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

Larissa Cristina Ribeiro Martins

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Por: Larissa Cristina Ribeiro Martins

Orientador: Professora Doutora Rita Fidalgo Pereira
Co-Orientador: Professor Doutor Júlio Souza

Viseu, 2025

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Professora Associada, CESPU

Orientador: Rita Cristina Pais Fidalgo Pereira

Professora Auxiliar Convidada, FMD-UCP

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Dedicatória

À minha mãe,
Dizem que quem tem, ao menos, uma única pessoa que seja genuinamente apoio na vida, é abençoado.
Eu sou, porque te tenho a ti.
Foste força quando me faltou coragem, colo nos meus dias escuros e abrigo seguro em todas as tempestades.
Esta caminhada foi nossa: cada conquista minha carrega a tua presença, o teu amor e a tua resiliência.
Que sorte a minha ter sido escolhida para vir neste mundo ao mesmo tempo que tu.
Obrigada, mãe.

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À minha orientadora, Professora Doutora Rita Fidalgo Pereira, pela orientação científica rigorosa, pela confiança depositada em mim e pela constante disponibilidade. A sua exigência, profissionalismo e dedicação foram pilares fundamentais para o desenvolvimento deste trabalho.

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À **Universidade do Minho e à Universidade de Pensilvânia** toda a colaboração na elaboração do projeto.

À minha mãe, pelo apoio incondicional, pelos princípios e valores que sempre me transmitiu, incentivando-me a tornar-me melhor todos os dias e a enfrentar os desafios do meu caminho com perseverança e humildade.

Ao meu namorado, pela paciência, pela preocupação, pelo incentivo e por celebrar comigo todas as minhas vitórias e conquistas.

A Deus, por me guiar com luz, propósito e fé ao longo de percurso.

Abstract

Purpose:

This in vitro study aimed to evaluate light transmittance through two different CAD-CAM indirect restorative materials: resin-matrix composite and 3 mol% yttria-stabilized tetragonal zirconia polycrystal (3YTZP) to understand how the intrinsic microstructure and optical characteristics of these materials influence light transmittance and the polymerization potential of the underlying resin-matrix cement.

Materials and Methods:

Eighteen disk-shaped specimens of both materials were prepared using CAD-CAM techniques. A dual-cure resin-matrix cement was applied under a standardized 60 N load. Both materials had 1.5 mm thickness and were cemented using the same 73 wt% resin-matrix cement. Specimens were light-cured at 900 mW/cm^2 for 40s. Light transmittance was analyzed before and after polymerization using a spectrophotometer with an integrated monocromator and during polymerization with a MiniGig device. Complementary optical microscopy was performed to evaluate microstructural characteristics of the materials. Statistical analysis was conducted using non-parametric tests with significance set at $p < 0.05$.

Results:

3YTZP zirconia demonstrated significantly higher light transmittance than the resin-matrix composite, both before and after polymerization ($p < 0.001$). The resin-matrix composite material showed greater variation in optical behavior, attributed to its heterogeneous filler distribution. Spectrophotometric and MiniGig measurements were consistent, reinforcing the validity of the findings. Optical microscopy revealed a homogeneous polycrystalline structure in 3YTZP, while the resin-matrix composite showed irregularly shaped fillers, contributing to greater light scattering. The presence of resin-matrix cement also reduced transmittance across all specimens.

Conclusions:

Within the limitations of this in vitro study, 3YTZP zirconia allowed higher light transmission than resin-matrix composite, challenging the traditional notion of zirconia's opacity. Advances in ceramic processing have improved the translucency of modern zirconia, supporting its use in indirect restorations where both mechanical strength and light transmittance are essential. Proper material selection, thickness standardization, and adequate curing protocols are crucial to optimize resin-matrix cement polymerization and restoration longevity.

Keywords:

Light transmittance, resin-matrix composite, 3YTZP zirconia, indirect restoration, polymerization.

Resumo

Objetivo:

Este estudo in vitro teve como objetivo avaliar a transmitância de luz através de dois materiais restauradores indiretos obtidos por CAD-CAM: resina composta e zircónia tetragonal policristalina estabilizada com 3 mol% de ítria (3YTZP), considerando a sua microestruturas e propriedades óticas que influenciam a passagem de luz e a polimerização do cimento resinoso subjacente.

Materiais e Métodos:

Dezoito corpos de prova foram confecionados em forma de disco para ambos os materiais, utilizando tecnologia CAD-CAM. A cimentação foi realizada com um cimento resinoso de polimerização dual com 73% em peso de partículas inorgânicas, sob força padronizada de 60 N. A análise da transmitância de luz foi efetuada antes e após a polimerização, utilizando um espectrofotómetro e durante a polimerização pelo dispositivo MiniGig. Microscopia ótica foi utilizada para avaliar as características microestruturas dos materiais. Os dados foram tratados estatisticamente com testes não paramétricos, considerando-se significância quando $p < 0,05$.

Resultados:

A zircónia 3YTZP apresentou valores de transmitância significativamente superior aos da resina composta, antes e após a polimerização ($p < 0,001$). A resina composta demonstrou maior variabilidade no comportamento ótico, atribuída à distribuição heterogênea das partículas inorgânicas. Os resultados obtidos pelo espectrofotómetro e pelo MiniGig foram coerentes entre si. A microscopia revelou uma estrutura policristalina homogênea na zircónia, enquanto a resina composta apresentou partículas inorgânicas com formas e tamanhos irregulares, aumentando a dispersão da luz. A presença do cimento resinoso reduziu a transmitância de luz em ambos os materiais.

Conclusão:

Dentro das limitações deste estudo in vitro, a zircónia 3YTZP demonstrou maior capacidade de transmitir luz do que a resina composta, contrariando a visão tradicional de que a zircónia é sempre mais opaca. Avanços na manufaturação da zircónia têm aumentado a sua translucidez, o que favorece a sua utilização em restaurações indiretas que exigem não só resistência mecânica, mas também adequada passagem de luz para uma eficiente polimerização do cimento resinoso. A seleção apropriada dos materiais, o controle da espessura restauradora e protocolos adequados de fotopolimerização são essenciais para a durabilidade clínica das restaurações.

Palavras-chave:
Transmitância de luz, resina composta, zircónia 3YTZP, restauração indireta, polimerização.

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List of abbreviations

3YTZP - 3 mol% Yttria-stabilized Tetragonal Zirconia Polycrystal

Al_2O_3 - Aluminium Oxide

Bis-EMA - Ethoxylated Bisphenol A Dimethacrylate

Bis-GMA - Bisphenol A-glycidyl Methacrylate

CAD-CAM - Computer-Aided Design / Computer-Aided Manufacturing

CQ - Camphorquinone

DC - Degree of Conversion

HEMA - Hydroxyethyl Methacrylate

HF - Hydrofluoric Acid

LCU - Light Curing Unit

MDP - 10-Methacryloyloxydecyl Dihydrogen Phosphate

MiniGig - Portable Spectroradiometer by Gigahertz Optik

np - Non-polymerized

p - Polymerized

PICN - Polymer-infiltrated Ceramic Networks

SEM - Scanning Electron Microscopy

SiO_2 - Silicon Dioxide

TEGDMA - Triethylene Glycol Dimethacrylate

UDMA - Urethane Dimethacrylate

ZrO_2 - Zirconium Oxide

DMA – Glycerol Dimethacrylate.

