CATÓLICA
FACULDADE DE MEDICINA DENTÁRIA
VISEU

# Effect of the load and thickness of resin cement on the light transmittance through zirconia onlays: an in vitro study

Dissertação apresentada à Universidade Católica Portuguesa para obtenção do grau de Mestre em Medicina Dentária

Smila Leduc

Viseu, 2025

# Effect of the load and thickness of resin cement on the light transmittance through zirconia onlays: an in vitro study

Dissertação apresentada à Universidade Católica Portuguesa para obtenção do grau de Mestre em Medicina Dentária

Por: Smila Leduc

**Orientador:** Professora Doutora Rita Fidalgo Pereira

**Co-Orientador:** Professor Doutor Júlio Souza

Viseu, 2025

# Membros do Júri das Provas Públicas

Presidente: Nuno Ricardo das Neves Rosa
(Professor associado, Universidade Católica Portuguesa)

Arguente: Orlanda de Araújo Lamas Correia Torres
(Professora associada, Instituto Superior de Ciências da Saúde)

Orientador: Rita Cristina País Fidalgo Pereira
(Professor auxiliar convidado, Universidade Católica Portuguesa)

Data das provas públicas: 03 / 07 / 2025

Classificação: 19

***Dédicace***

*À ma mère, pour tout l'amour et le soutien inconditionnel qu'elle m'a donné.*

*À Samuel, pour ce bonheur et ces rires qui rendent mes journées plus belles.*

*« Même la nuit la plus sombre se terminera et le soleil se lèvera » - Victor Hugo*

***Agradecimentos***

*À minha orientadora,* ***Professora Doutora Rita Pereira****, por toda a simpatia, ajuda e apoio que me deu. Aprendi muito durante este ano, estou muito grata e tenho uma grande admiração para o seu trabalho. Muito obridada por tudo!*
*Ao meu co-orientador,* ***Professor Doutor Júlio Souza*** *por toda a ajuda e apoio durante este ano.*

***À ma mère,*** *mon héroïne, pour son courage et son rôle si important dans ma vie. Ma reconnaissance est éternelle. Merci pour tout, merci d'être toi, je t'aime.*

***À ma grand-mère****, pour son amour, son soutien et sa force de caractère.*

***À ma famille****, pour son soutien sans faille depuis toujours.*

***À ma moitié, Samuel****, pour me rendre heureuse et me faire rire chaque jour. « Je t'aime dans le temps. Je t'aimerai jusqu'au bout du temps. Et quand le temps sera écoulé, alors, je t'aurai aimé. Et rien de cet amour, comme rien de ce qui a été, ne pourra jamais être effacé. » - Jean d'Ormesson*

***À mes amis (Lucie, Roxane, Romain, Théo et Titouan),*** *pour cette amitié précieuse que je chéris chaque jour et pour tous ces fous-rires au fil des années. Je vous souhaite tout ce que la vie a de plus beau à offrir. Je vous aime.*

***À ceux qui nous ont quittés,*** *merci pour le bout de chemin partagé.*

**Abstract**

**Purpose:** The objective of this study was to evaluate the light transmittance behavior of resin-matrix cement and zirconia onlays after cementation, subjected to two different loading magnitudes.

**Materials and Methods:** Eighteen CAD-CAM fabricated 3Y-TZP zirconia onlays (1.5 mm thickness) were cemented onto zirconia disks following the APC protocol. Specimens were divided into two groups: Z20 (20 N load) and Z60 (60 N load), each applied for 60 seconds and analyzed in triplicate. All samples were cemented using a 73 wt% resin-matrix cement and light-cured at 900 mW/cm². Optical transmittance was assessed using a spectrometer with a monochromator before, during, and after polymerization, with additional real-time irradiance data from a MiniGig device. Post-cementation, specimens were sectioned perpendicularly and examined under optical microscopy for structural evaluation.

**Results:** The highest light transmittance for uncemented zirconia onlays occurred near 300 nm, with increased transmission from 600 to 850 nm and peaks around 830–850 nm. Cemented specimens in the Z60 group exhibited higher light transmittance and radiant power at 840 nm than those in Z20, suggesting superior polymerization efficiency. MiniGig analysis revealed increased real-time irradiance and Rp/np ratios in Z60, while benchtop spectrophotometry showed no significant difference before and after curing. Both instruments provided complementary insights—absolute transmittance and dynamic irradiance, respectively.

**Conclusions:** This study confirms that higher cementation loads (60 N) improve light transmittance and polymerization efficiency through 1.5 mm 3Y-TZP zirconia onlays. Increased pressure reduces cement layer thickness, minimizing light scattering. Both benchtop and in situ spectrophotometry validated the optical benefits of higher loads. Clinically, adequate cementation force is critical for optimal curing under opaque zirconia restorations. Standardized cementation protocols are recommended to enhance long-term restoration performance.

**Keywords:** onlay; zirconia; resin-matrix cement; cementation load; light transmission

**Resumo**

**Objetivo:** Este estudo teve como objetivo avaliar a transmissão da luz através de onlays de zirconia de cimento à base de resina após cimentação com duas forças de cimentação diferentes.

**Materiais e Métodos:** Dezoito discos de zircónia 3Y-TZP receberam onlays de 1,5 mm, fabricados por CAD-CAM, e foram cimentados conforme protocolo APC. As amostras foram divididas em dois grupos: Z20 (20 N) e Z60 (60 N), com cargas aplicadas por 60 segundos. Todas foram cimentadas com cimento resinoso contendo 73% de partículas inorgânicas e fotopolimerizadas a 900 mW/cm². A transmitância óptica foi avaliada por espectrofotómetro com monocromador integrado antes e após a polimerização, e durante esta, com o dispositivo MiniGig. Após a cimentação, os espécimes foram seccionados e analisados por microscopia ótica para avaliar a interface e a morfologia do conjunto restaurador.

**Resultados:** Os maiores valores de transmitância foram observados em 300 nm nas amostras sem cimento resinoso, com aumento entre 600–850 nm, especialmente entre 830–850 nm. As amostras cimentadas com 60 N apresentaram maior transmitância e rácios Rp/np aos 840 nm em comparação às de 20 N. O espectrofotómetro não revelou diferenças significativas antes e após a polimerização, enquanto o MiniGig indicou maior potência radiante para o grupo Z60 durante a fotopolimerização. Ambos os dispositivos forneceram dados complementares: o espectrofotómetro mediu transmitância absoluta e o MiniGig, irradiância em tempo real.

**Conclusões:** Este estudo demonstra que forças de cimentação mais elevadas (60 N) aumentam a transmitância de luz e a eficiência de polimerização sob onlays em zircónia. A maior pressão reduz a espessura do cimento, diminuindo a dispersão luminosa. Clinicamente, a aplicação controlada de força e a padronização dos protocolos de cimentação são essenciais para otimizar o desempenho restaurador.

**Palavras-chave:** onlay; zircónia; cimento resinoso; força de cimentação; transmissão de luz

**Index**

**1. INTRODUCTION ........ 3**

**1.1 State of the art ........ 4**

1.1.1 Resin cements and zirconia ........ 4

1.1.2 Zirconia surface preparation ........ 6

1.1.3 Relation between zirconia thickness and polymerization of resin-matrix cements ........ 7

**2. MATERIALS AND METHODS ........ 11**

**2.1 Preparation of specimens ........ 11**

**2.2 Light transmittance analysis ........ 16**

**2.3 Chemical and microscopic assays ........ 17**

**2.4 Statistical analysis ........ 17**

**3. RESULTS ........ 21**

**3.1 Microstructural aspects ........ 21**

**3.2 Optical transmittance results ........ 21**

**4. DISCUSSION ........ 31**

**5. CONCLUSIONS ........ 39**

**6. BIBLIOGRAPHY ........ 40**

**7. APPENDIX ........ 48**

## List of abbreviations

**3Y-TZP** – 3% mol yttria-stabilized tetragonal zirconia polycrystals

**DC** – Degree of conversion

**GI** – Glass ionomer

**RMGI** – Resin-modified glass ionomer

**MDP** – Methacryloyloxydecyl dihydrogen phosphaste

**TA** – Tertiary amine

**CQ** – Camphorquinone

**Bis-GMA** – 2,2-bis-[4-(2-hydroxy-3-methacrylo-xypropoxy)phenyl]-propane

**UDMA** – Urethane-dimethacrylate

**TEGDMA** - triethyleneglycol dimethacrylate

**PENTA** – Dipentaerythritol penta-acrylate phosphate

**4-MET** – 4-methacryloxyethyl trimellitic acid

**APC** – Air-borne particle abrasion / primer / resin-matrix cement

**CIP** – Cold isostatic pressing

**LED** – Light emitting diode

**LCU** – Light-curing unit

**UV** – Ultraviolet

**Index of Tables**

**Table 1.** Details of the materials used in this study ................................................ 13
**Table 2.** Analysis of variance of the transmittance results at 834 nm for the Z20 and Z60 onlays bonded to resin-matrix cements with a load of 20 N and 60N. Each measurement corresponds to an individual sample. ................................................ 23
**Table 3.** Analysis of variance of the Rp/np results at 834 nm for the Z20 and Z60 onlays bonded to resin-matrix cements with a load of 20 N and 60N. Each measurement corresponds to an individual sample. ................................................ 24
**Table 4.** Analysis of variance of the Radiant Power in MiniGig for Z20 and Z60 onlays bonded to resin-matrix cements with a load of 20 N and 60N. Each measurement corresponds to an individual sample. ........................................................ 28
**Table 5.** Analysis of variance of the Radiant Power in MiniGig for Z20 and Z60 onlays bonded to resin-matrix cements with a load of 20 N and 60N. Each measurement corresponds to an individual sample ........................................................ 28

**Index of Figures**

**Figure 1.** (A) Cementation procedure, (B) Resin cement light-curing, (C) Adhesive interface. Image adapted from (31)....6

**Figure 2.** Carver Press Machine for Zirconia Green body Preparation. The image shows the machine with a zirconia powder in the mold, where it is subjected to a pressing force of 1 ton for 5 min....11

**Figure 3.** Cold Isostatic Pressing (CIP) Machine for Zirconia Sample Compaction. ..12

**Figure 4.** Prepared Zirconia Samples....12

**Figure 5.** Assessment of light transmittance under two different loading magnitudes. ....14

**Figure 6.** Specimens preparation steps: A- Ultrasonic specimens cleaning: 10 min in isopropyl alcohol and 10 min in distilled water / B- Preparations of inner surfaces: Air-borne particle abrasion with 50 µm aluminium oxide (Al2O3) particles / C- Preparations of inner surfaces: Primer (Ceramic bond™, VOCO GmbH, Cuxhaven, Germany) with silane and 10-MDP during 60 sec and dry 5 sec / D- Application of the Universal Adhesive (Futurabond, VOCO, Germany) on the microbrush / E- Universal Adhesive during 20 s / F- Cementation with resin-matrix cement (Bifix QM™, VOCO GmbH, Cuxhaven, Germany) / G- Cementation under 20 N and 60 N / H-Photopolymerization during 60 s....15

**Figure 7.** Optical microscopy at the cementation interface with a x50 magnification.17

**Figure 8.** Optical microscopy (OM) images acquired at ×50 magnification (A) Depict the interfacial regions of restorations luted with a dual-curing, adhesive resin-matrix cement containing 73 wt% inorganic filler content. Higher magnification images at ×100 (B) provide a more detailed visualization of the same restorative interfaces, further illustrating the morphological characteristics and continuity of the cement layer.. (C) Resin-matrix cement layer at x200, (D) Resin-matrix cement microstructure at x500 magnification....21

**Figure 9.** ADC count of the 3Y-TZP specimens with 1.5 mm thickness without resin-matrix cement (Z0) in the wavelength range from 290 up to 850 nm....22

**Figure 10.** ADC count of the of the polymerized and non-polymerized 1.5 mm specimens with (A) 20N and (B) 60N magnitudes on 3Y-TZP specimens of 1.5 mm thickness cemented to resin-matrix cement before and after light curing for 60 s in the wavelength range from 290 up to 850 nm at light irradiance. ....23

**Figure 11.** Transmittance ratio (arbitrary units, a.u.) comparing polymerized to non-polymerized (Rp/np) 1.5 mm thick 3Y-TZP onlay specimens subjected to (A) 20 N and (B) 60 N loading conditions, measured within the 830 to 850 nm wavelength range under light irradiation. ........ 25
**Figure 12.** Rp/np of all samples, measured at 834 nm. ........ 25
**Figure 13.** LCU irradiance, radiant power results from MiniGig. (A) Before measurements (B) Radiant power values, 502.5 mW from 360 up to 830 nm and (C) Irradiance values of 999.7 mW/cm2 from 360 up to 830 nm. ........ 26
**Figure 14.** (A) Radiant power and (B) Irradiance of LCU graphs extracted from MiniGig. ........ 27
**Figure 15.** Z0, Z20 and Z60 Radiant power results measured by MiniGig between a wavelength of 360-830 nm. ........ 27
**Figure 16.** Rp/np from all samples using MiniGig device. ........ 28

# INTRODUCTION

## 1. INTRODUCTION

Recently, an increased demand for restorative materials with good esthetic and enhanced mechanical and physical properties have arisen (1,2). Among these materials, zirconia is one of the most used due to its great mechanical and esthetic properties, showing a fracture toughness of 9 ± 0.34 MPa and elastic modulus around 240 ± 9.5 GPa (1,3,4) and three-point bending strength of around 1200 ± 130 MPa, (1,5). Moreover, zirconia can be used for several types of chair-side restorations including onlays when the tooth damage involves the cusps (6). Indeed, monolithic zirconia is the most used material for indirect ceramic restorations (7,8).This material has optimal mechanical properties such as high hardness values (around 14 GPa), resistance to wear and does not wear when is polished. The strength of monolithic zirconia can range from 400 to 1300 MPa depending on yttria concentration and has a fracture toughness that can range from 2.4 to 6 MPa $m^{1/2}$(2,7). However, concerns have arisen regarding the light transmittance through zirconia and the influence of cementation load on the light transmittance.

