additionally, measuring the irradiance of a light unit with a benchtop clinical radiometer provides an overall assessment of the output power of the curing unit, while a spectroradiometer allows a more detailed analysis of the light spectrum transmitted through the resin barrier. Spectroradiometer data yields more precise values regarding light transmission, particularly in cases where light heterogeneity may affect cement polymerization [24]. Notably, the radiometer sensor failed to detect transmitted light in the 3.5 mm specimens, which may be attributed to the equipment limitations, despite the observed hardening of the light-cured cement under these conditions.

Dual-cure resin cement combines the desirable characteristics of an adhesive material for indirect and semi-direct restorations [25], as it features additional chemical polymerization in deeper areas where light penetration may be deficient. This results in enhanced mechanical properties, ensured by adequate polymerization [26].

When light transmission is low or absent, as observed in materials with dual polymerization, the chemical polymerization initiation rate is lower, leading to a reduced number of free radicals forming polymer chains [27]. However, unlike exclusively light-cured materials, dual-cure materials still generate free radicals responsible for chemical polymerization even under low-intensity light exposure [28].

The results of this study demonstrated that light attenuation increased with the thickness of the resinous barrier, which also influenced the microhardness of dual-cure resin cement. Higher microhardness values were found in specimens with the lowest thickness, reinforcing findings from other studies, which report that increasing restorative material thickness reduces transmitted light intensity and compromises the polymerization of underlying resin cement [29].

Other studies also report the influence of the translucency of the restorative material and the healing mechanisms and encourage the study of these variables [30]. In this study, the translucency of the restorative material was standardized in all specimens using a resin material in the A2 shade for enamel, evaluating the behavior of two distinct healing mechanisms, with divergent potencies.

Analysis of different cement regions revealed that the center of the specimen exhibited superior hardness compared to other regions, following the pattern: Center > Intermediate > Peripheral region at the smallest thickness [31]. However, at 3.5 mm, the microhardness in the intermediate region was lower than in other areas, showing a distinct behavior that may be related to light dispersion and heterogeneous polymerization [32].

At the center and intermediate regions, there was a progressive decrease in the microhardness of dual-cure resin cement as the thickness of the restorative material increased. This behavior is directly related to the attenuation of incident light through the resin composite, limiting effective cement polymerization [33]. Other authors have also reported that the microhardness of dual-cure cements decreases significantly under thicknesses exceeding 2.5 mm in lithium disilicate and 2 mm in zirconia, suggesting that the choice of restorative material and polymerization protocol is crucial for clinical success [5,34].

Although it was reported that a light-curing protocol applied from the buccal, lingual, and occlusal surfaces of thick indirect restorations is not always necessary for adequate polymerization and may waste valuable clinical time [34], this protocol may have contributed to the hardening of dual-cure resin cement under adverse conditions. Therefore, the appropriate selection of a light-curing device should consider not only output power but also factors such as emission spectrum, tip design, and compatibility with the resin photoinitiator system [35-37].

Notably, evaluating and comparing the hardness of the resin cement at the peripheral and central regions of the restoration is essential because, clinically, the effectiveness of light-curing can only be reliably checked at the restoration margins. This is because the peripheral areas are accessible to clinical tools for tactile or visual inspection, while the internal regions remain hidden. Therefore, hardness measurements at the margins act as a practical indicator of overall curing quality. Uneven light-curing between the center and periphery may lead to compromised mechanical properties, marginal leakage, or long-term failure of the restoration, highlighting the importance of ensuring adequate light transmission across the entire cement layer.

CONCLUSION

Based on the results of this study, the greater thickness and consequent light attenuation compromise the hardening of the dual-cured resin cement. Additionally, greater hardening was observed in the center of the specimen, which suggests that the peripheral hardening observed by clinicians in indirect composite resin restorations can be used as a reference to evaluate the effectiveness of polymerization in more critical areas.

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Author's Contributions

LSS, TMFC, EB: Conceptualization. LSS, SVSO, MFM, TMFC, EB: Data Curation. LSS, SVSO, MFM, TMFC, EB: Formal Analysis. LSS, SVSO, MFM, TMFC, EB: Investigation. LSS, SVSO, MFM, TMFC, EB: Methodology. LSS, SVSO, TMFC, EB: Visualization. LSS, SVSO, TMFC, EB: Writing – Original Draft Preparation. LSS, SVSO, MFM, TMFC, EB: Writing – Review & Editing. TMFC, EB: Validation. EB: Funding Acquisition. EB: Project Administration. EB: Resources. EB: Supervision.

Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

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Regulatory Statement

This study did not require submission to the ethics committee.