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INTRODUCTION

1. Introduction

Restorative dentistry has greatly evolved in recent decades, due to high-strength and aesthetically pleasing materials for indirect restorations like onlays (1,2). These developments are mostly due to the advent of computer-aided design/computer-aided manufacturing (CAD-CAM) processes, resin-matrix restorative materials, and contemporary ceramics, which ensure improved clinical efficacy and durability (3,4). From digital scanning to the final fitting and cementation of the onlay to the tooth surface, CAD-CAM restorations have been shown to be more effective due to their ability to facilitate high-precision manufacture. These restorations are particularly beneficial for structures that demand a high level of fit and accuracy (1,4). Indirect restorations in CAD-CAM resin-matrix composites and yttria-stabilized tetragonal zirconia polycrystal (3YTZP) CAD-CAM have become a daily practice in dentistry. However, some concerns have arisen regarding the influence of material´s microstructure and restorative thickness on the light transmittance through the materials that can negatively affect the degree of monomers conversion (DC) of the resin-matrix cements under the indirect restorations (3,5).

DC is the percentage of double carbon bonds (C = C) in the chemical reaction that become converted into single bonds within the polymer chain. DC is directly influenced by resin-matrix cement properties itself, ceramic thickness, and polymerization procedure (1,6–8). DC of resin-matrix composites and resin-matrix cements depend on light transmission, light-curing unit (LCU) and irradiation conditions which directly influence the restoration's long-term durability, physical mechanical properties, such as elastic modulus, flexural strength, hardness and wear resistance (9–11).

Achieving a proper DC requires an irradiance between 400–1765 mW/cm², exposure time between 20 up to 60 seconds, and a wavelength between 300–500 nm, depending on the photoinitiator system. The effectiveness of the LCU and the exposure time are critical to provide an acceptable DC (8,12,13). To provide a correct DC, the distance between the photopolymerization unit (LCU) and the indirect restoration should be less than 7 mm, the LCU should ensure proper irradiance, and the exposure time should be sufficient to ensure proper polymerization reaction (1,7).

The materials frequently applied to indirect restorations are, zirconia, feldspar-based ceramics, lithium disilicate-reinforced glass ceramics, resin-matrix composites, or polymer-infiltrated ceramic networks (PICN). Resin-matrix cements are crucial for the long-term success of indirect restorations as well as the adhesion provided by the surface conditioning of the substrate (14,15).

1.1 State of the art

1.1.1 Indirect restorations cementation and resin-matrix cements properties

A crucial stage in the longevity of indirect restorations is cementation, which is frequently accomplished with dual polymerization resin-matrix cements that combine light and chemical polymerization pathways (1,3). Camphorquinone (CQ) is the common photoinitiator, activated by visible light at a wavelength between 420 and 490 nm. This type of resin-matrix cement allows longer control of the working time before being exposed to light, which facilitates adjustment and removal of excess at the margins of the restoration (3,7,8). Self-polymerizing cements use a chemical reaction between a peroxide (usually benzoyl peroxide) and a tertiary amine to initiate curing reaction. These cements do not depend on light, being useful in areas where light cannot reach, but they have limitations in terms of controlling working time and finishing (1,3). Dual-cured resin-matrix cement start the reaction with light combining CQ, benzoyl peroxide and a tertiary amine and continue to chemically polymerize in areas where light does not reach (7,8). For thicker indirect ceramic restorations, dual-cured cements are recommended (14,16).

Currently the dual-cured resin-matrix cements are the most used in restorative dentistry and contain an organic matrix (22-60 wt%) of methacrylate monomers, such as Bis-GMA (bisphenol A-glycidyl methacrylate), UDMA (urethane dimethacrylate), TEGDMA (triethylene glycol dimethacrylate) and ethoxylated bisphenol A dimethacrylate (Bis-EMA) (6,7,17). The inorganic particles varying from 40 up to 80 wt% are added to the organic matrix, and contain inorganic filler particles of amorphous silica, ytterbium fluoride, zirconium or barium silicate that increase the mechanical and optical properties of resin matrix-cement (4,7,8).

For dual-polymerized resin-matrix cements, DC values between 55% and 75% are recommended, values below this could jeopardize the restoration's mechanical strength, stability, and duration (3,7,18,19).

When monomers do not fully convert into polymers, flexural strength is impaired, lowering the resin-matrix cement's capacity to sustain masticatory stresses and increasing the possibility of fractures. Incomplete polymerization also results in a lower modulus of elasticity, which means the material deforms more easily under stress, compromising the restoration's long-term durability (7,12). Another important feature affected by low DC is hardness, as insufficient polymerization reduces resin-matrix cement hardness, making it more susceptible to wear and abrasion over time (7,20). Fracture toughness, or the material's ability to resist crack propagation, is also reduced when the DC is low, resulting in a more brittle resin-matrix cement prone to catastrophic fractures (3,21). Furthermore, dimensional stability and polymerization contraction are impacted, potentially resulting in gaps, microleakage and debonding between the cement and dental substrate (7,22).

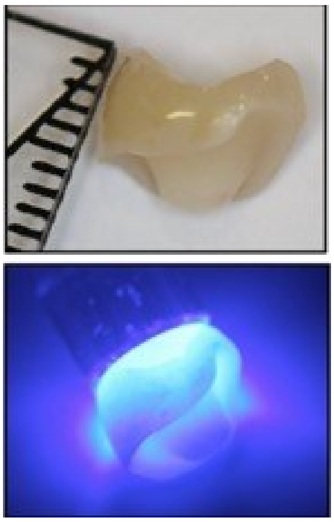


Figure 1. Shows how different thicknesses of restorative materials affect light transmittance. Image adapted from (14).

1.1.2 Factors that can impair light transmission through CAD-CAM materials

Light transmission refers to the amount of light that passes through a material when it is exposed to illumination (23,24). Several factors influence the effectiveness of light transmission through indirect restorative materials, particularly in the context of resin-matrix cements. Among these, the type, thickness, intrinsic opacity, Irradiation time, light irradiance, light transmittance and light curing protocols (14,25).

Regarding the factors that can impair light transmission through CAD-CAM resin-matrix composites and ceramics, the opacity and thickness of these restorative materials play a significant role. Their inherent opacity and greater thickness limit the amount of light that can penetrate the resin cement. This component restricts photopolymerization, resulting in a decreased DC in locations where light does not penetrate sufficiently (5,26). Additionally, the inorganic particle composition and size can influence the light transmission. When inorganic filler particles of various sizes (nano and micro) are present, larger particles or particles with uneven surfaces can impair the light transmission, lowering the efficiency of photopolymerization (3,9).

These limitations in light transmission not only affect photopolymerization but also have a direct impact on the resin-matrix cement. As previously mentioned, a low DC, resulting from insufficient light penetration, compromises the mechanical properties of the resin cement, raising concerns about the longevity of indirect restorations in CAD-CAM resin-matrix composites or 3YTZP CAD-CAM (5,6,27). A critical aspect in the polymerization of resin matrix-cements, particularly when light-curing is employed, is the light transmission through restorative materials. Therefore, these may cause failures on the adhesive interface, microleakage, marginal discoloration, and other clinical problems, including post-operative sensitivity and catastrophic fractures of the restorative interface, can arise resulting in inadequate DC (3,4,8).