At atmospheric pressure, pure zirconia can have three forms: a monoclinic form from room temperature to 1170°C, a tetragonal form between 1170°C and 2370°C and a cubic form from 2370°C to melting temperature 2700°C (2,9,10). Tetragonal zirconia is the most resistant but needs to be stabilized with yttria to be retained at room temperature. For instance, with 3 mol% of yttria a 3Y-TZP zirconia with 62.73% of Zirconium and 8.03% of Yttrium (11) can be obtained. Cubic zirconia is the most translucent zirconia since translucency increases with yttria concentration. For this reason, zirconia containing more cubic phase (4Y-TZP or 5-TZP) are mainly used for esthetic dentistry, while stronger and more opaque zirconia like 3Y-TZP is mainly used for posterior restorations (7,9). Regarding density, for a 3Y-TZP zirconia, the tetragonal phase is 6083 $kg/m^3$ and the cubic phase is 6053 $kg/m^3$. When zirconia is sintered above ~1400°, the concentration of cubic phase increases which leads to an increase of translucency and decrease of flexural strength and grain size (5,9). Unlike 4Y-TZP or 5Y-TZP zirconia, 3Y-TZP zirconia is opaquer due to the interaction of grain size (approximately 0.4 µm) with light wavelength 0.1 and 0.7 µm, which leads to light refraction instead of light transmission. As a result, 3Y-TZP zirconia has fewer surface defects, is denser and has a better grains uniformity (11).

Is important to highlight that the ceramic thickness, zirconia microstructure and resin-matrix cement are crucial parameters on light-curing, translucency, color of the indirect restoration. Therefore, these parameters also play a crucial role on the degree of monomers conversion of resin-matrix cement, that not only depends on the resin-matrix cement, restorative thickness, indirect restorative material and light-curing procedure (12,13).

## 1.1 State of the art

### 1.1.1 Resin cements and zirconia

Indirect dental restorations, such as onlays, are typically luted using resin-matrix cements that require proper polymerization to ensure adequate retention and long-term durability of the restoration (6). Currently the majority of resin-matrix cements are dual or light cured, and it is crucial to understand the influence of the type and thickness of resin-matrix cements under zirconia indirect restorations. Indeed, the ceramic thickness, microstructure and the type of resin-matrix cement can impact the light transmittance leading to a low degree of conversion (DC) and impair the outcome of the indirect restoration (1,14). Furthermore, during cementation, a change in loading can impact the properties of the restoration and the light transmittance, since it can range from 12N up to 67N (6,15).

There are different alternatives for zirconia cementation like glass ionomer (GI) cement, resin-modified glass-ionomer (RMGI) cement, or resin-matrix cement containing 10-methacryloyloxydecyl dihydrogen phosphate (MDP) (16). The resin-matrix cement containing 10-MDP demonstrated higher bond strength compared to the GI and RMGI cement (16,17). Regarding resin-matrix cement polymerization pathways, there are three types: light-cured, self-cured and dual-cured resin cements (18,19,19). For zirconia with decreased light transmission, dual- or self-cured resin-matrix cements should be used to guarantee adequate polymerization and DC (20). Indeed, dual-cured resin-matrix cements have both light and chemical activation to ensure a proper polymerization when there is a lower light transmission (21,22). For dual-cured resin-matrix cements, polymerization is initiated by a chemical reaction between benzoyl peroxide and a tertiary amine (TA) while a photoinitiator system composed by camphorquinone (CQ) and TA (CQ/TA) is stimulated by visible light (21,23). Dual-cured resin-matrix cements are one of the most used types of resin-matrix cements because it allows an adequate polymerization even when light transmission is reduced (24). Also, resin-matrix cements that have high proportion of micro- and nano- scale inorganic fillers can lead to variation of the absorption and refraction of light (25). Consequently, a high degree of light refraction can lead to a decrease of light transmittance which will result in an inefficient DC of the organic matrix of the resin-matrix cements (25). Various inorganic fillers such as glass ceramics, ytterbium fluoride, and amorphous silica were found in the resin-matrix cements (26). The organic matrix of resin-matrix cements typically comprises monomers such as bisphenol A-glycidyl dimethacrylate (Bis-GMA), urethane dimethacrylate (UDMA), and triethylene glycol dimethacrylate (TEGDMA). Most formulations incorporate high molecular weight monomers including Bis-GMA, UDMA, TEGDMA, and hydroxyl ethyl methacrylate (HEMA). Bis-GMA is characterized by a relatively high molecular weight ($512\ g\cdot mol^{-1}$) and elevated viscosity (600–1000 Pa·s), which imposes limitations on the loading of inorganic fillers within resin-based composites. UDMA is commonly employed as the primary base monomer, typically combined with TEGDMA to enhance the resin’s overall performance. Consequently, achieving an optimal balance between the proportions of inorganic fillers and the organic matrix is essential (26). Furthermore, self-adhesive resin-matrix cements typically contain acid-functionalized monomers, enabling simultaneous demineralization and adhesion to the tooth substrate (27,28). These monomers are designed to penetrate and etch the dental substrate, creating chemical interactions with methacrylate monomers and $Ca^{2+}$ ions from hydroxyapatite to partially "silanize" the tooth surface. The gold standard functional monomer now is 10-methacryloyloxydecyl dihydrogen thiophosphate (10-MDP), even though dental resin-matrix cements also use other functional acidic monomers, including dipentaerythritol penta-acrylate phosphate (PENTA), 4-methacryloxyethyl trimellitic acid (4-MET), and 4-methacryloxyethyl tri-mellitic anhydride (4-META). In addition to hydrogen bonding with collagen molecules, this phosphoric acid-spacer-methacrylate group molecule also produces highly strong and stable interactions with hydroxyapatite, generating 10-MDP-Ca salts. On the other end of the spectrum, this molecule creates binds with the carbon chain of the resin monomers. Furthermore, it has been demonstrated that endogenous dentinal matrix-metalloproteinases that break down the hybrid layer and shorten the durability of resin-dentin bonds are inhibited by 10-MDP and 10-MDP-Ca salts (29,30).

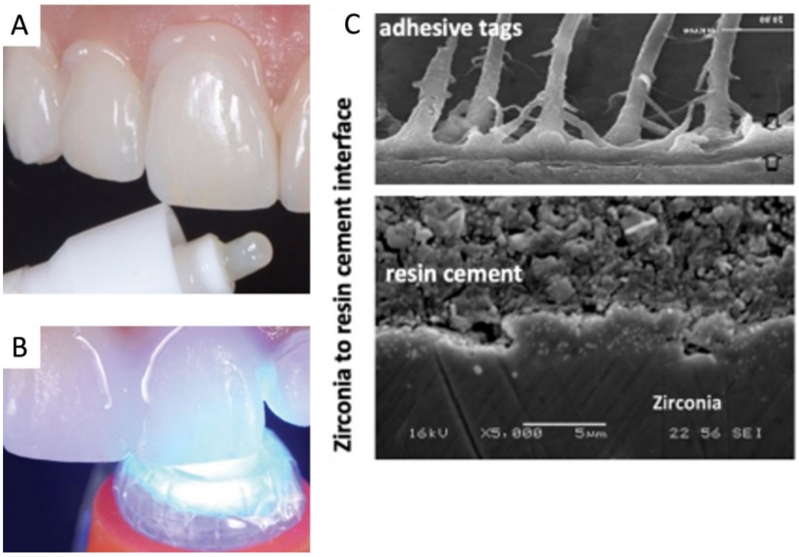



Figure 1. (A) Cementation procedure, (B) Resin cement light-curing, (C) Adhesive interface. Image adapted from (31).

### 1.1.2 Zirconia surface preparation

The inner surface preparation of zirconia differs, however the most used methods are: sandblasting, the use of silane, acrylizing or using a tribochemical silica coating on the YPSZ zirconia. All these procedures showed an initial bond which decreased significantly over time (32,33). For this reason, there is a specific protocol for zirconia bonding, which allows a long-lasting bond. This protocol requires an air-particle abrasion, a ceramic primer containing 10-methacryloyloxydecyl dihydrogen phosphate (MDP) monomer and a resin-matrix cement and is called the APC protocol. The first step is cleaning the restoration and air-particle abrade zirconia (APC - Step A) with alumina or silica-coated alumina particles, which is called sandblasting or microetching. This step provides an increase of micro-mechanical retention (34). The second step is the application of specific ceramic primer (APC - Step P), which contains adhesive phosphate monomers, on the zirconia bonding surface. This step permits to establish a chemical bond toward a metal oxide (34). The last step of this protocol is using a dual- or self-cure resin-matrix cement (APC - Step C) to guarantee an adequate polymerization and conversion through the zirconia restoration (7,20). Indeed, high-strength ceramic restorations have shown a strong and durable bonding after being pre-treated with air-particle abrasion and after using an adhesive containing 10-MDP. In fact, the 10-MDP monomers allow better moisten slightly rough surfaces and provide air-particle-abraded high-strength ceramics improved long-term bond strengths. 10-MDP monomers are also very effective to bond to metal oxides (P-O-ZR) and can increase the bonding ability of other cements to zirconia. This leads to a better durability of different bonding protocols of 3Y-TZP to enamel, dentin, composite cores, titanium abutments and bases, zirconia abutments, and lithium disilicate crowns (20,35).

#### 1.1.3 Relation between zirconia thickness and polymerization of resin-matrix cements

Various factors can influence the polymerization and the DC of monomers like irradiation time, light irradiance, light transmission, light-curing protocols, and type, thickness, and shade of the restorative materials. It was shown that restorative materials over 1.5 mm reduce light transmittance and that their color may change over time. Thus, an increase of the zirconia thickness can negatively affect the light transmittance to the resin-matrix cement. This may lead to a decrease of the DC of resin-matrix cement monomers resulting in low chemical stability and low microhardness values (1,21,25,36,37). Another important point in light transmission is zirconia microstructure. It can differ based on chemical composition and sintering process by different manufacturers (1). Also, dual-curing polymerization combines the greater DC of light-curing polymerization and the overtime curing of the self-curing polymerization (36,38).

Optimizing light-curing parameters is critical and must be tailored to the specific thickness and microstructural features of zirconia, as these factors significantly influence light transmission and, consequently, the polymerization efficacy of resin-based materials. (1). For example, thicker and more opaque zirconia requires higher light-curing intensity during a longer time. (1) Regarding light cure efficiency, 40s/surface leads to an optimal resin-matrix cement curing (7). Moreover, during cementation, a change in cementation load can affect the uniformity of the cement film thickness, light transmittance during polymerization process and can affect the durability of the restoration (15). It is crucial to guarantee a minimum film thickness, between 50 and 100μm (39,40). Indeed, a higher loading during cementation can promote a most adequate resin-matrix cement layer thickness at the onlay interface (6).

The main objective of the present study was to assess the optical transmittance through resin-matrix cement and zirconia onlay after cementation on two different loading magnitudes. It was hypothesized that the resin-matrix cement layer varies at the onlay to dentin interfaces depending on the loading magnitude used for cementation and, as a result, light transmittance values will be different;

# MATERIALS AND METHODS

## 2. MATERIALS AND METHODS

### 2.1 Preparation of specimens

Samples of 3Y-TZP zirconia powders (TOSOH - Zpex) were prepared in collaboration with University of Pennsylvania. Approximately 2.1 grams of 3Y-TZP zirconia powder were measured using an analytical balance (Mettler Toledo, Columbus, OH, USA). The powders were uniaxially pressed in a hardened steel die using a 1-tonne Carver Manual Bench Top Pellet Press (Wabash, IN, USA) for 5 minutes (Figure 2). The green body samples were then vacuum-packed in preparation for Cold Isostatic Pressing (CIP) using a YLJ-CIP-20b Cold Isostatic Press (YLJ, China), pressed at 250 MPa to produce disc-shaped specimens (Figure 3). After pre-sintering, the samples were manually polished using 280-grit sandpaper from Buehler (Buehler, Illinois, USA). The polishing was performed in a figure-eight motion for approximately 15 s on each side until the samples reached a thickness of 1.9 mm ± 0.01 mm. Finally, the polished samples were subjected to the full conventional sintering process at 1500°C for 120 minutes with a heating and cooling rate of 5°C/min and prepared for shipment to the Faculty of Dental Medicine of Portuguese Catholic University in, Viseu Portugal for further testing (Figure 4).