REFERENCES

1. Watts DC. The quest for stable biomimetic repair of teeth: technology of resin-bonded composites. Dent Mater J. 2020;39(1):46-51. http://doi.org/10.4012/dmj.2019-201. PMid:31666489.
2. Ghodsi S, Shekarian M, Aghamohseni MM, Rasaeipour S, Arzani S. Resin cement selection for different types of fixed partial coverage restorations: a narrative systematic review. Clin Exp Dent Res. 2023;9(6):1096-111. http://doi.org/10.1002/cre2.761. PMid:37427500.
3. Carek A, Dukaric K, Miler H, Marovic D, Tarle Z, Par M. Post-cure development of the degree of conversion and mechanical properties of dual-curing resin cements. Polymers. 2022;14(17):3649. http://doi.org/10.3390/polym14173649. PMid:36080725.
4. Aldhafyan M, Silikas N, Watts DC. Influence of curing modes on conversion and shrinkage of dual-cure resin-cements. Dent Mater. 2022;38(1):194-203. http://doi.org/10.1016/j.dental.2021.12.004. PMid:34924201.
5. El-Mowafy OM, Rubo MH. Influence of composite inlay/onlay thickness on hardening of dual-cured resin cements. J Can Dent Assoc. 2000;66(3):147. PMid:10859728.
6. Breeding LC, Dixon DL, Caughman WF. The curing potential of light-activated composite resin luting agents. J Prosthet Dent. 1991;65(4):512-8. http://doi.org/10.1016/0022-3913(91)90291-4. PMid:2066888.
7. Haugen HJ, Ma Q, Linskens S, Par M, Mandic VN, Mensikova E, et al. 3D micro-CT and O-PTIR spectroscopy bring new understanding of the influence of filler content in dental resin composites. Dent Mater. 2024;40(11):1881-94. http://doi.org/10.1016/j.dental.2024.09.001. PMid:39277488.
8. Fidalgo-Pereira R, Catarino SO, Carvalho Ó, Veiga N, Torres O, Braem A, et al. Light transmittance through resin-matrix composite onlays adhered to resin-matrix cements or flowable composites. J Mech Behav Biomed Mater. 2024;151:106353. http://doi.org/10.1016/j.jmbbm.2023.106353. PMid:38194785.
9. Maghaireh GA, Price RB, Abdo N, Taha NA, Alzraikat H. Effect of thickness on light transmission and vickers hardness of five bulk-fill resin-based composites using polywave and single-peak light-emitting diode curing lights. Oper Dent. 2019;44(1):96-107. http://doi.org/10.2341/17-163-L. PMid:29953339.
10. Lee H, Young Kim RJ, Seo DG. Shear bond strength of dual-cured resin cements on zirconia: the light-blocking effect of a zirconia crown. J Dent Sci. 2023;19(1):162-8. http://doi.org/10.1016/j.jds.2023.05.011. PMid:38303887.
11. Bansal R, Taneja S, Kumari M. Effect of ceramic type, thickness, and time of irradiation on degree of polymerization of dual-cure resin cement. J Conserv Dent. 2016;19(5):414-8. http://doi.org/10.4103/0972-0707.190010. PMid:27656058.
12. Mounajjed R, Salinas TJ, Ingr T, Azar B. Effect of different resin luting cements on the marginal fit of lithium disilicate pressed crowns. J Prosthet Dent. 2018;119(6):975-80. http://doi.org/10.1016/j.prosdent.2017.08.001. PMid:29150135.
13. Gregor L, Bouillaguet S, Onisor I, Ardu S, Krejci I, Rocca GT. Microhardness of light- and dual-polymerizable luting resins polymerized through 7.5-mm-thick endocrowns. J Prosthet Dent. 2014;112(4):942-8. http://doi.org/10.1016/j.prosdent.2014.02.008. PMid:24767899.
14. Shimokawa CAK, Carneiro PMA, Lobo TRS, Arana-Chavez VE, Youssef MN, Turbino ML. Five second photoactivation? A microhardness and marginal adaptation in vitro study in composite resin restorations. Int Dent J. 2016;66(5):257-63. http://doi.org/10.1111/idj.12227. PMid:27061395.
15. De Angelis F, Vadini M, Capogreco M, D'Arcangelo C, D'Amario M. Effect of light-sources and thicknesses of composite onlays on micro-hardness of luting composites. Materials. 2021;14(22):6849. http://doi.org/10.3390/ma14226849. PMid:34832251.
16. Breeding LC, Dixon DL, Caughman WF. The curing potential of light-activated composite resin luting agents. J Prosthet Dent. 1991;65(4):512-8. http://doi.org/10.1016/0022-3913(91)90291-4. PMid:2066888.
17. Paula AB, Tango RN, Sinhoreti MAC, Alves MC, Puppin-Rontani RM. Effect of thickness of indirect restoration and distance from the light-curing unit tip on the hardness of a dual-cured resin cement. Braz Dent J. 2010;21(2):117-22. http://doi.org/10.1590/S0103-64402010000200005. PMid:20640357.
18. Musanje L, Darvell BW. Curing-light attenuation in filled-resin restorative materials. Dent Mater. 2006;22(9):804-17. http://doi.org/10.1016/j.dental.2005.11.009. PMid:16364419.
19. Ruyter IE, Øysæd H. Conversion in different depths of ultraviolet and visible light activated composite materials. Acta Odontol Scand. 1982;40(3):179-92. http://doi.org/10.3109/00016358209012726. PMid:6957140.
20. Campbell PM, Johnston WM, O'Brien WJ. Light scattering and gloss of an experimental quartz-filled composite. J Dent Res. 1986;65(6):892-4. http://doi.org/10.1177/00220345860650060501. PMid:3011867.
21. Elgendy H, Maia RR, Skiff F, Denehy G, Qian F. Comparison of light propagation in dental tissues and nano-filled resin-based composite. Clin Oral Investig. 2019;23(1):423-33. http://doi.org/10.1007/s00784-018-2451-9. PMid:29713891.
22. Watts DC, Cash AJ. Analysis of optical transmission by 400-500 nm visible light into aesthetic dental biomaterials. J Dent. 1994;22(2):112-7. http://doi.org/10.1016/0300-5712(94)90014-0. PMid:8195476.
23. Cadenaro M, Navarra CO, Antoniolli F, Mazzoni A, Di Lenarda R, Rueggeberg FA, et al. The effect of curing mode on extent of polymerization and microhardness of dual-cured, self-adhesive resin cements. Am J Dent. 2010;23(1):14-8. PMid:20437721.
24. Go YR, Kim KM, Park SH. Influence of inhomogeneity of the polymerization light beam on the microhardness of resin cement under a CAD-CAM block. J Prosthet Dent. 2022;127(5):802.e1-10. http://doi.org/10.1016/j.prosdent.2022.02.004. PMid:35272842.
25. Prieto LT, Araújo CTP, Pierote JJA, Oliveira DCRS, Coppini EK, Paulillo LAMS. Evaluation of degree of conversion and the effect of thermal aging on the color stability of resin cements and flowable composite. J Conserv Dent. 2018;21(1):47-51. http://doi.org/10.4103/JCD.JCD_128_17. PMid:29628647.