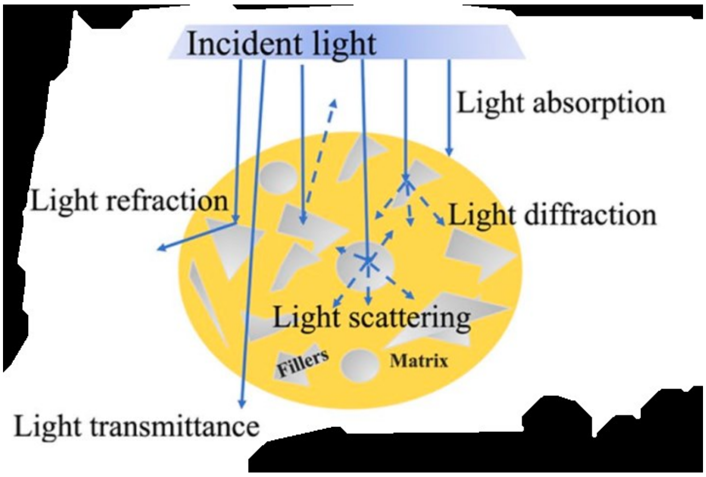


Figure 2. Scheme representing the main optical phenomena during the passage of light through resin-matrix composites: refraction, absorption, diffraction, dispersion and transmittance. Adapted from Fidalgo-Pereira et al., 2023 (8).

1.1.3 <u>CAD-CAM resin-matrix composites and 3YTZP zirconia</u>

CAD-CAM resin-matrix composites are a popular option for onlays because of their elastic modulus ranging from 15 to 20 GPa, flexural strength ≈ 333 MPa, and toughness similar to dentin and enamel. Moreover, even with different thicknesses of indirect restorations, good aesthetic effects can be obtained because to the ability to customize the translucency and opacity of these materials. This is crucial for procedures in areas with high aesthetic standards (3,5).

The organic matrix of CAD-CAM resin-matrix composites is composed of methacrylate monomers, including Bis-GMA (bisphenol A-glycidyl methacrylate), Bis-EMA (ethoxylated bisphenol A dimethacrylate), and TEGDMA (triethylene glycol dimethacrylate). These monomers provide structural strength, which is critical for polymerization and resin cement adherence. In addition to the organic matrix, inorganic particles range from 75 up to 90 wt% and 60-80% vol (5,8,19,28). The inorganic particles include barium glass and zirconia ceramic, with sizes ranging from the microscale (0.5 to 3 µm) to the nanoscale (~ 40 nm) for silica particles that enhance the aesthetics and resistance to abrasion (3,4). The particle size distribution enhances mechanical strength and optimizes optical properties such as translucency and opalescence (3,8).

The 3YTZP is known for its strong mechanical properties, including as high flexural strength and toughness, making it an excellent material for indirect restorations. Because of its properties this type of zirconia is extensively used in applications where structural stability is essential (1,8).

3YTZP is composed of zirconium dioxide (ZrO_2), stabilized with approximately 3 mol% of yttrium oxide (Y_2O_3). This specific composition allows zirconia to retain its tetragonal phase at room temperature, a characteristic that is crucial for its high strength and durability (1,29). 3YTZP zirconia exhibits a high flexural strength of approximately 1200 MPa, which enables it to withstand significant masticatory forces essential for applications requiring durability under intense load. It also demonstrates excellent fracture toughness, which gives it a strong resistance to crack propagation, enhancing the longevity of restorations (29,30). Additionally, 3YTZP has a modulus of elasticity approximately 240 ± 9.5 GPa and a flexural strength between 9 ± 0.34 MPa, allowing rigidity and structural stability. Its high opacity is particularly advantageous for masking underlying structures, which is ideal for covering darker shades or metallic abutments (5). However, this opacity also reduces light transmission, which may have an impact on the underlying resin-matrix cement polymerization effectiveness requiring careful attention to the process to ensure optimal adhesion and performance (4,8). In the case of 3YTZP zirconia, restorative thickness plays a critical role in light transmittance. Studies have shown that zirconia thicknesses ranging from 0.2 mm to 1.65 mm result in substantial variations in light transmission (5,31).

Materials used to indirect restorations such as 3YTZP and CAD-CAM resin-matrix composites with high opacity can impair light transmission and they are better suited for dual polymerization resin-matrix cements. Thus, even in regions that are not as accessible to light, like the interface between the restoration and the dental substrate, the combination of light and chemical polymerization ensures effective curing (1,3).

With an emphasis on the different types of materials, the impact of resin-matrix cement type and restorative material thickness on polymerization, the present study aims to assess the influence of materials microstructure and restorative thickness on the light transmittance using CAD-CAM resin-matrix composites and 3YTZP CAD-CAM. By researching these factors, we intend to further our knowledge of how various materials and their properties impact light transmission and polymerization, supporting the selection of materials and methods that promote indirect restorations long-term viability. The null hypothesis is that there is no difference between light transmittance between CAD-CAM resin-matrix composites and 3YTZP zirconia specimens.

MATERIALS AND METHODS

2. Materials and Methods

2.1 Preparation of specimens

Eighteen disk shaped resin-matrix composites and 3YTZP zirconia specimens were prepared.

Resin-matrix composites specimens were manufactured from Grandio ™ disc (Voco, Germany) by CAD-CAM with 15 mm and ∅ 98.4 mm diameter. The resin-matrix composites specimens were designed by CAD files hyperDENT™ software (LaserMaq, Aveleda, Portugal). The disk-shaped resin-matrix composite specimens were meticulously designed to meet specific morphological and dimensional criteria required for cementation procedures. The digital models were subsequently exported as STL files utilizing Modellier™ software (Zirkonzahn GmbH, Gais, Italy). The standardized cementation procedure was performed under a constant load of 60 N for 60 seconds as seen in Figure 3. The chemical composition of the material is described in Table 1.

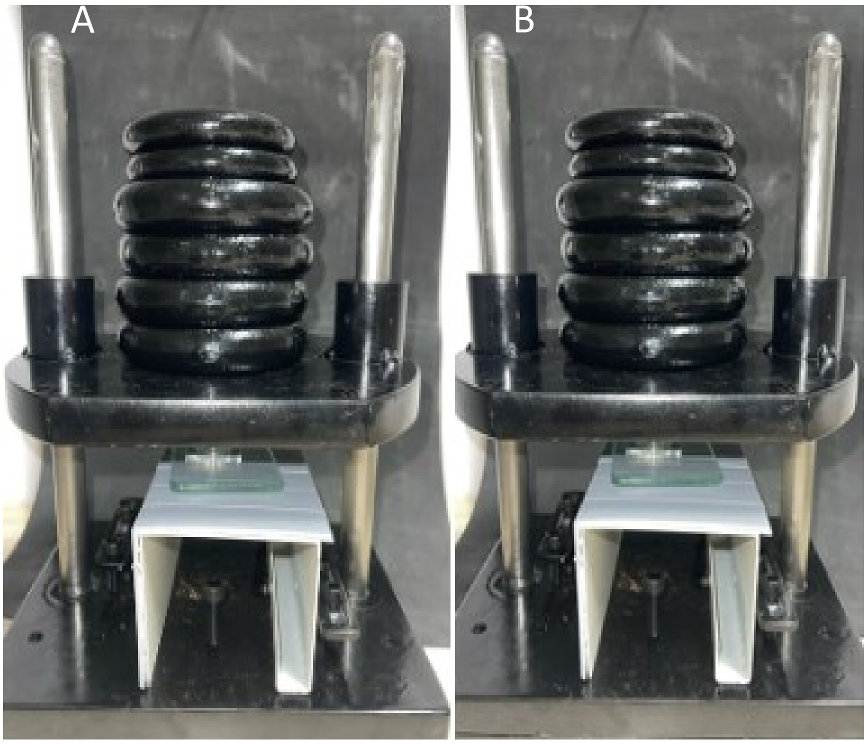


Figure 3. Cementation load of 60N applied during 60s: 60s/ 60N (A) CAD-CAM Resin-matrix composite and (B) 3YTPZ.