**Figure 2.** Carver Press Machine for Zirconia Green body Preparation. The image shows the machine with a zirconia powder in the mold, where it is subjected to a pressing force of 1 ton for 5 min.

**Figure 3.** Cold Isostatic Pressing (CIP) Machine for Zirconia Sample Compaction.

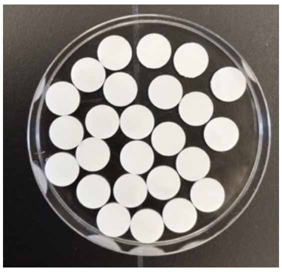


**Figure 4.** Prepared Zirconia Samples.

After sintered specimens of CAD/CAM zirconia 3Y-TZP disks had the following dimensions: -15 mm diameter and -1.5mm thickness. Indeed, the conventional thickness usually used for posterior onlay restoration is between 1.5mm and 2mm (41). The chemical composition and general features of the material are described in Table 1. Eighteen zirconia samples were analysed. The inner surfaces of specimens were polished with 320 mesh SIC paper after presinter and sintered after polished. Before tests, specimens were ultrasonically rinsed in isopropyl alcohol for 10 min and then in distilled water for 10 min. The inner surfaces of the onlays were conditioned with a silane compound (Ceramic bond™, VOCO GmbH, Cuxhaven, Germany) over a period of 60 s, then gently oil-free air dried for 5 s following the manufacturer's instructions. Before bonding, zirconia needs a mechanical and chemical pre-treatment in order to follow the APC protocol, this acronym stands for Air-borne particle abrasion, Primer, and resin-matrix Cement (7)(42). The mechanical pre-treatment involves air-borne particle abrasion with 50 µm aluminium oxide ($Al_2O_3$) particles, under 2.5 bar pressure for 10 s at a 10 mm standoff distance. The chemical pre-treatment involves a ceramic primer that contains silane and a 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) monomer Ceramic bond TM, VOCO, GmbH, Cuxhaven, Germany (7).

On the cementation, a dual-cured resin-matrix cement was used (Bifix QM, transparent, VOCO GmbH, Cuxhaven, Germany, Table 1).

**Table 1.** Details of the materials used in this study.

| Material Type (Brand, Manufacturer) | Organic Matrix | Fillers %(w/w) | Fillers %(v/v) | Filler Type | Elastic Modulus (GPa) |
|---|---|---|---|---|---|
| **Silane** (Ceramic bondTM, VOCO GmbH, Cuxhaven, Germany) | Acetone,3-methacryloxypropyltrimethoxysilane, methacrylated phosphoric acid ester | ND | ND | ND | ND |
| **Dual-curing, adhesive resin-matrix cement** (Bifix QMTM, VOCO GmbH, Cuxhaven, Germany) | Bi-functional methacrylate, acid methacrylate, Bis-GMA, benzoyl peroxide, amines and BHT, Gly-DMA, UDMA, phosphate monomers (30 wt%) | 71-73% | 61% | Glass fillers, amorphous silica; (size~2.9 µm) | 6-7.5 |
| **Adhesive** (Futurabond, VOCO, Germany) | Ethanol, Bis-GMA, HEMA, $H_2O$, HEDMA, methacrylate phophoric acid ester, methacrylate-modified polyacid, UDMA, initiators, stabilisers | 71-73% | 61% | Micro-scale barium-aluminium-borosilicate glass ceramic and nano-scale amorphous silica fillers | 5.44 ± 0.52 |
| **Zirconia 3Y-TZP** | ND | ND | ND | Functionalized nano-scale $SiO_2$ particles (20nm) | 240 ± 9.5 |

Furthermore, a 20 N axial loading and a 60 N axial loading using respectively a 2 kg weight and 6 kg weight the materials were applied using a device developed for the present study for 60 seconds, following standardized application protocols, as seen in Figure 5 (6).The excessive cement layer was avoided using a microbrush  (6,43).

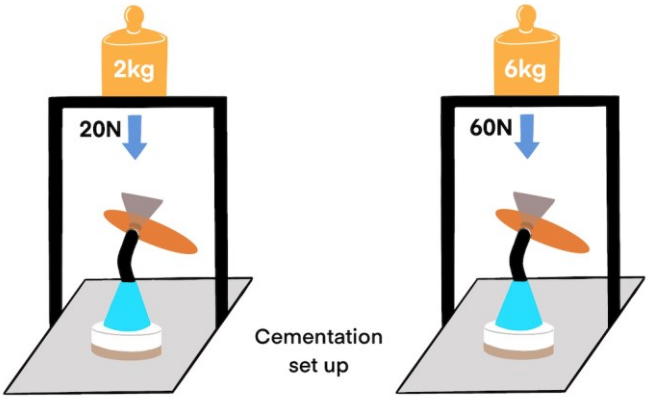



**Figure 5.** Assessment of light transmittance under two different loading magnitudes.

Finally, the luting materials were light-cured under visible light in the 400–500 nm wavelength range using a Light Emitting Diode (LED) curing unit (SmartLite Focus™, Dentsply Sirona, Charlotte, NC, USA) operating at an intensity of 900 mW/cm², that was verified by a MiniGig radiometer, Ultradent/GigaHertz Optik Türkenfeld Germanyto avoid low irradiance of the LCU. The tip of the LCU was applied directly on the zirconia-resin cement-glass complex to ensure a systematic irradiance distance (25). The polymerization time was standardized for 60 s per segment (6,7).

Zirconia onlay specimens were also bonded to human dentin to establish an interface suitable for microscopic analysis. Twenty extracted third molars, obtained from human donors, were initially immersed in distilled water for 10 minutes, followed by treatment in a 2% sodium hypochlorite (NaOCl) solution for an additional 10 minutes. Subsequently, the teeth were preserved in a 10% formalin solution for one week. Prior to cementation, the samples were rehydrated by storing them in a 0.9% NaCl solution for seven days. The cementation process was performed in accordance with ISO 4882:2015 standards (25). The management of extracted third molars was approved by the Human Research Ethics Committee at the University Institute of Health Sciences, reference number 13/CE-IUCS/- CESPU/2022, that is in agreement with the Helsinki declaration of 1964 and submitted to Catholica ethics committee for approval. The participants signed the informed consent prior to inclusion in the project since the objective of the project was described. The participants did not suffer from any systemic disease and therefore they showed worthy oral health, free of antibiotic therapy over the last 24 weeks.

During the tooth preparation phase, both the coronal and root segments were sectioned, and all enamel was entirely removed from the surfaces using a tapered diamond bur (1.2 mm in diameter). Dentin slices were then prepared and refined using a cylindrical diamond bur with a 1.5 mm diameter. The exposed dentin surfaces were etched with 37% phosphoric acid (Kerr Orange, USA) for 15 seconds, rinsed thoroughly with distilled water for 30 seconds, and gently dried using cotton pellets. Prior to cementation, a universal adhesive was applied to the conditioned dentin surfaces, which had been mounted in a custom acrylic or glass mold. The luting materials were applied to the surfaces of 3YZPT onlay specimens, which were subsequently seated onto the prepared dentin surfaces. A static load of either 20 N or 60 N was applied vertically onto the onlays using an apparatus specifically developed for the present study (44,45), Figure 6. Following cementation, The specimens were embedded in an autopolymerizing polyether-modified resin (Technovit 400; Kulzer GmbH, Wehrheim, Germany) using a polyvinyl chloride (PVC) mold to ensure stabilization. Cross-sectional slices were obtained orthogonally (at a 90° angle) to the central area of the restoration's pulpal floor. Sectioning was conducted through low-speed wet grinding utilizing a standard metallographic apparatus (Struers, Cleveland, OH, USA), employing silicon carbide (SiC) abrasive papers with grit sizes ranging from 120 to 400 mesh. Subsequently, the exposed surfaces were subjected to ultrasonic cleaning in isopropyl alcohol for five minutes, followed by air-drying at room temperature (6).

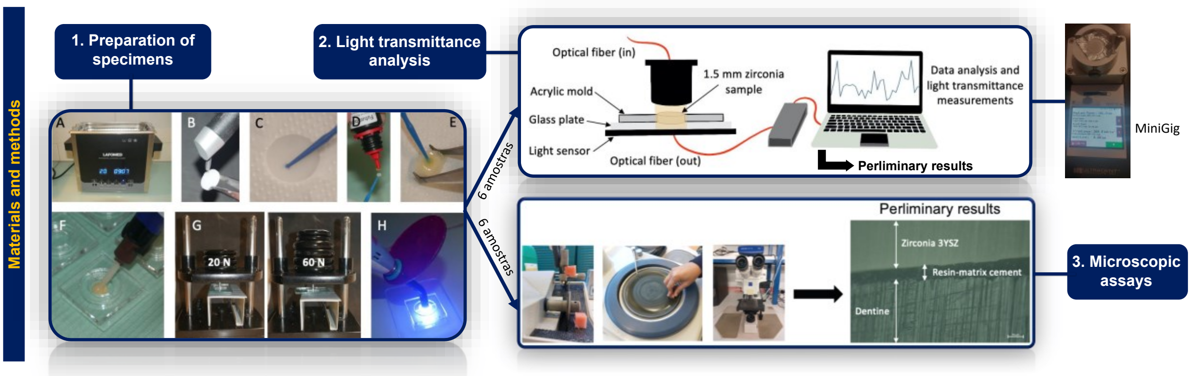



**Figure 6.** Specimens preparation steps: A- Ultrasonic specimens cleaning: 10 min in isopropyl alcohol and 10 min in distilled water / B- Preparations of inner surfaces: Air-borne particle abrasion with 50 µm aluminium oxide (Al2O3) particles / C- Preparations of inner surfaces: Primer (Ceramic bond$^{TM}$, VOCO GmbH, Cuxhaven, Germany) with silane and 10-MDP during 60 sec and dry 5 sec / D- Application of the Universal Adhesive (Futurabond, VOCO, Germany) on the microbrush / E- Universal Adhesive

during 20 s / F- Cementation with resin-matrix cement (Bifix QM™, VOCO GmbH, Cuxhaven, Germany) / G- Cementation under 20 N and 60 N / H- Photopolymerization during 60 s.

## 2.2 Light transmittance analysis

The resin-matrix cement Bifix QM™, transparent, VOCO GmbH, Cuxhaven, Germany which is a dual cured resin-matrix cement was used as cementation material. To evaluate the light transmittance of the resin-matrix cement layer, specimen´s groups will be divided concerning loading on 20N (3 samples) and 60N (3 samples) for 60s and analysed in triplicate. Light transmittance assays will be performed using a hand-held spectrometer during light-curing procedures.

Light transmittance measurements were conducted across a spectral range of 350 to 850 nm, employing a measurement integration time of 10 milliseconds. These assessments were carried out using a benchtop spectrophotometric system equipped with an integrated monochromator (AvaSpec-ULS2048XL EVO™, Avantes, NS Apeldoorn, The Netherlands). The experimental setup included a 200 W quartz tungsten-halogen light source (Model 66,881, Oriel Newport, USA), fiber-optic probes for light transmission, and a metallic specimen holder to ensure consistent positioning during analysis. (3,4) .

The MiniGig, Ultradent (Gigahertz Optik, Türkenfeld, Germany), consists of a compact integrating sphere coupled to the input apperture of the MSC-15 radiometer. This portable, laboratory-grade spectroradiometer is designed to output calibrated measurements of spectral radiant power, total optical power, and irradiance. The MSC-15 is calibrated in accordance with ISO/IEC 17025 standards, ensuring the accuracy and reliability of spectral irradiance data (48) . Three specimens from each group (Z0, Z20, and Z60) were measured in triplicate. The MiniGig device facilitates the quantification of irradiance (mW/cm²) at the tip of the light-curing unit (LCU), a parameter also referred to as radiant exitance or radiant emittance. This value is derived by dividing the radiant flux (power in watts) emitted by the LCU by the surface area of its light-emitting tip ($cm^2$). In the present study the tip of LCU measured was 8 mm, SmartLite Focus™, Dentsply Sirona, Chalotte, NC, USA. The tip of LCU was placed at 0 mm distance from the device. For the light measurement a blocking material was used to avoid light interference for the exterior.