26. Park SH, Kim SS, Cho YS, Lee CK, Noh BD. Curing units ability to cure restorative composites and dual-cured composite cements under composite overlay. Oper Dent. 2005;29(6):627-35. PMid:15646217.

27. Meng X, Yoshida K, Atsuta M. Influence of ceramic thickness on mechanical properties and polymer structure of dual-cured resin luting agents. Dent Mater. 2008;24(5):594-9. http://doi.org/10.1016/j.dental.2007.06.014. PMid:17669482.

28. Meng X, Yoshida K, Atsuta M. Hardness development of dual-cured resin cements through different thicknesses of ceramics. Dent Mater J. 2006;25(1):132-7. http://doi.org/10.4012/dmj.25.132. PMid:16706308.

29. Ikemoto S, Komagata Y, Yoshii S, Masaki C, Hosokawa R, Ikeda H. Impact of CAD/CAM material thickness and translucency on the polymerization of dual-cure resin cement in endocrowns. Polymers. 2024;16(5):661. http://doi.org/10.3390/polym16050661. PMid:38475344.

30. Meleka NM, Elbanna A, El-Korashy DI. Color stability and degree of conversion of amine-free dual cured resin cement used with two different translucencies of lithium disilicate ceramics. Braz Dent Sci. 2023;26(2):e3614. http://doi.org/10.4322/bds.2023.e3614.

31. Blumentritt FB, Cancian G, Saporiti JM, Holanda TA, Barbon FJ, Boscato N. Influence of feldspar ceramic thickness on the properties of resin cements and restorative set. Eur J Oral Sci. 2021;129(2):e12765. http://doi.org/10.1111/eos.12765. PMid:33455026.

32. Al Hendi KD, Alyami MH, Yadav NS, Alqahtani AS, Gajdhar S, Almakrami AI. Assessment of dual-cure resin cement properties of microhardness and water sorption/solubility through various shades of monolithic zirconia. J Pharm Bioallied Sci. 2024;16(Suppl 4):S3188-90. http://doi.org/10.4103/jpbs.jpbs_659_24. PMid:39926817.

33. Pishevar L, Ashtijoo Z, Khavvaji M. The effect of ceramic thickness on the surface microhardness of dual-cured and light-cured resin cements. J Contemp Dent Pract. 2019;20(4):466-70. http://doi.org/10.5005/jp-journals-10024-2540. PMid:31308278.

34. Turp V, Turkoglu P, Sen D. Influence of monolithic lithium disilicate and zirconia thickness on polymerization efficiency of dual-cure resin cements. J Esthet Restor Dent. 2018;30(4):360-8. http://doi.org/10.1111/jerd.12390. PMid:30070739.

35. Daher R, Krejci I, Rocca GT, Di Bella E, Kleverlaan CJ, Feilzer AJ, et al. Effect of light-curing time and direction on microhardness of a light-cured resin composite to cement CAD-CAM restorations. Am J Dent. 2022;35(3):123-7. PMid:35798705.

36. Arikawa H, Fujii K, Kanie T, Inoue K. Light transmittance characteristics of light-cured composite resins. Dent Mater. 1998;14(6):405-11. http://doi.org/10.1016/S0300-5712(99)00014-7. PMid:10483402.

37. Price RB, Ferracane JL, Shortall AC. Light-curing units: a review of what we need to know. J Dent Res. 2015;94(9):1179-86. http://doi.org/10.1177/0022034515594786. PMid:26156516.

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