Table 1. Chemical composition of the resin-matrix composites discs manufactured by CAD-CAM, 3YTZP zirconia discs, ceramic bond, adhesive systems, and luting materials.

Material Type (Brand, Manufacturer, country)	**Organic Matrix**	**Fillers %(w/w)**	**Fillers %(v/v)**	**Filler Type**	**Elastic Modulus (GPa)**
Onlay: Resin-matrix composites discs manufactured by CAD-CAM and dimensions with 15 mm and ∅ 98.4 mm diameter) (GrandioSO TM, VOCO GmbH, Germany)	Bis-GMA,Bis-EMA,TEGDMA	89%	73%	Micro-scale barium glass and zirconium glass ceramics particles (0.5–3 μm); Nano-scale sio_2 particles (~40 nm)	15 - 20 GPa
Onlay: 3YTZP zirconia discs (dimensions with 1,5mm and 13,80mm diameter)	--	ND	ND	Functionalized nano-scale SiO_2 particles (20 nm)	240 ± 9,5 GPa GPa
Adhesive: Universal adhesive system (Futurabond M +™, VOCO GmbH, Germany)	Organophosphate monomer (10-MDP), Methacrylates (2 HEMA, bis-GMA, UDMA), ethanol, catalyst, pyrogenic silicic acids, BHT, water DMA	71–73%	61%	Micro-scale barium-aluminum-borosilicate glass ceramic and nano-scale amorphous silica fillers	3-7 GPa
Dual curing, adhesive resin-matrix cement (Bifix QM™ Transparent,VOCO, GmbH, Germany)	Bi-functional methacrylate, acid methacrylate, Bis-GMA, benzoyl peroxide, amines, DMA	71-73%	61%	Barium-aluminiumboro-silicate glass and amorphous silica fillers; (size~2.9 μm)	6–7.5
Silane compound (Ceramic bond™, VOCO GmbH, Cluxhaven, Germany)	Organic acid, 3-methacryloxypropyltrimethoxysilane, acetone	ND	ND	ND	ND

.Bis-GMA - bisphenol A-glycidyl dimethacrylate; TEGDMA - triethylene glycol dimethacrylate; UDMA - urethane dimethacrylate; Bis-EMA- ethoxylated bisphenol A dimethacrylate; DMA- Dimetacrilato de Glicerol; HEMA- 2-Hidroxietil Metacrilato; ND- not disclosed.

Also, 3YTZP zirconia with 1.5mm thickness and ∅ 13.80 was manufactured in University of Pennsylvania to be used in the present study. The zirconia powder was pressed into a green body, densified with cold isostatic pressing, pre-sintered, polished, and then fully sintered at 1500°C for 120 minutes to achieve its final properties.

The inner surfaces of the CAD-CAM resin-matrix composite discs and 3YTZP underwent mechanical and chemical pretreatment. Initially, they were ultrasonically cleaned in isopropyl alcohol for 10 minutes and then grit-blasted with 50 µm alumina (Al_2O_3) at 2 bar pressure and 10 mm distance from the surface for 20 seconds, and then the surfaces, followed by a rinse in distilled water for another 10 minutes. The internal surfaces of the resin-matrix composite onlays and 3YTZP were treated with a silane coupling agent (Ceramic bond™, VOCO GmbH, Cuxhaven, Germany) for 60 seconds, followed by gentle air-drying using oil-free air for 5 seconds, in accordance with the manufacturer's guidelines (3,4,32).

The groups of resin-matrix composite onlay specimens and CAD-CAM 3YTZP zirconia were bonded to human dentin to establish a suitable interface for optical and scanning electron microscopy (SEM) analyses.

A total of 12 molars extracted from human participants were initially immersed in distilled water for 10 minutes, followed by immersion in a 2% sodium hypochlorite (NaOCl) solution for another 10 minutes. Subsequently, the teeth were submerged in 10% formalin for 1 week. After this period, the teeth were stored in a 0.9% NaCl solution for 7 days to rehydrate before the cementation procedure. This protocol was followed according to the ISO 4882:2015 guidelines (4).

The handling 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, and presented to Catholica ethics committee for approval that is in agreement with the Helsinki declaration of 1964. 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 (4). During dental preparation, the radicular and coronal portions of the teeth were withdrawn, followed by withdraw of enamel from all surfaces using a conical trunk diamond bur with a 1.2 mm.

Dentin slices were prepared with a 15 mm diameter and 1.5 mm thickness, and the surfaces were finished with a 1.5 mm cylindrical diamond bur. The dentin surfaces were then etched with 37% phosphoric acid (Kerr,Orange,USA) for 15 seconds, followed by rinsing with distilled water for 30 seconds. Excess water was removed with cotton (3).

The dentin slices were positioned in acrylic and glass customized molds to ensure mechanical stability during the cementation procedure and were then conditioned with universal adhesive (Futurabond M+™, VOCO GmbH, Cluxhaven, Germany), rubbed with a microbrush for 20 seconds (4,8). Oil-free air was applied over the adhesive layer for 5 seconds before applying the cementation materials (3).

On the cementation a dual-cured resin-matrix cement (Bifix QM™ Transparent, VOCO, Germany) was used, the composition is detailed in Table 1. The cementation materials were applied to the internal surfaces of the resin-matrix composite and 3YTZP zirconia specimens, which were then precisely positioned over the dentin substrate. Figure 3 illustrates the cementation process using an axial load of 60 N (6 kg weigth) applied with an apparatus manufactured for this study purpose for 60 seconds. To prevent horizontal specimens' displacement and guarantee solid alignment, customized mold was used. The microbrush was used to remove excess cement (3,4).

To achieve polymerization for 60 seconds, visible light with wavelength between 420 and 540 nm and an intensity of 900 mW/cm² was emitted by a light curing unit (LCU). A light curing device (LED) (Smartlite™ Focus™, Dentsply, Germany) was used for 60 seconds to light cure the specimens (3,4,33).

To verify and standardize the irradiance prior to polymerization, thus minimizing any risk of insufficient light exposure to the specimens, a MiniGig radiometer (Ultradent/GigaHertz Optik Türkenfeld Germany) was used. The MiniGig incorporates a small integrating sphere positioned over the entrance port, which enables it to accurately capture and integrate light emitted from different types of light-curing units (LCUs) (4,33,34).