### 2.3 Chemical and microscopic assays

The resin-matrix cement interface microstructure and thickness were inspected by optical microscopy and scanning electron microscopy.

The cross-sectioned specimens were analyzed via optical microscopy at magnifications ranging from ×50 to ×1000. Detailed microstructural characterization of the cement layer interface was conducted across multiple regions using a Leica DM 2500 M™ transmitted light microscope (Leica Microsystems, Wetzlar, Germany). Image capture and analysis were facilitated through a computer-integrated system utilizing the Leica Application Suite™ software (Leica Microsystems, Wetzlar, Germany), Figure 7.

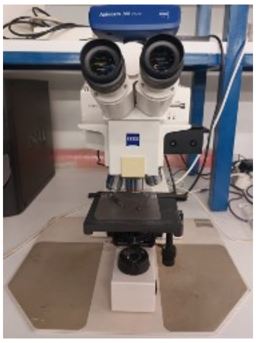


**Figure 7.** Optical microscopy at the cementation interface with a x50 magnification.

Black-and-white images were analyzed using Adobe Photoshop™ (Adobe Systems Software, San Jose, CA, USA), where dark regions corresponded to the organic matrix and light regions to the inorganic fillers. The dimensions of inorganic filler particles were assessed both parallel and perpendicular to their longitudinal axis.

### 2.4 Statistical analysis

Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS™) Version 29.0 (IBM Corp., Armonk, NY, USA). Tests of normality were performed under the assumption of no significant associations or differences among variables. The Kolmogorov–Smirnov and Shapiro–Wilk tests were employed to assess whether the sample distributions conformed to a normal distribution. To enhance the robustness of the Kolmogorov–Smirnov test under conditions of normality, Levene's test was applied as a correction for homogeneity of variances. However, the data failed to meet the assumption of normal distribution based on the outcomes of both the Kolmogorov–Smirnov and Levene's tests, with the significance threshold set at $p < 0.05$. Consequently, non-parametric statistical methods were used to evaluate differences in optical transmittance between experimental groups.

# RESULTS

## 3. RESULTS

### 3.1 Microstructural aspects

Figure 8 shows the polycrystalline zirconia microstructure and the interfaces between 3YTZP, resin-matrix cement reinforced with 73 wt% of inorganic particles and dentin. Inorganic filler particles were observed on the resin-matrix cement that varied in size, between 1-6 µm and shape along the resin-matrix cement interface.

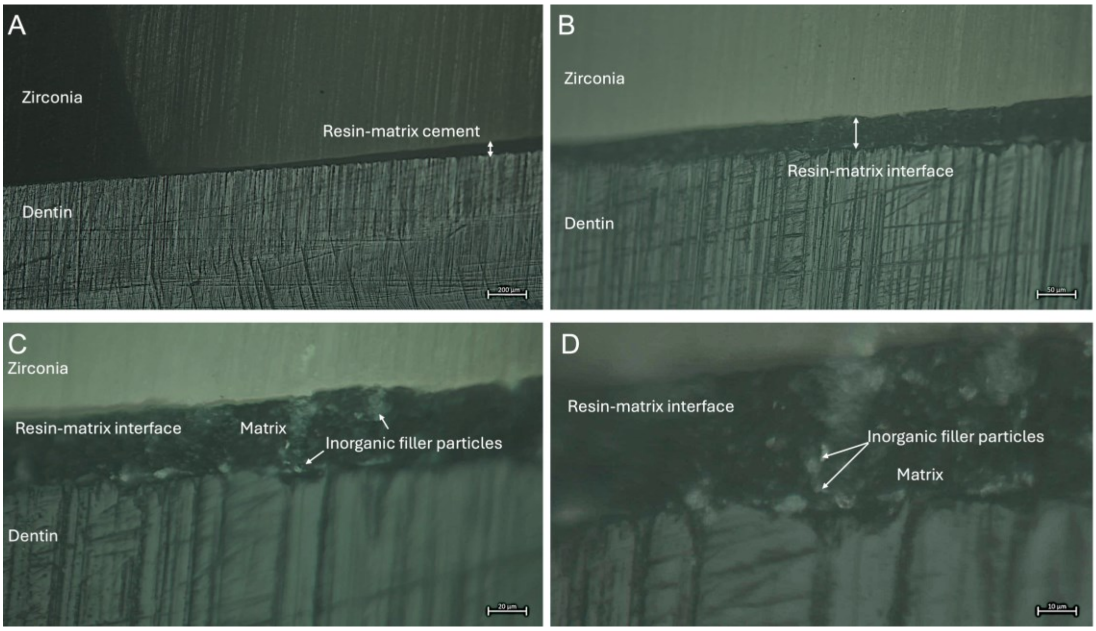



**Figure 8.** Optical microscopy (OM) images acquired at ×50 magnification (A) Depict the interfacial regions of restorations luted with a dual-curing, adhesive resin-matrix cement containing 73 wt% inorganic filler content. Higher magnification images at ×100 (B) provide a more detailed visualization of the same restorative interfaces, further illustrating the morphological characteristics and continuity of the cement layer.. (C) Resin-matrix cement layer at x200, (D) Resin-matrix cement microstructure at x500 magnification.

### 3.2 Optical transmittance results

At first, preliminary optical transmittance assays were performed to evaluate the light transmittance through the 3Y-TZP specimens in the absence of resin-matrix cement (Z0). The 3Y-TZP specimens were produced at a 1.5 mm thickness. The optical transmittance spectra for the specimens free of luting agent are shown in Figure 9.

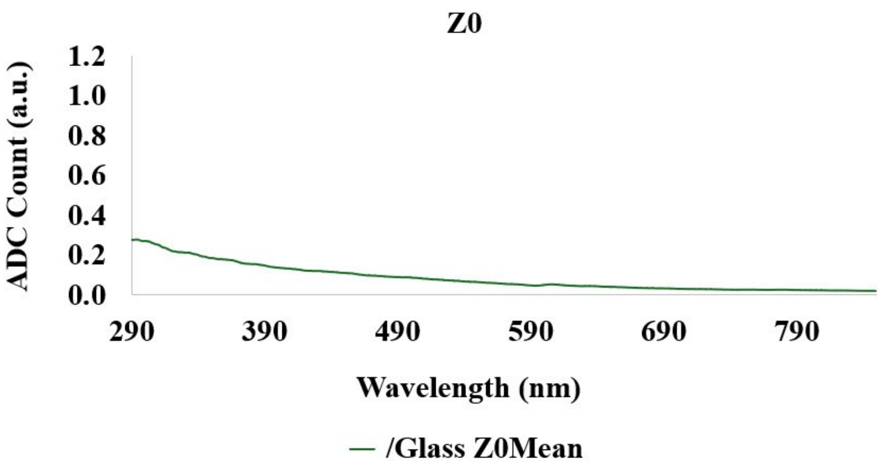
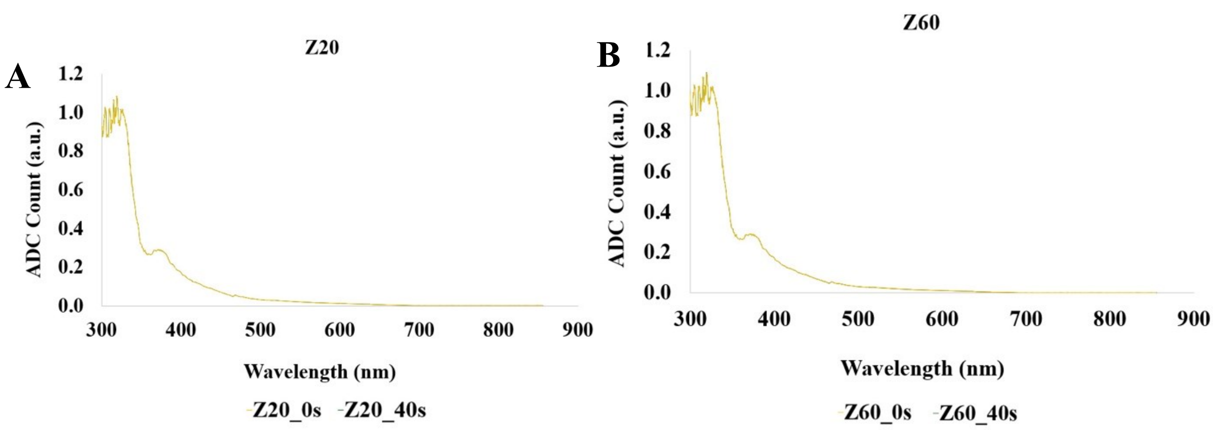



**Figure 9.** ADC count of the 3Y-TZP specimens with 1.5 mm thickness without resin-matrix cement (Z0) in the wavelength range from 290 up to 850 nm.

For the 1.5 mm-thick 3Y-TZP specimens without the application of resin-matrix cement, the findings indicate that only a limited amount of light was able to transmit through the onlay structures, especially in the 600–850 nm range. The highest light transmission is achieved at 300 nm with a value around 0.3 a.u.

Figure 10 shows that a small amount of light is still transmitted through the onlays in the 600-850 nm range through the specimens towards the luting material the resin-matrix cement with 73 wt% inorganic filler particles.



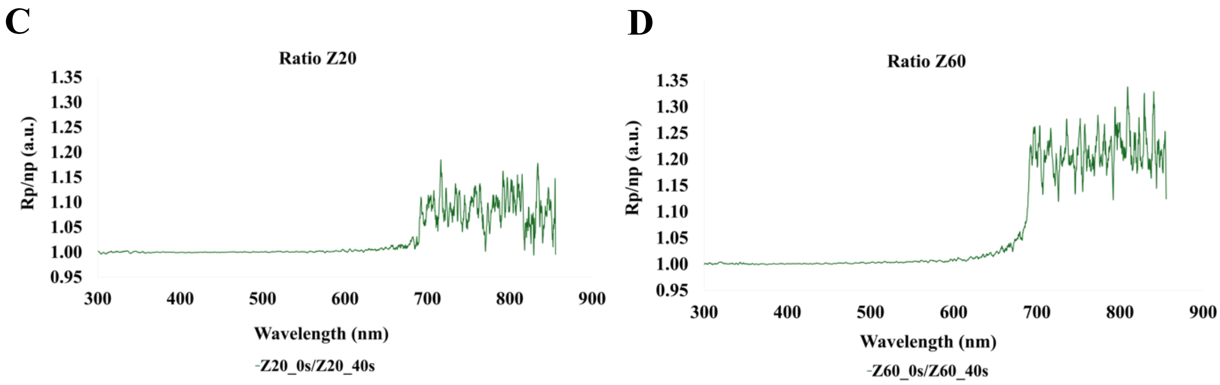



**Figure 10.** ADC count of the of the polymerized and non-polymerized 1.5 mm specimens with (A) 20N and (B) 60N magnitudes on 3Y-TZP specimens of 1.5 mm thickness cemented to resin-matrix cement before and after light curing for 60 s in the wavelength range from 290 up to 850 nm at light irradiance.

The transmitted light decreases at approximately 300 nm for both zirconia specimens cemented with a load of 20 (Z20) and 60 N (Z60).

The transmittance spectra of the pre-polymerized and post-polymerized specimens were largely superimposed across the measured wavelength range, indicating that polymerization did not produce a significant change in light transmittance. The highest values of light transmittance were recorded between 290 and 300 nm. It was verified a decrease in light transmittance above 390 nm, that reached values of almost 0 from 390 up to 800 nm. Meaning that for the interval of 390 up to 800 nm almost no light was transmitted. In Figure 10A and B, the optical transmittance values for the Z20 and Z60 groups remained similar before and after 60 seconds of light-curing, indicating no significant change in transmittance following polymerization. That means light-curing does not influence light transmittance considering the 3Y-TZP onlay thickness and light-curing set. For the 3Y-TZP specimens Z20 and Z60 groups demonstrated statistically significant differences ($p < 0.001$) in optical transmittance at 840 nm when compared to their respective measurements prior to polymerization., as seen in Table 2.

**Table 2.** Analysis of variance of the transmittance results at 834 nm for the Z20 and Z60 cemented with resin-matrix cement with a load of 20 N and 60N. Each data point represents an individual specimen measurement.

| Group | t | df | Mean Difference | 95% Confidence Interval of the difference lower | p-value |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| **Z20** | 19.268 | 17 | 1052.8 9055554 | 937.5 22342 | < 0.001 |
| **Z60** | 6.353 | 17 | 934.,287733 0000002 | 610,6186709 19291 | < 0.001 |

At 840 nm for 3Y-TZP onlays cemented to the resin-matrix cement reinforced with 73 wt% inorganic fillers, the average ratio (Rp/np) between the polymerized and non-polymerized specimens at the same wavelength is the lowest for the Z20 specimens Figure 10C and D. From 690 nm, Z60 ($p<0.05$) shows a better Rp/np than Z20 ($p<0.05$). In Figure 10D, the highest ratio value for Z60 is almost 1.35, whereas in Figure 10C, the highest ratio value is approximately 1.20. For the ratio the test groups revealed statistically differences ($p < 0.001$) for optical transmittance at 840 nm, as seen in Table 3.

**Table 3.** Analysis of variance of the Rp/np results at 834 nm for the Z20 and Z60 onlays bonded to resin-matrix cements with a load of 20 N and 60N. Each measurement corresponds to an individual sample.

| Group | t | df | Mean Difference | 95% Confidence Interval of the difference lower | p-value |
|---|---|---|---|---|---|
| **Z20** | 4.135 | 17 | 280.05951199 68889 | 137.1709404 56025 | < 0.05 |
| **Z60** | 3.330 | 17 | 280.2098000 234167 | 94.99943417 5341 | < 0.05 |

Figure 11 shows the light transmittance ratio detail in a wavelength range from 830 to 850 nm. This interval reveals that Z60 samples which were submitted to a higher magnitude during cementation, allow a better light transmittance through the 3Y-TZP onlay.

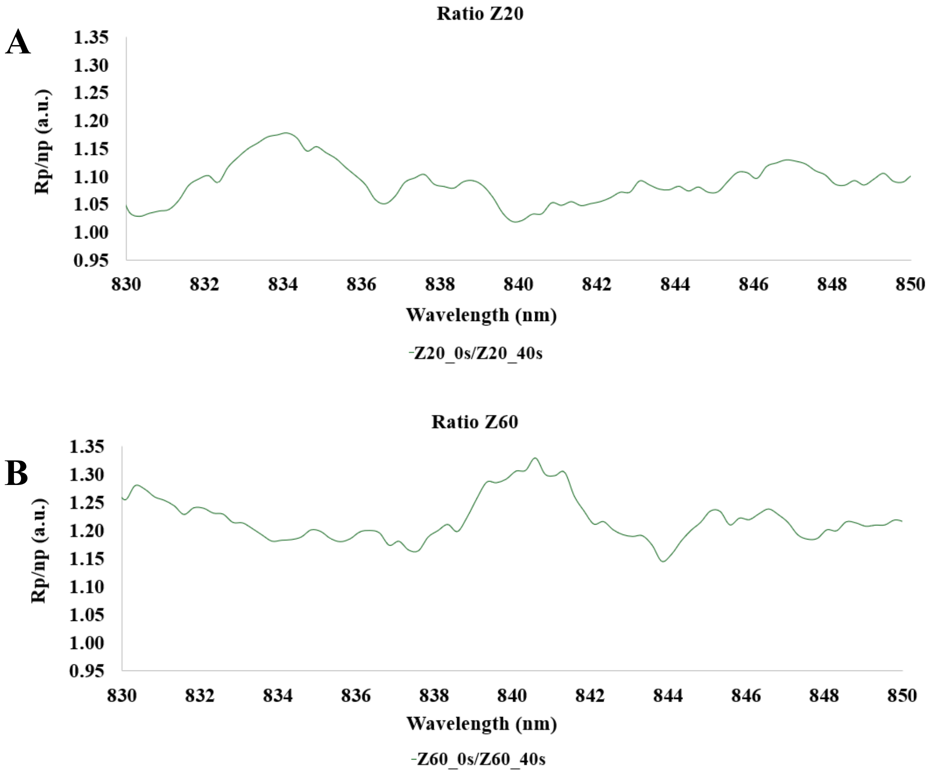



**Figure 11.** Transmittance ratio (arbitrary units, a.u.) comparing polymerized to non-polymerized (Rp/np) 1.5 mm thick 3Y-TZP onlay specimens subjected to (A) 20 N and (B) 60 N loading conditions, measured within the 830 to 850 nm wavelength range under light irradiation.

In Figure 12, the average Rp/np of the light transmittance between the polymerized and non-polymerized 3Y-TZP specimens are shown regarding an 834 nm wavelength.

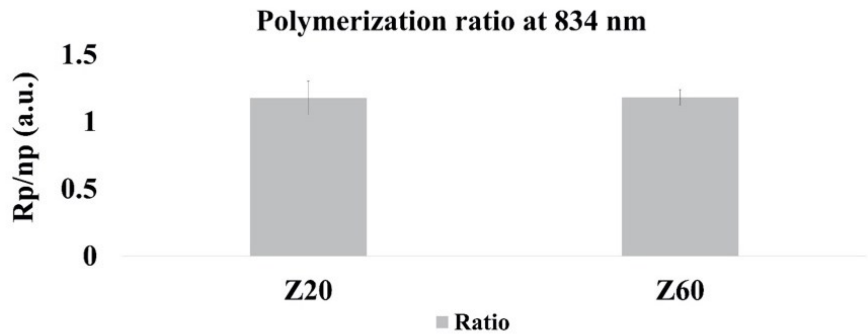



**Figure 12.** Rp/np of all samples, measured at 834 nm.

At 834 nm, Z20 and Z60 show similar values, with a ratio around 1.2, indicating efficient polymerization in both cases. The error bars are small, suggesting good reproducibility and little variability, especially for the Z60 group. Therefore, there is no notable difference in the polymerization ratio between the two groups.

Another light transmittance analysis was performed during polymerization reaction with MiniGig, Ultradent (Gigahertz Optik, Türkenfeld, Germany). The device measurements were obtained for intervals of wavelength, 385-425nm, 400-450nm, 385-515 nm, 425-515nm, 600-650 nm, 650-700nm, 380-540nm and 360-830 nm. The measurement reference used was the wavelength interval from 360 up to 830 nm. Figure 13 shows the results for the irradiance and radiant power for the LCU. For an LCU aperture of 8 mm and a distance of 0 mm from the LCU tip to the device. Figure 14 shows the plots of radiant power and Irradiance of LCU, SmartLite Focus™, Dentsply Sirona, Chalotte, NC, USA. Two indicators are represented: radiant power and irradiance, showing that for a LCU tip point of 8mm the values of radiant power, 503.5 mW are lower when compared with irradiance, 999.7 mW/cm$^2$

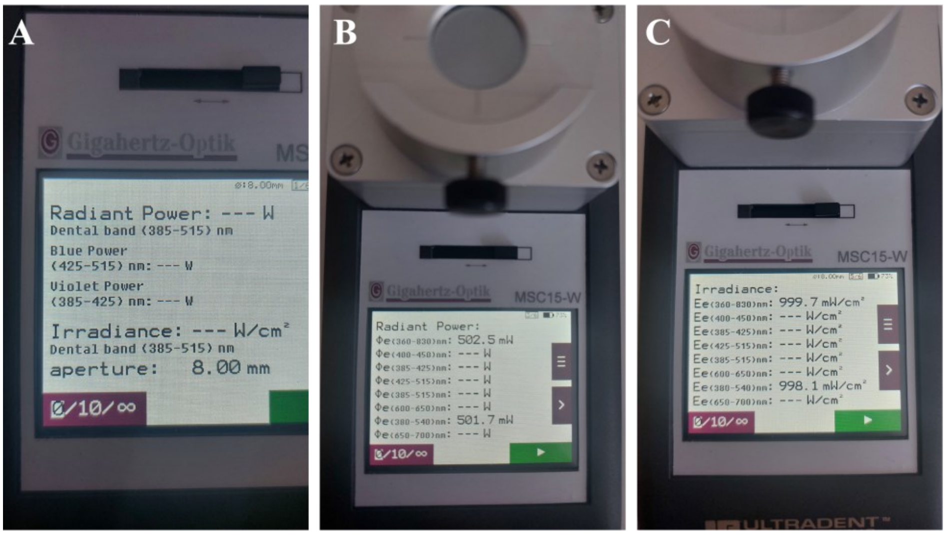



**Figure 13.** LCU irradiance, radiant power results from MiniGig. (A) Before measurements (B) Radiant power values, 502.5 mW from 360 up to 830 nm and (C) Irradiance values of 999.7 mW/cm2 from 360 up to 830 nm.

The values of radiant power and irradiance without 3Y-TZP specimens are represented on Figure 14. These data showed that the value of radiant power was lower than the irradiance values, once the irradiance values are approximated values of a possible LCU tip area of 10 mm.

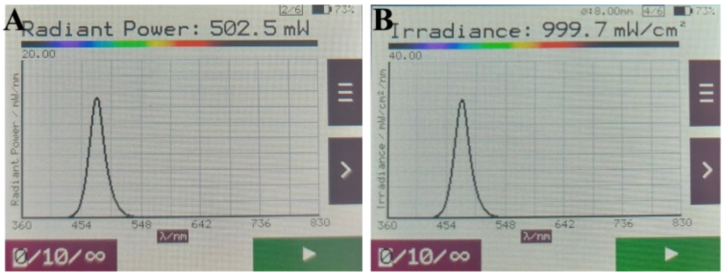



**Figure 14.** (A) Radiant power and (B) Irradiance of LCU graphs extracted from MiniGig.

Regarding the zirconia specimens without resin-matrix cement (Z0), zirconia specimens cemented with a load of 20N (Z20) and zirconia specimens cemented with a load of 60N (Z60) three specimens of each were produced and analyzed in triplicate. The Z0 mean radiant power was 188 mW, comparatively higher than Z20, that showed a mean radiant power approximately of 168 mW ($p < 0.001$). Meaning that less light reached the zirconia cemented with 73 wt% resin-matrix cement with a load of 20N. Comparatively the Z60 sample demonstrated mean values approximately of 178 mW, with more light transmitted to resin-matrix cement ($p< 0.001$), The results revealed highly statistically significant with p values < 0.001 both for Z20 and Z60 measurements, Table 4. The polymerization ratio values were higher for Z60 when compared to the ratio for Z20, Figure 15. Also, the statistical analysis demonstrated statistically significant results with p values < 0.05, Table 5.

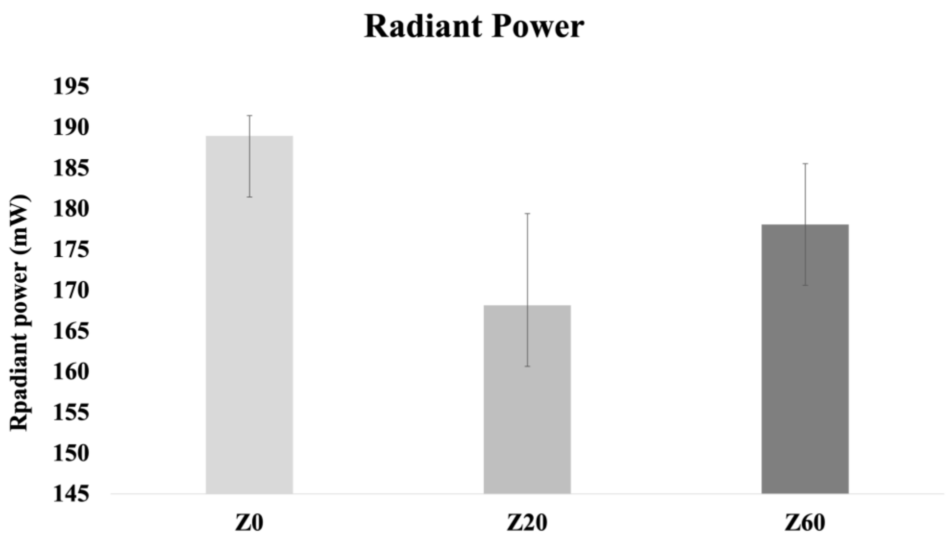



**Figure 15.** Z0, Z20 and Z60 Radiant power results measured by MiniGig between a wavelength of 360-830 nm.

**Table 4.** Analysis of variance of the Radiant Power in MiniGig for Z20 and Z60 onlays bonded to resin-matrix cements with a load of 20 N and 60N. Each measurement corresponds to an individual sample.

| Group | t | df | Mean Difference | 95% Confidence Interval of the difference lower | p-value |
|---|---|---|---|---|---|
| **Z20** | 56.914 | 17 | 178.53333333 33333 | 171.9150345 30070 | < 0.001 |
| **Z60** | 100.074 | 17 | 183.50000000 00000 | 179.63136548 8748 | < 0.001 |

In Figure 16, the polymerization ratios of 3Y-TZP zirconia onlay samples Z20 and Z60 are analyzed with a Minigig. The bar for Z20 is slightly lower than that of Z60, but both have very close Rp/np values, around 0.9 to 1.0. Error bars are present, indicating some variability in the measurements, but they are very small, suggesting good reproducibility.