This device allows for the export of calibrated spectral radiant power, total radiant power (mW), and irradiance (mW/cm²) across the spectral range of 360 nm to 830 nm. During measurements, the tip of the LCU was positioned flat and parallel to the entrance port of the radiometer, maintaining a constant distance (0 mm) to ensure full light collection without beam dispersion. The light output was stabilized before each reading, and five consecutive measurements were performed for each specimen to improve accuracy. The mean irradiance and radiant power values were calculated for subsequent analysis (3,33,34).

In a PVC mold, the specimens were subsequently placed in polyester-modified self-polymerizing resin (Technovit 400™, Kulzer, GmbH, Germany) for cross-sectional cuts at a 90° angle to the interface plane, Figure 4. The specimens were sectioned by wet grinding using SiC papers (Trizact™, 3M ESPE, USA) with grit sizes ranging from 380 to 2,400 mesh, followed by polishing with SiC papers of 300 and 6,000 mesh (3 µm particle size) (8). Finally, the specimens were ultrasonically rinsed with isopropyl alcohol for 5 minutes, followed by rinsing with distilled water for 10 minutes and air-dried at room temperature (3,4).

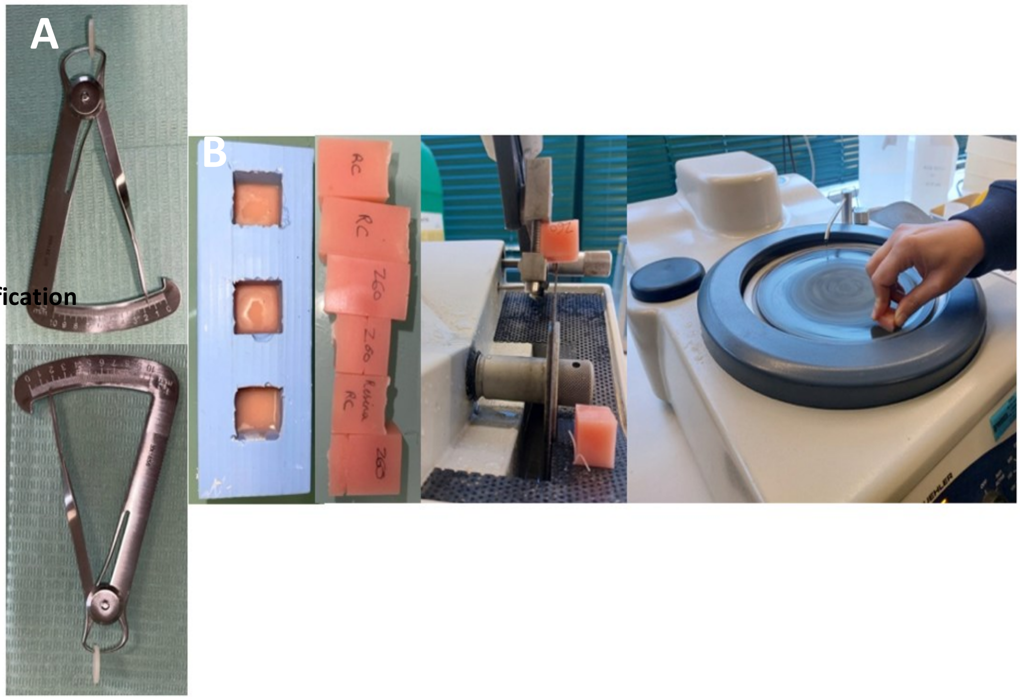


Figure 4. (A) Thickness of resin-matrix composite and 3YTPZ disks; (B) Preparation, samples cross-section and wet grinding using Sic papers.

2.2 Chemical and Microscopic Analysis

The specimens were examined using an optical microscope (Leica DM 250™, Leica Microsystems, Germany) connected to a computer for image acquisition and processing through the Leica Application Suite™ software (Leica Microsystems, Germany), employing magnifications between 50× and 1000×. The restorative interfaces were subsequently analyzed using Adobe Photoshop™ (Adobe Systems Software, Ireland), allowing differentiation between the organic matrix (appearing white) and the inorganic filler particles (appearing black) (3,8).

The size of the inorganic particles were measured using ImageJ™ software (National Institutes of Health, USA).

2.3 Optical Transmittance

An integrated monochromator benchtop spectrophotometer (AvaSpec-ULS2048XL EVO™, Avantes, NS Apeldoorn, Netherlands) was used to measure optical transmittance throughout a wavelength range of 350 nm to 850 nm with an integration time of 10 ms. Ten, twenty, and forty seconds prior to and following photopolymerization, measurements were made (8). The apparatus consisted of a metallic sample holder, optical fiber probes, and a 200 W Quartz Tungsten Halogen light source (Model 66.881, Oriel Newport, USA) (3).

For data collection and processing, including smoothing based on the average of 100 readings (a total analysis time of 1 second), the spectrophotometer was connected to a computer. Based on the Czerny-Turner symmetric design, the spectrophotometer's optical bench included focal lengths of 37.5, 50, 75, or 100 mm (3).

Light entered the spectrometer using a standard SMA-905 connector and was collimated by a spherical mirror on the optical bench. A second spherical mirror focused the diffracted light after a plane grating had diffracted the collimated light. According to the manufacturer's instructions, the spectrum image was projected onto a one-dimensional array of linear detectors. Three duplicates of each experiment were carried out (3,8).

Optical transmittance was measured for each specimen both before and after polymerization (i.e., in pre-polymerized and post-polymerized states). Initially, measurements were performed on non-polymerized specimens, followed by 40 seconds of light-curing. Immediately after polymerization, transmittance was measured again to assess changes induced by the curing process. For calibration purposes, reference optical measurements were acquired between each set of readings to ensure consistency and accuracy (3,33).

Another method was used to measure light transmittance during polymerization, the MiniGig, Ultradent (Gigahertz Optik, Türkenfeld, Germany), is composed of a small integrating sphere to the entrance port of the Gigahertz Optik MSC-15 radiometer. The MiniGig is a portable spectroradiometer that exports calibrated spectral radiant power and irradiance values. This hand-held laboratory-grade radiometer is calibrated to provide accurate spectral irradiance recordings according to ISO/IEC 17025 standard (35) . Three specimens of R0, RC60 and Z60 were measured in triplicate. The MiniGig device allows the measurement of irradiance in mW/cm^2 at the tip of LCU, also known as the radiant exitance or radiant emittance, and is the value provided by the radiant flux (power in watts) from the LCU divided by the area of the light tip of the LCU (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.

2.4 Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS™), Version 29.0 (IBM Corp., Armonk, NY, USA). Tests for normality were conducted under the assumption of no association or significant differences among the elements and variables. The Kolmogorov–Smirnov and Shapiro–Wilk tests were employed to assess whether the sample distributions conformed to normality. When normal distribution was indicated, Levene's test was used to adjust for variance homogeneity, thereby enhancing test power. However, in this study, the data did not meet the criteria for normal distribution as indicated by the Kolmogorov–Smirnov test followed by Levene's test, with the significance threshold set at $p < 0.05$. Consequently, non-parametric statistical methods were applied to evaluate differences in optical transmittance among the experimental groups.