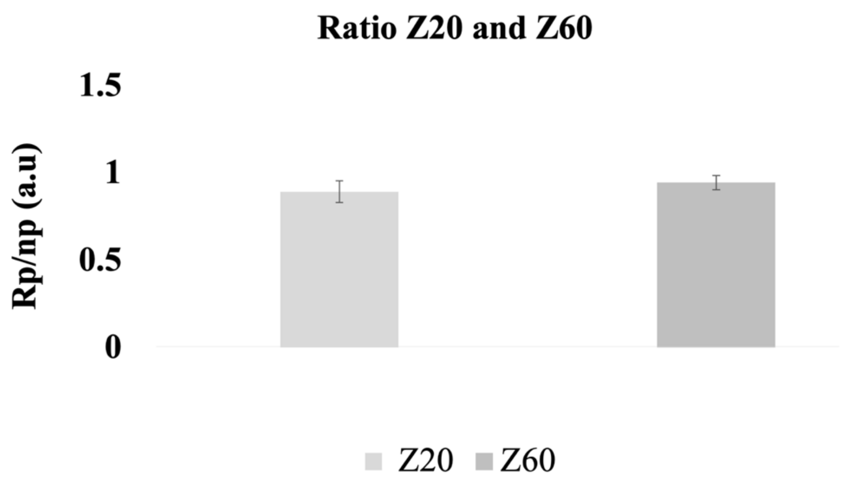



**Figure 16.** Rp/np from all samples using MiniGig device.

**Table 5.** Analysis of variance of the Radiant Power in MiniGig for Z20 and Z60 onlays bonded to resin-matrix cements with a load of 20 N and 60N. Each measurement corresponds to an individual sample.

| Group | t | df | Mean Difference | 95% Confidence Interval of the difference lower | p-value |
|---|---|---|---|---|---|
| **Z20** | 4.161 | 17 | 94.91174795 26667 | 46.79276476 9165 | < 0.05 |
| **Z60** | 4.164 | 17 | 94.93922857 20000 | 46.83430767 0979 | < 0.05 |

## DISCUSSION

## 4. DISCUSSION

The primary objective of this study was to evaluate the light transmittance properties of resin-matrix cement and zirconia onlays following cementation under two distinct loading conditions. Several studies investigated the cementation magnitude, which can range between 12 and 67 N, and cement layer thickness influence the strength bond of the restoration (6,15,49–51).

Indeed, at 830 to 850 nm wavelength range, there is a statistical difference between the light transmittance of the 3Y-TZP samples cemented with a 20 N and 60 N magnitude, where the 60 N samples allowed higher light transmission. Consequently, the hypothesis proposing that variations in the resin-matrix cement layer at the onlay-to-dentin interface are influenced by the magnitude of the applied cementation load, leading to corresponding differences in light transmittance values, was confirmed.

In this study, 1.5 mm thickness 3Y-TZP zirconia onlays were cemented to an adhesive resin-matrix cement reinforced with 73 wt% inorganic filler particles.

Partially yttrium-stabilized zirconia, more precisely 3Y-TZP (3 mol% Yttria-stabilized Tetragonal Zirconia Polycrystals), is a ceramic whose microstructure is carefully controlled to optimize its mechanical performance. It is composed mainly of homogeneous, submicron-sized metastable tetragonal zirconia grains (generally between 0.2 and 0.5 µm), giving the material excellent transformation toughness. This toughness results from the stress-induced martensitic transformation of the tetragonal phase into the monoclinic phase, accompanied by a volume change (~4%) that generates compressive stresses around the cracks, slowing their propagation. Indeed, it exists three different phases: monoclinic phase, tetragonal phase and cubic phase. The monoclinic phase is stable at room temperature in pure zirconia and is characterized by low crystalline symmetry. The tetragonal phase is stabilized at room temperature by the addition of a compound such as yttrium oxide ($Y_2O_3$). In 3Y-TZP materials, it is the predominant phase. It can transform into the monoclinic phase under mechanical stress. The cubic phase is present at high temperatures or with higher yttrium concentration.

Moreover, the role of yttrium is crucial, thus it partially stabilizes the tetragonal phase at room temperature, while allowing some reversibility under mechanical stress (1,2,52,53).

Various studies showed that a thickness above 3 mm could negatively impact light transmission and DC of the resin-matrix cement (1,39,54–56). The thickness of indirect restorations requires meticulous control, as restorative materials may absorb, reflect, or refract incident light, potentially diminishing the light intensity that reaches the underlying luting agents and thereby impairing their polymerization efficacy. The observed Rp/np ratio, along with the reduced optical transmittance following polymerization, supports the recommendation of using dual-cure resin-matrix cements for restorative materials exceeding 3 mm in thickness, in accordance with existing literature (1,37,39,54).In addition to the thickness of zirconia, its chemical composition and intrinsic color have been demonstrated to significantly impact both light transmittance and DC (57). Furthermore, the shade of the resin-matrix cement also influences the translucency of zirconia, consequently impacting the overall propagation of light through the material. (58).

This investigation employed a dual-cured resin-matrix cement, a commonly utilized luting agent due to its capacity to achieve adequate polymerization even in situations where light transmission is limited (24). However, the presence of a high concentration of micro- and nanoscale inorganic fillers within the resin-matrix cement can alter light absorption and refraction properties, potentially reducing light transmittance. Such a decrease in transmittance may adversely affect the DC of the resin's organic matrix. (25). The results indicated that a reduced content of inorganic particles diminishes light scattering, a phenomenon typically associated with interfaces containing a high proportion of inorganic fillers. Previously published studies confirmed the importance of reducing refractive index and particle size of the silica filler in order to increase the rate of polymerization and DC (26,59,60).

In the present investigation, the 3Y-TZP specimens with a thickness of 1.5 mm and without resin-matrix cement (Z0) exhibited limited light transmittance, particularly in the range of 600–850 nm. The maximal recorded light transmittance occurred at approximately 300 nm, reaching a value near 0.3 arbitrary units (a.u.).

In this study, the light transmittance was measured before and after photopolymerization with a top-bench spectrophotometer. The optical transmittance spectra recorded in this study demonstrated an increasing trend beyond 600 nm, reaching peak values at 850 nm through the zirconia onlays, consistent with previously published data. (61–64).

Also, no statistical difference was shown for the light transmittance, before and after photopolymerization. Highest light transmission was measured between 830-850 nm wavelength range and showed a statistical difference (< 0.001), which means a 60 N cementation magnitude enables a better light transmission than a 20 N cementation. Indeed, various published studies refer that a higher cementation load allow a thinner layer cement thickness and a better light transmittance (6,15,25,50).

These findings are consistent with previous studies that have reported a significant attenuation of light transmission through zirconia ceramics, especially those with higher crystalline content and greater thickness. The light transmission through zirconia decreases as thickness of the material increases, and materials such as 3Y-TZP, known for their high opacity, transmit only minimal amounts of light beyond 1 mm thickness. Specifically, at 1.5 mm, light attenuation is pronounced due to the high refractive index and scattering of tetragonal zirconia grains (65).

Moreover, some studies evaluated the spectral transmission of zirconia and confirmed that the optical transmission efficiency is wavelength-dependent, with better transmission in the ultraviolet (UV) and lower visible range compared to the near-infrared spectrum (66). Additionally, it was demonstrated that 3Y-TZP shows extremely low transmittance in the visible and near-infrared regions, largely due to its dense microstructure and lack of glassy phase (67).

The optical behaviour of zirconia-based restorations, especially when combined with resin-matrix cements, is of critical importance for ensuring adequate polymerization of the underlying luting agents. In this study, the light transmittance ratio between polymerized (Rp) and non-polymerized (np) samples at 840 nm was analysed for 3Y-TZP onlays cemented with two different loads: 20 N (Z20) and 60 N (Z60). The results demonstrate that Z20 specimens exhibited the lowest Rp/np values, with a maximum ratio around 1.20, whereas Z60 specimens achieved higher values up to approximately 1.35. Statistically significant differences were observed between the groups ($p < 0.001$), with Z60 consistently showing improved light transmittance ratios from 690 nm onwards.

These findings are aligned with studies highlighting that increased cementation load improves the adaptation of the luting agent and reduces interface thickness, thereby decreasing the number of light-scattering interfaces and enhancing transmittance. Some studies confirmed that increased seating pressure during cementation significantly reduces film thickness of resin cements, promoting better optical continuity and thus improved light transmission (25,50,68).

In the present study, the resin-matrix cement contained 73 wt% inorganic fillers, which can substantially influence light propagation. Although higher filler content can reduce light transmission due to increased scattering. A uniform and thin cement layer under higher load (Z60) minimizes such effects by reducing thickness and improving filler-matrix packing. The higher Rp/np ratio observed in Z60 also suggests more efficient polymerization under higher compressive force during cementation. Efficient polymerization improves the refractive index between the matrix and fillers, resulting in reduced internal light scattering post-cure. This contributes to the improved light transmission seen in the Z60 group, particularly at 840 nm, where polymerization-induced changes in optical properties are more distinguishable (1,14,26).

Another device, which is a Minigig, was used to measure the light transmission during photopolymerization. A Minigig is a spectrophotometer with a small integrating sphere. This instrument is a portable spectroradiometer capable of outputting calibrated measurements of spectral radiant power, total radiant power, and irradiance. Radiant power (W) refers to the radiant energy emitted per unit time, whereas irradiance ($mW/cm^2$) denotes the radiant power incident upon a surface of defined dimensions, representing an average value across the entire surface area (69). In this study, the tip of LCU was 8 mm and for the irradiance, the light quantity are approximated values of a possible LCU tip area of 10 mm. For this reason, the radiant power values were used as the reference.

The SmartLite Focus™ LCU used in this study showed an irradiance of 999.7 $mW/cm^2$ and a radiant power of 503.5 mW at 0 mm distance with an 8 mm aperture. These values are in line with expected performance for high-intensity LCUs and align with the literature showing that total radiant exposure (product of irradiance and exposure time) is more predictive of adequate polymerization than irradiance alone (70).

Importantly, for a wavelength range of 360-830 nm, the radiant power values recorded after transmission through zirconia specimens varied significantly: Z0 (no cement) showed the highest radiant power (188 mW), followed by Z60 (178 mW) and Z20 (168 mW), with statistically significant differences ($p < 0.001$). These data confirm that the presence of resin-matrix cement, especially when applied under lower pressure (Z20), introduces additional light attenuation, reducing the transmitted radiant power

necessary for adequate polymerization, which means that an increased load magnitude during cementation permits a higher light transmittance during photopolymerization.
Polymerization ratio values (Rp/np), obtained via MiniGig analysis, show the influence of cementation load. Although the values for Z20 and Z60 are close (ranging between 0.9 and 1.0), the slightly higher values observed in the Z60 group indicate improved light activation and potentially a higher degree of conversion. The presence of low error bars confirms the reproducibility and reliability of the data.
These findings are corroborated by several studies who emphasized that deeper layers of resin cement under ceramic restorations can only polymerize adequately when exposed to sufficient radiant energy. Furthermore, the combination of radiant power losses and filler-induced scattering within high-filled resin-matrix cements (73 wt% in this study) makes light propagation highly sensitive to interfacial and mechanical factors such as seating force (71,72).

Also, radiant power was measured without sample in order to obtain the amount of light transmitted. Radiant power was also measured with a 3Y-TZP zirconia sample with and without resin-matrix cement with the aim of knowing if a variation of light transmittance would come from the sample of 3Y-TZP zirconia or from the resin-matrix cement.
Since the top-bench spectrophotometer measures the light transmittance before and after photopolymerization and the Minigig measures during the photopolymerization, these two devices can be complementary methods for the analysis of the light transmittance.

The spectrophotometer top-bench results showed that highest light transmission occurred at around 300 nm (0.3 a.u.) through 1.5 mm 3Y-TZP onlays and that the presence of resin-matrix cement (especially with 73 wt% fillers) further reduced light transmittance, with significant differences between Z20 and Z60 at 840 nm (Z60 showing higher Rp/np). While MiniGig results showed a measured irradiance and radiant power between 360 and 830 nm. MiniGig also detected slightly higher radiant power values for Z60 (around 178 mW) than for Z20 (around 168 mW), with polymerization ratios (Rp/np) close to 1.0 for Z60 and slightly lower for Z20. Benchtop spectrophotometers, especially with integrating spheres, are superior for absolute transmittance measurements due to controlled conditions and better collimation of light beams. Whereas portable devices like the MiniGig, although less precise in absolute spectral transmission, are effective for real-time irradiance and polymerization monitoring, which is clinically relevant. Moreover, top-bench spectrophotometer measured pre- and post-polymerization transmittance, showing no major increase in light transmittance post-polymerization, while the MiniGig directly evaluated irradiance during polymerization, offering a clinical approximation of how much light reaches the luting agent layer (73–76).

In this study, several limitations can be mentioned. Indeed, only two loading magnitudes were assessed, and intermediate values could provide a more comprehensive understanding between cementation force and light transmittance. Also, only one zirconia thickness was used, and the results cannot be extrapolated to other zirconia types, since light transmittance is thickness-dependent. In addition, only a 73 wt% inorganic fillers resin-matrix cement was used, which didn't allow any comparison with other types of resin-matrix cements. Also, light transmittance and polymerization were measured under controlled laboratory conditions and didn't took in consideration the intraoral variables. Moreover, both spectrophotometers have inherent limitations, the bench-top spectrophotometer doesn't reflect clinical conditions and the Minigig has a lower precision and sensitivity. Finally, variables such as angulation or light curing distance weren't assessed.