RESULTS

3. Results

3.1 Optical Transmittance Results

Optical transmittance tests were performed to evaluate the passage of light through CAD-CAM resin-matrix composite with 89 wt% inorganic particles (RC60) and 3YTZP zirconia (Z60) specimens, both cemented under a 60 N load for 60 seconds with a 73 wt% resin-matrix cement. Transmittance measurements were conducted before and after 40 seconds of photopolymerization, using a manual spectrophotometer.

Initial optical transmittance tests were conducted to assess light transmission through 89 wt% CAD-CAM resin-matrix composite and 3YTZP zirconia specimens in the absence of cement, as shown in Figure 5.

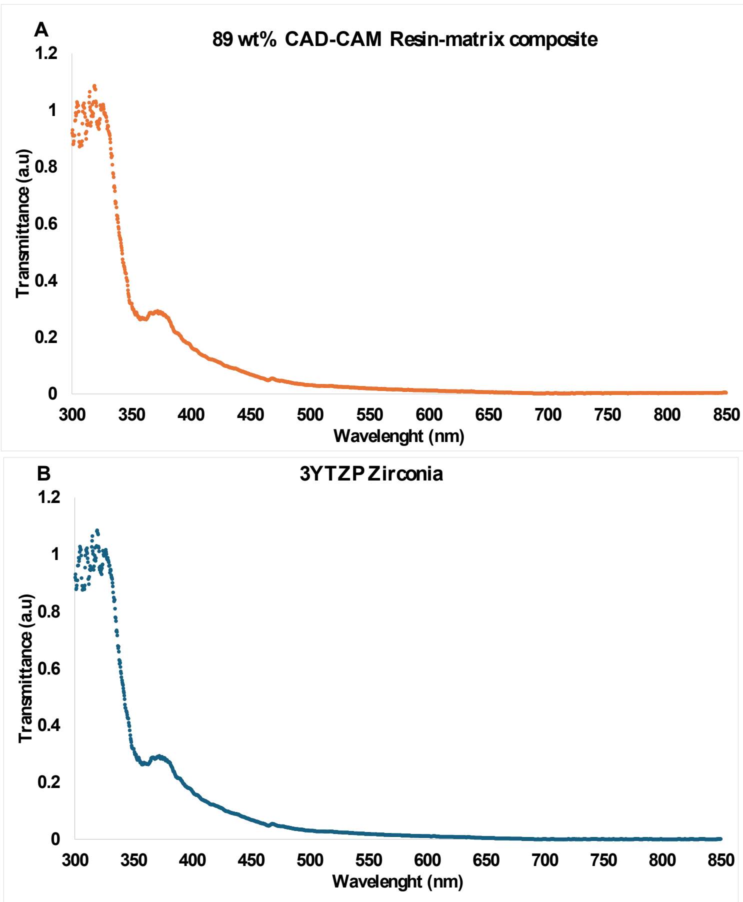


Figure 5. Optical transmittance tests through spectrophotometer preformed in (A) 89 wt% CAD-CAM resin-matrix composite and (B) 3YTZP zirconia specimens without resin-matrix cement.

The optical transmittance spectra, recorded within the wavelength range of 350 to 850 nm (X-axis), presented transmittance values ranging from 0.0 to 0.4 arbitrary units (a.u.) on the Y-axis.

The transmittance spectra of the non-polymerized resin-matrix composite specimens (0s) were similar, exhibiting relatively high transmittance in the ultraviolet (UV) region, particularly at wavelengths below 400 nm, as shown in Figure 5A. However, from 400 nm to 850 nm, the non-polymerized specimens (np) demonstrated very low optical transmittance, as the incident light was almost entirely absorbed. Consequently, no significant differences in optical transmittance were observed among the CAD-CAM resin-matrix composites for wavelengths above 450 nm.

The zirconia specimens (Z60) exhibited consistently low transmittance values across the entire spectral range (360–850 nm), with all values remaining below 0.1 a.u., regardless both for non-polymerized and polymerized specimens as shown in Figure 5B.

After 40s of exposure time, all polymerized 89 wt% CAD-CAM resin-matrix composite specimens exhibited an increase in optical transmittance at wavelengths above 700 nm ($p < 0.001$), particularly as the spectrum entered the near-infrared (near-IR) region, Figure 6A. In contrast, the zirconia specimens showed only a minimal increase in transmittance following polymerization ($p < 0.001$), Table 2, with values remaining below 0.1 a.u. across the entire spectral range, Figure 6B.

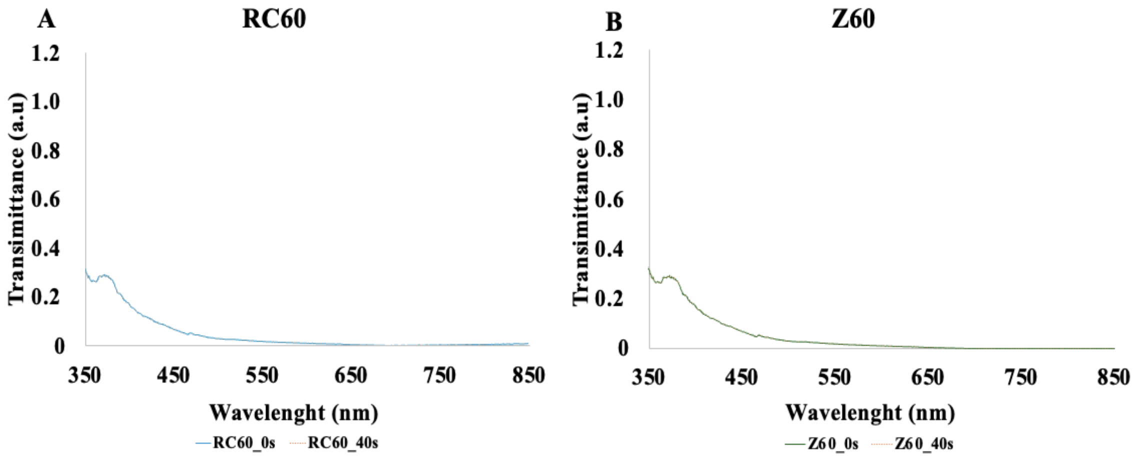


Figure 6. Transmittance (a.u) of CAD-CAM resin-matrix composites (RC60) and 3YTZP zirconia (Z60), before polymerization (0s) and after polymerization (40s) in the wavelength range from 350 up to 850 nm.

Table 2. Analysis of variance at 809 nm at wavelength for RC60 and Z60 before and after polymerization.

Group	t	df	Mean Difference	95% Confidence Interval of the difference lower	p-value
RC60	17.040	17	230.9274073 400000	202.5618946 98902	< 0.001
Z60	9.549	17	15.37870371 44167	11.83401033 8343	< 0.001

After polymerization, optical transmittance in the ultraviolet (UV) region was found to be lower than that registered in the infrared (IR) region. Spectral analysis of non-polymerized and polymerized resin-matrix composite specimens revealed that light within the visible spectrum is predominantly absorbed, whereas UV radiation is largely transmitted through the material.