Despite the limitations of the present study, the findings hold clinical relevance, particularly regarding the potential insufficiency of light irradiance and energy received by light-cured resin-matrix composites for polymerization through thick restorative zirconia onlays, which can compromise long-terms success 3Y-TZP zirconia indirect restorations. The present study also brings relevant data for clinicians once a proper cementation load is crucial for the light-curing of resin-cement when the adhesive protocols for zirconia cementation are followed.

Further studies are needed to develop a clinical methodology to ensure that a proper cementation load is accomplished.

# CONCLUSIONS

## 5. CONCLUSIONS

This study demonstrated that the magnitude of cementation load significantly influences light transmittance through 3Y-TZP zirconia onlays cemented with resin-matrix cement. Specifically, a higher load (60 N) led to thinner cement layers, resulting in reduced light scattering and improved light transmission, particularly in the 830–850 nm wavelength range. These findings validate the hypothesis that cementation pressure affects the optical behavior at the zirconia–cement–dentin interface, ultimately influencing the polymerization efficiency of resin cements.

The use of a 1.5 mm thick 3Y-TZP onlay, which is a highly opaque ceramic with dense microstructure, was shown to significantly attenuate light, particularly when combined with a high-filler (73 wt%) resin-matrix cement. However, higher cementation forces mitigated this attenuation by promoting a more uniform, thinner luting layer. Spectrophotometric analysis, both benchtop and in situ (MiniGig), confirmed that higher pressure during cementation increases radiant power transmission and improves polymerization ratios (Rp/np), enhancing the degree of conversion of the resin-matrix cement.

Clinically, these findings highlight the necessity of applying adequate cementation pressure during the luting procedure of zirconia restorations to optimize light curing of the resin-matrix cement. Insufficient pressure may result in suboptimal polymerization, potentially compromising the mechanical properties and longevity of the adhesive interface. Therefore, ensuring appropriate pressure not only enhances the DC but also contributes to the overall durability and clinical success of the restoration. This is particularly critical when using dual-cure systems under zirconia restorations, where light attenuation is already a limiting factor. The complementary use of top-bench spectrophotometers and real-time irradiance monitoring devices, such as the MiniGig, provides valuable insights into both laboratory and clinical aspects of resin cement polymerization.

Ultimately, this study highlights the need for standardized cementation protocols, especially in terms of applied load, to improve the long-term clinical performance of zirconia-based indirect restorations. Further research should focus on establishing practical guidelines to ensure consistent and effective light-curing outcomes in routine dental practice.

## 6. BIBLIOGRAPHY


1. Tafur-Zelada CM, Carvalho O, Silva FS, Henriques B, Özcan M, Souza JCM. The influence of zirconia veneer thickness on the degree of conversion of resin-matrix cements: an integrative review. Available from: https://doi.org/10.1007/s00784-021-03904-w
2. Zhang Y, Lawn BR. Novel Zirconia Materials in Dentistry. J Dent Res. 2018 Feb 1;97(2):140–7.
3. Lümkemann N, Pfefferle R, Jerman E, Sener B, Stawarczyk B. Translucency, flexural strength, fracture toughness, fracture load of 3-unit FDPs, Martens hardness parameter and grain size of 3Y-TZP materials. Dental Materials. 2020 Jul 1;36(7):838–45.
4. Stawarczyk B, Frevert K, Ender A, Roos M, Sener B, Wimmer T. Comparison of four monolithic zirconia materials with conventional ones: Contrast ratio, grain size, four-point flexural strength and two-body wear. J Mech Behav Biomed Mater. 2016 Jun 1;59:128–38.
5. Lümkemann N, Pfefferle R, Jerman E, Sener B, Stawarczyk B. Translucency, flexural strength, fracture toughness, fracture load of 3-unit FDPs, Martens hardness parameter and grain size of 3Y-TZP materials. Dental Materials. 2020 Jul 1;36(7):838–45.
6. Magalhães T, Fidalgo-Pereira R, Torres O, Carvalho Ó, Silva FS, Henriques B, et al. Microscopic Inspection of the Adhesive Interface of Composite Onlays after Cementation on Low Loading: An In Vitro Study. J Funct Biomater. 2023 Mar 1;14(3).
7. Sulaiman TA, Suliman AA, Abdulmajeed AA, Zhang Y. Zirconia restoration types, properties, tooth preparation design, and bonding. A narrative review. Vol. 36, Journal of Esthetic and Restorative Dentistry. John Wiley and Sons Inc; 2024. p. 78–84.
8. Russo DS, Cinelli F, Sarti C, Giachetti L. Adhesion to zirconia: A systematic review of current conditioning methods and bonding materials. Vol. 7, Dentistry Journal. MDPI Multidisciplinary Digital Publishing Institute; 2019.
9. Lim CH, Vardhaman S, Reddy N, Zhang Y. Composition, processing, and properties of biphasic zirconia bioceramics: Relationship to competing strength and optical properties. Ceram Int. 2022 Jun 15;48(12):17095–103.

10. Zhang Y, Chen HX, Duan L, Fan J Bin, Ni L, Ji V. A comparison study of the structural and mechanical properties of cubic, tetragonal, monoclinic, and three orthorhombic phases of ZrO2. J Alloys Compd. 2018 Jun 15;749:283–92.
11. Arcila LVC, de Carvalho Ramos N, Campos TMB, Dapieve KS, Valandro LF, de Melo RM, et al. Mechanical behavior and microstructural characterization of different zirconia polycrystals in different thicknesses. Journal of Advanced Prosthodontics. 2021;13(6):385–95.
12. Harada K, Raigrodski AJ, Chung KH, Flinn BD, Dogan S, Mancl LA. A comparative evaluation of the translucency of zirconias and lithium disilicate for monolithic restorations.
13. Kim MJ, Kim KH, Kim YK, Kwon TY. Degree of conversion of two dual-cured resin cements light-irradiated through zirconia ceramic disks. Journal of Advanced Prosthodontics. 2013 Nov;5(4):464–70.
14. Fidalgo-Pereira R, Torres O, Carvalho Ó, Silva FS, Catarino SO, Özcan M, et al. A Scoping Review on the Polymerization of Resin-Matrix Cements Used in Restorative Dentistry. Vol. 16, Materials. MDPI; 2023.
15. Effects of Finger Pressure Applied By Dentists during Cementation of All-Ceramic. Crowns.
16. Begum Turker S, Ozcan M, Mandali G, Damla I, Bugurman B, Valandro LF. Bond strength and stability of 3 luting systems on a zirconia-dentin complex [Internet]. Available from: www.agd.org
17. Vivek VJ, Venugopal P, Divakar N, Bharath S, Sarin K, Mohammed N. Comparison of Zirconia to Dentin Bonding Using Resin-Based Luting Cements and Resin-Modified Glass-Ionomer Cement. J Pharm Bioallied Sci. 2022 Jul;14(Suppl 1):S460–3.
18. Rüttermann S, Alberts I, Raab WHM, Janda RR. Physical properties of self-, dual-, and light-cured direct core materials. Clin Oral Investig. 2011 Aug;15(4):597–603.
19. Meng K, Wang L, Wang J, Yan Z, Zhao B, Li B. Effect of Optical Properties of Lithium Disilicate Glass Ceramics and Light-Curing Protocols on the Curing Performance of Resin Cement. Coatings. 2022 Jun 1;12(6).
20. How to Bond Zirconia. The APC Concept.

21. Fidalgo-Pereira R, Torres O, Carvalho Ó, Silva FS, Catarino SO, Özcan M, et al. A Scoping Review on the Polymerization of Resin-Matrix Cements Used in Restorative Dentistry. Vol. 16, Materials. MDPI; 2023.
22. Faria-e-Silva AL, Pfeifer CS. Development of dual-cured resin cements with long working time, high conversion in absence of light and reduced polymerization stress. Dental Materials. 2020 Oct 1;36(10):e293–301.
23. Kowalska A, Sokolowski J, Bociong K. polymers The Photoinitiators Used in Resin Based Dental Composite-A Review and Future Perspectives. 2021; Available from: https://doi.org/10.3390/polym130
24. Shim JS, Kang JK, Jha N, Ryu JJ. Polymerization Mode of Self-Adhesive, Dual-Cured Dental Resin Cements Light Cured Through Various Restorative Materials. Journal of Esthetic and Restorative Dentistry. 2017 May 1;29(3):209–14.
25. 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 Mar 1;151.
26. Fidalgo-Pereira R, Carvalho Ó, Catarino SO, Henriques B, Torres O, Braem A, et al. Effect of inorganic fillers on the light transmission through traditional or flowable resin-matrix composites for restorative dentistry. Clin Oral Investig. 2023 Sep 1;27(9):5679–93.
27. Fidalgo-Pereira R, Torres O, Carvalho Ó, Silva FS, Catarino SO, Özcan M, et al. A Scoping Review on the Polymerization of Resin-Matrix Cements Used in Restorative Dentistry. Vol. 16, Materials. MDPI; 2023.
28. Fidalgo-Pereira R, Evangelista Carpio DM, Carvalho Ó, Catarino S, Torres O, M. Souza JC. Relationship between the inorganic content and the polymerization of the organic matrix of resin composites for dentistry: a narrative review. RevSALUS - Revista Científica da Rede Académica das Ciências da Saúde da Lusofonia. 2022 Jan 28;4(1).
29. Maravić T, Mazzitelli C, Mancuso E, Del Bianco F, Josić U, Cadenaro M, et al. Resin composite cements: Current status and a novel classification proposal. Vol. 35, Journal of Esthetic and Restorative Dentistry. John Wiley and Sons Inc; 2023. p. 1085–97.

30. Yoshihara K, Hayakawa S, Nagaoka N, Okihara T, Yoshida Y, Van Meerbeek B. Etching Efficacy of Self-Etching Functional Monomers. J Dent Res. 2018 Aug 1;97(9):1010–6.
31. Tafur-Zelada CM, Carvalho O, Silva FS, Henriques B, Özcan M, Souza JCM. The influence of zirconia veneer thickness on the degree of conversion of resin-matrix cements: an integrative review. Clin Oral Investig. 2021/03/31. 2021;25(6):3395–408.
32. Kern M, Wegner SM. Bonding to zirconia ceramic: adhesion methods and their durability.
33. Kern M, Thompson VP. Bonding to glass infiltrated alumina ceramic: Adhesive methods and their durability. 1995.
34. Luna-Domínguez CR, Luna-Domínguez JH, Blatz M. Full-mouth rehabilitation in a completely digital workflow using partially adhesive monolithic zirconia restorations. Journal of Esthetic and Restorative Dentistry. 2023 Oct 1;35(7):1050–7.
35. Alammar A, Blatz MB. The resin bond to high-translucent zirconia—A systematic review. Vol. 34, Journal of Esthetic and Restorative Dentistry. John Wiley and Sons Inc; 2022. p. 117–35.
36. Samimi P, Kaveh S, Khoroushi M, Kaveh S. Effect of Delayed Light-Curing Through a Zirconia Disc on Microhardness and Fracture Toughness of Two Types of Dual-Cure Cement [Internet]. Vol. 15, Journal of Dentistry. 2018. Available from: www.jdt.tums.ac.ir
37. Castellanos M, Delgado AJ, Alexandre M, Sinhoreti C, Carvalho D, Salles De Oliveira R, et al. Effect of Thickness of Ceramic Veneers on Color Stability and Bond Strength of Resin Luting Cements Containing Alternative Photoinitiators. Vol. 21, J Adhes Dent. 2019.
38. Aldhafyan M, Silikas N, Watts DC. Influence of curing modes on conversion and shrinkage of dual-cure resin-cements. Dental Materials. 2022 Jan 1;38(1):194–203.
39. Secundar B, Fathi A, Baghaei K, Atash R. Effect of ceramic thickness on the polymerization quality and film thickness of dual-polymerizing versus heated light-polymerizing adhesive cement.
40. Peter A, Paul SJ, Lüthy H, Schärer P. Film thickness of various dentine bonding agents. J Oral Rehabil. 1997;24(8):568–73.