The mean post-/pre-polymerization transmittance ratio (Rp/np) is evaluated between 400 and 850 nm. The results showed 1.4 times ($p < 0.001$) higher transmittance ratio for 3YTPZ ($p = 0.007$), as shown in Figure 7A, compared to the CAD-CAM resin-matrix composite under light irradiance at ~750–850 nm wavelength, Figure 7B and detailed in Table 3, compared to CAD-CAM resin-matrix composite under light irradiance at 750-850nm wavelength.

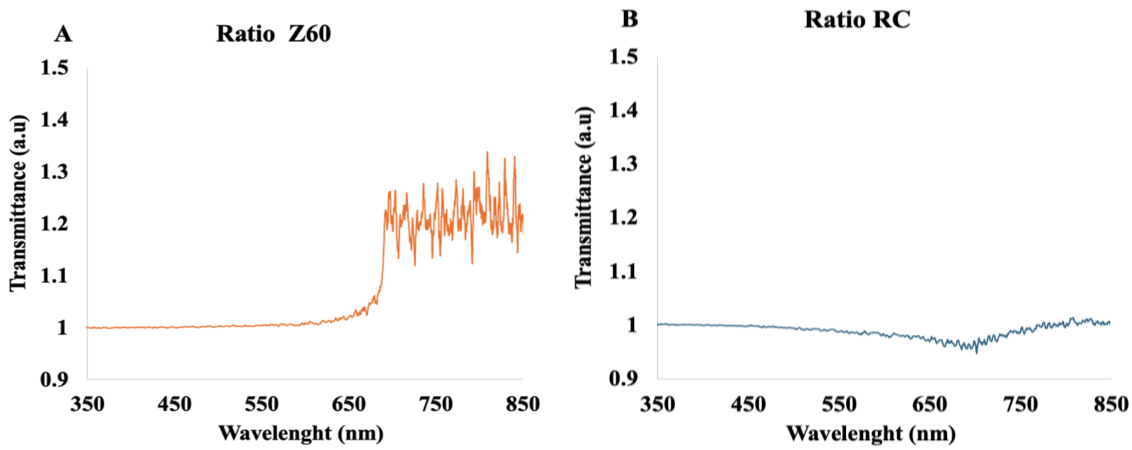


Figure 7. Transmittance ratio (a.u.) between the polymerized and non- polymerized resin-matrix composites in the wavelength range from 600 up to 850 nm at light irradiance of CAD-CAM resin-matrix composites reinforced with 89 wt% inorganic fillers and 3YTPZ zircónia.

Table 3. Analysis of variance of the p/np at 809 nm for RC60 and Z60.

Group	t	df	Mean Difference	95% Confidence Interval of the difference lower	p-value
RC60	4.457	17	53.48538239 83500	28.36693757 1044	< 0.001
Z60	3. 3.345	17	162.1382475 786666	55.45157338 5209	< 0.05

Initially, measurements were performed without the presence of a resin-matrix cement layer (designated as Z0 and RC0), serving as baseline controls. Subsequently, measurements were repeated after cementation of the samples using the 73 wt% resin-matrix cement.

Although the analysis primarily emphasized radiant power values for graphical representation, the average radiant power measurements followed a similar trend, showing a reduction after cementation. The values of radiant power were used as reference instead of irradiance, because, irradiance values are an approximated calculus of the light that reached an area of 10 mm, however, as mentioned before, the LCU used on the present study had a tip of 8 mm, and for that reason the values of radiant exposure were more accurate, Figure 8.

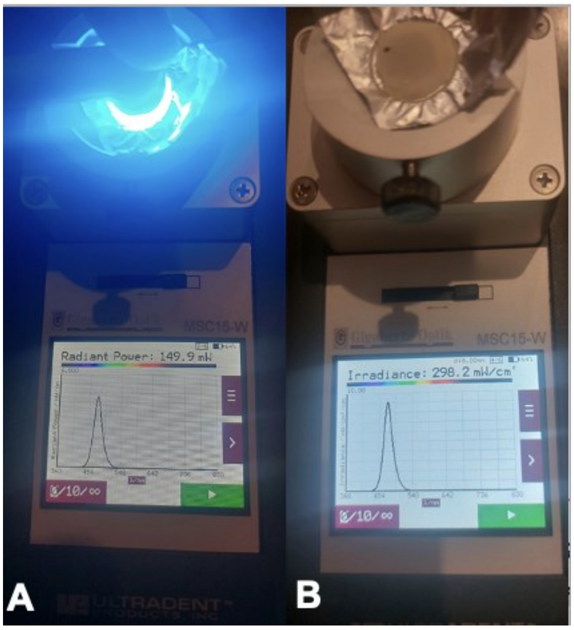


Figure 8. (A) Radiant power and (B) Irradiance measurements in MiniGig device for RC60.

The primary analysis focused on the cemented samples (Z60 and RC60 groups). For each group, three specimens were evaluated, and the mean values for both irradiance and radiant power were calculated, in triplicate. These mean values were subsequently used to generate a comparative graph, illustrating two main parameters: the mean radiant power post-cementation during light curing and the ratio of radiant power relative to the control group (Z0 or RC0).

The generated graph, Figure 9, shows that the mean radiant power decreased after cementation in both material groups (Z60 and RC60). Comparatively RC60 demonstrated lower values ($p < 0.001$) than Z60 during polymerization reaction, meaning that Z60 ($p < 0.001$) allowed that more light reached the resin-matrix cement. Also, before cementation, 3YTP zirconia allowed more passage of light when compared to 89 wt% CAD-CAM resin-matrix composite. The analysis of variance for the radiant exposure is showed on Table 4.

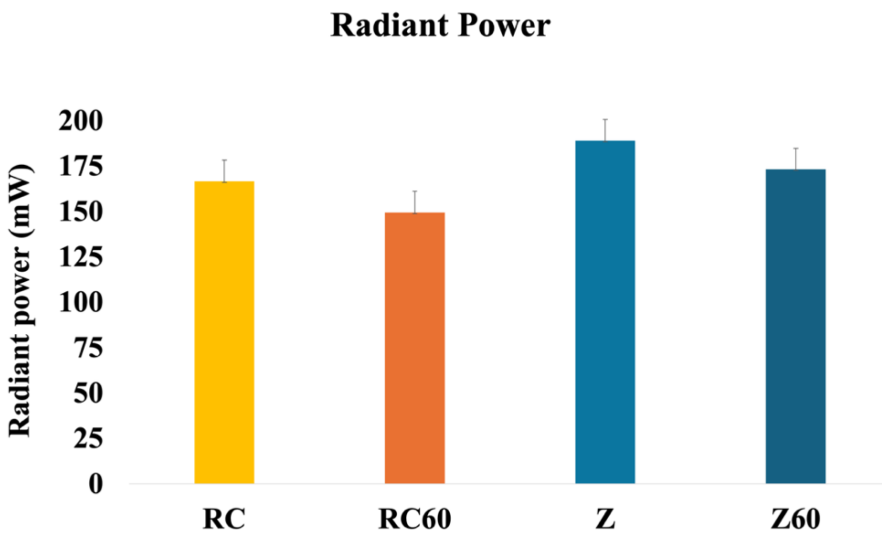


Figure 9. Radiant power values using MIniGig device of 89 wt% resin-matrix composite before cementation, 89 wt% resin-matrix composite after cementation (RC60), 3YTP zirconia before cementation (Z) and 3YTP zirconia after cementation from 360 up to 830 nm.