41. Bulut A, Atsü S. Occlusal Thickness and Cement-Type Effects on Fracture Resistance of Implant-Supported Posterior Monolithic Zirconia Crowns. Int J Oral Maxillofac Implants. 2021 May;36(3):485–91.
42. Joukhadar C, Osman E, Rayyan M, Shrebaty M. Comparison between different surface treatment methods on shear bond strength of zirconia (in vitro study). J Clin Exp Dent. 2020 Mar 1;12(3):e264–70.
43. Tekçe N, Tuncer S, Demirci M. The effect of sandblasting duration on the bond durability of dual-cure adhesive cement to CAD/CAM resin restoratives. Journal of Advanced Prosthodontics. 2018 Jun 1;10(3):211–7.
44. Straface A, Rupp L, Gintaute A, Fischer J, Zitzmann NU, Rohr N. HF etching of CAD/CAM materials: Influence of HF concentration and etching time on shear bond strength. Head Face Med. 2019 Aug 8;15(1).
45. Zhang L, Luo XP, Tan RX. Effect of Light-Cured Resin Cement Application on Translucency of Ceramic Veneers and Light Transmission of LED Polymerization Units. Journal of Prosthodontics. 2019 Jan 1;28(1):e376–82.
46. 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 [Internet]. 2024;151:106353. Available from: https://www.sciencedirect.com/science/article/pii/S1751616123007075
47. Fidalgo-Pereira R, Carvalho Ó, Catarino SO, Henriques B, Torres O, Braem A, et al. Effect of inorganic fillers on the light transmission through traditional or flowable resin-matrix composites for restorative dentistry. Clin Oral Investig [Internet]. 2023;27(9):5679–93. Available from: https://doi.org/10.1007/s00784-023-05189-7
48. Maucoski C, Price RB, Arrais CAG. Irradiance from 12 LED light curing units measured using 5 brands of dental radiometers. Journal of Esthetic and Restorative Dentistry. 2023 Sep 1;35(6):968–79.
49. Chen B, Yang L, Lu Z, Meng H, Wu X, Chen C, et al. Shear bond strength of zirconia to resin: The effects of specimen preparation and loading procedure. Journal of Advanced Prosthodontics. 2019;11(6):313–23.
50. Pinto P, Carvalho Ó, Ferreira R, Madeira S, Silva FS. Influence of Applied Pressure and Thickness Variation on the Bond Strength Between 3Y-TZP

Zirconia and Self-Adhesive Resin Cement. J Biomed Mater Res B Appl Biomater. 2025 Mar 1;113(3).

51. Maneenacarith A, Rakmanee T, Klaisiri A. THE INFLUENCE OF RESIN CEMENT THICKNESSES ON SHEAR BOND STRENGTH OF THE CEMENT-ZIRCONIA. Journal of Stomatology. 2022;75(1):7–12.

52. Wang L, Yao L, Jiao Y, Dou R. Effect of grain size on mechanical properties and aging of yttria-stabilized tetragonal zirconia polycrystal fabricated by stereolithography-based additive manufacturing. Ceram Int. 2025 Jan;51(2):1613–22.

53. Bona A, Pecho O, Alessandretti R. Zirconia as a Dental Biomaterial. Materials. 2015 Aug 4;8(8):4978–91.

54. Kilinc E, Antonson SA, Hardigan PC, Kesercioglu A. The effect of ceramic restoration shade and thickness on the polymerization of light- and dual-cure resin cements. Oper Dent. 2011 Nov;36(6):661–9.

55. Turp V, Turkoglu P, Sen D. Influence of monolithic lithium disilicate and zirconia thickness on polymerization efficiency of dual-cure resin cements. Journal of Esthetic and Restorative Dentistry. 2018 Jul 2;30(4):360–8.

56. Hardy CMF, Bebelman S, Leloup G, Hadis MA, Palin WM, Leprince JG. Investigating the limits of resin-based luting composite photopolymerization through various thicknesses of indirect restorative materials. Dental Materials. 2018 Sep 1;34(9):1278–88.

57. Mendonça LM de, Ramalho IS, Lima LASN, Pires LA, Pegoraro TA, Pegoraro LF. Influence of the composition and shades of ceramics on light transmission and degree of conversion of dual-cured resin cements. J Appl Oral Sci. 2019 Jul 29;27:e20180351.

58. Hernandes DKL, Arrais CAG, Lima E de, Cesar PF, Rodrigues JA. Influence of resin cement shade on the color and translucency of ceramic veneers. J Appl Oral Sci. 2016;24(4):391–6.

59. Fujita K, Ikemi T, Nishiyama N. Effects of particle size of silica filler on polymerization conversion in a light-curing resin composite. Dental Materials. 2011 Nov;27(11):1079–85.

60. FUJITA K, NISHIYAMA N, NEMOTO K, OKADA T, IKEMI T. Effect of Base Monomer’s Refractive Index on Curing Depth and Polymerization Conversion of Photo-cured Resin Composites. Dent Mater J. 2005;24(3):403–8.

61. Lise DP, Van Ende A, De Munck J, Yoshihara K, Nagaoka N, Cardoso Vieira LC, et al. Light irradiance through novel CAD–CAM block materials and degree of conversion of composite cements. Dental Materials. 2018 Feb;34(2):296–305.
62. UEDA K, GÜTH JF, ERDELT K, STIMMELMAYR M, KAPPERT H, BEUER F. Light transmittance by a multi-coloured zirconia material. Dent Mater J. 2015;34(3):310–4.
63. FARAH RI. Dental zirconia generations: a comparative study of translucency parameters and light transmittance across varying thicknesses. Braz Dent Sci. 2024;27(3):e4021.
64. LIEBERMANN A, FREITAS RAFAEL C, COLLE KAULING AE, EDELHOFF D, UEDA K, SEIFFERT A, et al. Transmittance of visible and blue light through zirconia. Dent Mater J. 2018 Sep 27;37(5):812–7.
65. Baldissara P, Llukacej A, Ciocca L, Valandro FL, Scotti R. Translucency of zirconia copings made with different CAD/CAM systems. J Prosthet Dent. 2010 Jul;104(1):6–12.
66. Zhang Y. Making yttria-stabilized tetragonal zirconia translucent. Dental Materials. 2014 Oct;30(10):1195–203.
67. Awad D, Stawarczyk B, Liebermann A, Ilie N. Translucency of esthetic dental restorative CAD/CAM materials and composite resins with respect to thickness and surface roughness. J Prosthet Dent. 2015 Jun;113(6):534–40.
68. Yu Z, Strutz JM, Kipnis V, White SN. Effect of Dynamic Loading Methods on Cement Film Thickness In Vitro. Journal of Prosthodontics. 1995 Sep 8;4(4):251–5.
69. Price RB, Ferracane JL, Shortall AC. Light-Curing Units. Vol. 94, Journal of Dental Research. SAGE Publications Inc.; 2015. p. 1179–86.
70. Rueggeberg FA, Caughman WF. The influence of light exposure on polymerization of dual-cure resin cements. Oper Dent. 1993;18(2):48–55.
71. Han SH, Shimada Y, Sadr A, Tabata T, Nakagawa H, Sato T, et al. Effect of Attenuated Light Through Translucent Zirconia on the Interfacial Adaptation and Polymerization of Resin Cements. J Adhes Dent. 2023 Nov 1;25:219–30.
72. Lee SY, Shimada Y, Sadr A, Tabata T, Sato T, Byun JE, et al. Degree of conversion and interfacial adaptation of touch-cure resin cement polymerized

by self-curing or dual-curing with reduced light. Clin Oral Investig. 2024 Aug 2;28(8):463.

73. 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.
74. Al Nahedh H, Al-Senan DF, Alayad AS. The Effect of Different Light-curing Units and Tip Distances on the Polymerization Efficiency of Bulk-fill Materials. Oper Dent. 2022 Jul 1;47(4):E197–210.
75. Aldossary MS, Santini A. The influence of two different curing regimens on light energy transmission through bulk-fill resin composites and Vickers hardness. Am J Dent. 2016 Oct;29(5):282–8.
76. Maucoski C, Price RB, Arrais CAG. Irradiance from 12 <scp>LED</scp> light curing units measured using 5 brands of dental radiometers. Journal of Esthetic and Restorative Dentistry. 2023 Sep 10;35(6):968–79.

## 7. APPENDIX


# Adhesive interface at zirconia to implant abutments in oral rehabilitation: a review


**Smila Leduc[a]*, Larissa Martins[a]*, Rita Fidalgo-Pereira[a], Bruno Henriques[b,c], Mutlu Özcan[d], Julio C. M. Souza[a,b,c,*]**

*** Smila Leduc and Larissa Martins contributed equally to this work.**

AFFILIATION

[a]Faculdade de Medicina Dentária da Universidade Católica Portuguesa, [a] Center for Interdisciplinary Research in Health (CIIS), Faculty of Dental Medicine (FMD), Universidade Católica Portuguesa (UCP), 3504-505, Viseu, Portugal, [b]Center for MicroElectroMechanical Systems (CMEMS-UMinho), University of Minho, 4800-058, Guimarães, Portugal, [c]LABBELS - Associate Laboratory, University of Minho, Guimaraes, 4710-057 Braga, Portugal, [d]Dental Materials Unit, Center of Dental Medicine, Clinic of Reconstructive Dentistry, University of Zurich, 8032 Zurich, Switzerland


## OBJECTIVE:

The main aim of this study was to perform a literature review on the resin cement thickness at zirconia to implant restorative interfaces.

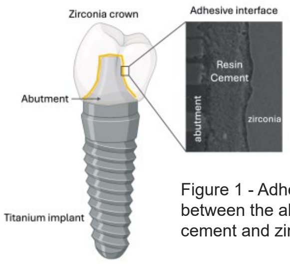



Figure 1 - Adhesive interface between the abutment, resin cement and zirconia crown

## MATERIALS AND METHODS

An electronic search was performed on PubMed using a combination of the following search items: zirconia, thickness, degree of conversion, resin cement, light curing and polymerization. Articles published in English language, up to July 2020, were included regarding the influence of resin cement thickness through zirconia.

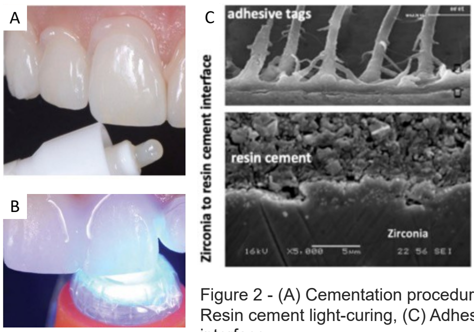



Figure 2 - (A) Cementation procedure, (B) Resin cement light-curing, (C) Adhesive interface

## RESULTS

Results revealed that thick resin cement layers ranging from 50 up to 400 µm in function of the cementation loading magnitude. Also, the type of resin cement affected the thickness of the adhesive interface. Micro- and nano-scale inorganic fillers were identified by scanning electron microscopy. The size and content of the inorganic fillers influenced the viscosity of the resin cement that resulted in the variation in the cement thickness. Resin cement layer thickness of 50-150 µm did not affect shear bond strength, however layer thicknesses higher than 200 µm led to decrease of shear bond strength.

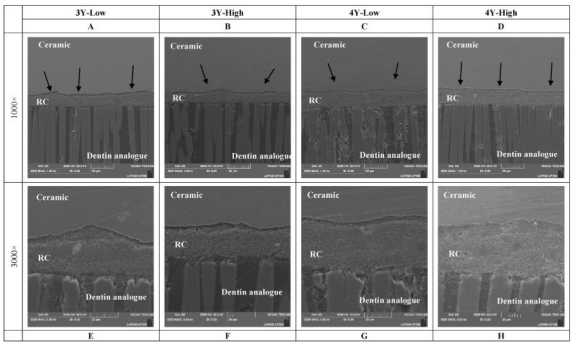



Figure 3 - Representative SEM interface analyses (1000 × and 3000 × magnification) illustrate the interface among the dentin analogue-resin cement-ceramic and reveal the presence of elongated depression in the ceramic/cement layer, pointed out by black arrows; the resin cement layer is described as RC.

## CONCLUSIONS

Chair-side cementation procedures involve an intrinsic and sensitive technique leading to an irregular layer of resin cement. The variation in thickness cementation layer is highly important since that can affect the long-term success of the prostheses.


**REFERENCES**

Tafur-Zelada, C.M., Carvalho, O., Silva, F.S. *et al.* The influence of zirconia veneer thickness on the degree of conversion of resin-matrix cements: an integrative review. *Clin Oral Invest* **25**, 3395–3408 (2021). https://doi.org/10.1007/s00784-021-03904-w

Gabriela Carrão Aragonez, Fernanda Dalla-Nora, Pablo Machado Soares, Gabriel Kalil Rocha Pereira, Luiz Felipe Valandro, Sailer Santos dos Santos, Marília Pivetta Rippe,Load-bearing capacity under fatigue of bonded-yttria tetragonal zirconia polycrystals and -yttria-stabilized zirconia: Effects of the viscosity of a dual-cured resin cement,Journal of the Mechanical Behavior of Biomedical Materials,Volume 148,2023,106233,https://doi.org/10.1016/j.jmbbm.2023.106233



fct Fundação para a Ciência e a Tecnologia

This work is financially supported by National Funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project UIDB/04279/2020"