Table 4. Analysis of variance of RC60 and Z60.

Group	t	df	Mean Difference	95% Confidence Interval of the difference lower	p-value
RC60	68.852	17	157.9444444444445	153.104619137494	< 0.001
Z60	66.539	17	181.0277777777778	175.287754192884	< 0.001

Moreover, the ratio values, consistently lower than 1 (p=0.007), confirm that the presence of the resin-matrix cement layer significantly attenuates the transmission of light, Figure 9. The specimens Z60 revealed higher ratio values when compared to RC60 (p=0.007). The analysis of variance for the radiant exposure is showed on Table 4

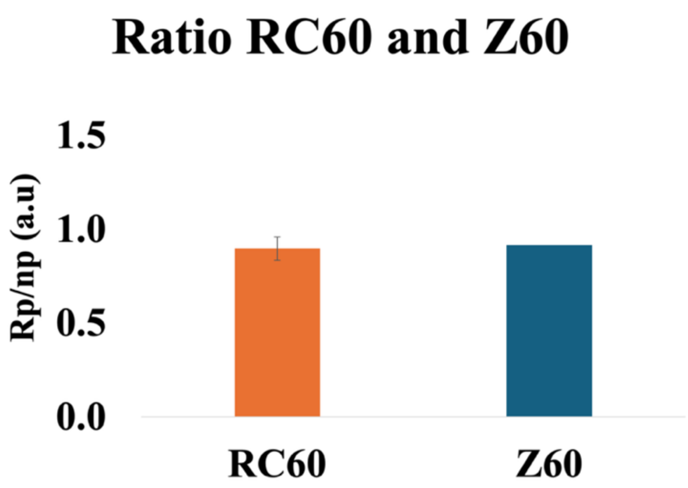


Figure 10. Ratio of the transmittance of the polymerized and non-polymerized (p/np ratio) for 89 wt% CAD-Cam resin-matrix composite and 3YTP zirconia after 40s of exposure time.

The ratio was calculated by dividing the radiant power value obtained after cementation by the corresponding initial radiant power measured without the resin-matrix cement layer. The comparison of the transmittance ratio (Rp/np) between RC60 and Z60 groups is illustrated in Figure 10 and detailed in Table 5. This approach enabled normalization of the results and facilitated the comparison of light transmission efficiency across different groups, regardless of minor variations in initial conditions.

Table 5. Analysis of variance of the ratio p/np for RC60 and Z60.

Group	t	df	Mean Difference	95% Confidence Interval of the difference lower	p-value
RC60	4.168	17	83.71512635 05556	41.33617176 8571	< 0.05
Z60	4.163	17	94.92471346 96111	46.81236386 4851	< 0.05

3.2 Optical microscopy

The microstructure of restorative interfaces is shown in Figure 11. Microscale barium-aluminum-silicate glass at around 1-6 μm and nano-scale amorphous silica fillers were detected in the microstructure of resin-matrix cement with 73 wt% in inorganic fillers in both restorative interfaces. Regarding CAD-CAM resin-matrix composite inorganics fillers were observed revealing different types of fillers and variable dimensions with micro-scale glass fillers with irregular shape and different sizes embedded within the organic matrix, showed on Figure 11A. Figure 11B, analyses the microstructure of zirconia interface revealing a polycrystalline zirconia microstructure.

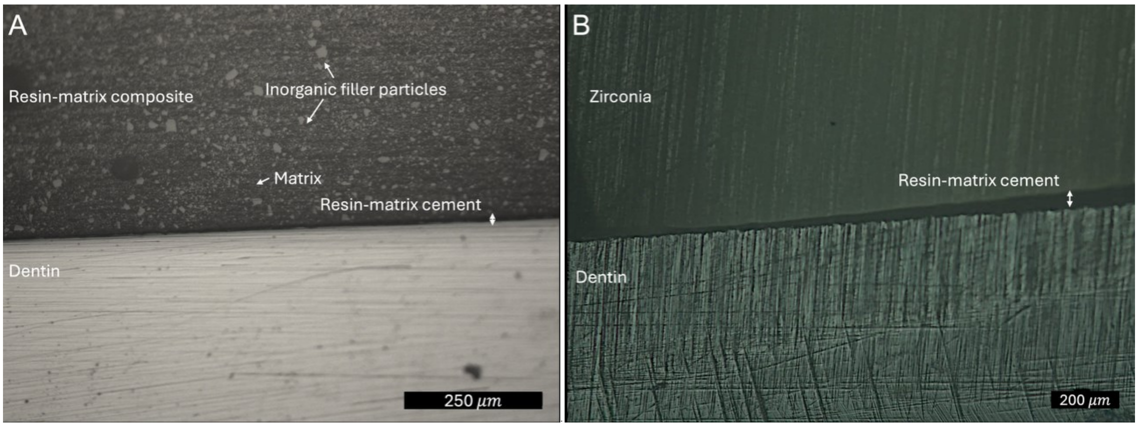


Figure 11. Optical microscopy images of restorative interfaces x 50 magnification (A) Resin-matrix composite at x 100 magnification cemented with resin-matrix cement with 73 wt% inorganic fillers. (B) 3YTZP zirconia at x 50 magnification specimens cemented with resin-matrix cement with 73 wt% inorganic fillers.

DISCUSSION

4. Discussion

In this study, two different indirect restorative materials were analyzed by spectrophotometry, also a complementary analysis using MiniGig device was performed, and the microstructure of materials was evaluated through optical microscopy analysis. Specifically, a resin-matrix composite and 3 mol% yttria-stabilized tetragonal zirconia polycrystal (3YTZP), cemented with the same resin-matrix cement under standardized thickness and loading conditions. The findings reported that both the microstructure and intrinsic opacity of the restorative materials significantly influence the amount of light that reaches the resin-matrix cement, ultimately impacting its potential degree of conversion (DC) (8). The chemical composition affected the optical transmittance trough the interfaces. Thus, the present findings rejected the null hypothesis of this study.

The initial optical transmittance tests (Figure 5), were performed directly on the CAD-CAM resin-matrix composite (89 wt%) and 3YTZP zirconia specimens without any intervening resin-matrix cement. The spectra revealed that the CAD-CAM resin-matrix composite presented slightly lower transmittance compared to the 3YTZP, across the 350 to 850 nm wavelength range. Notably, both materials showed an increase in transmittance above 600 nm up to 850 nm. The 3YTZP superior performance in light transmittance, even without cement, is supported by findings in recent articles, which attribute such behavior to optimized microstructural characteristics such as reduced grain size and elimination of light-scattering defects (36–38). Additionally, the transmittance values recorded in the present study for 3YTZP specimens fall within the range previously reported for similar thicknesses. In the study by Sulaiman et al (2015) (26), it was shown that 3YTZP zirconia with a 1.5 mm thickness presented mean transmittance values below 0.1 a.u., aligning with the low but consistent values obtained in this research. This reinforces the notion that microstructural refinement can enhance zirconia's optical behavior, even at clinically relevant thicknesses.

The resin-matrix composite, despite its high filler load, demonstrated adequate transmittance, in agreement with previous studies (8).

The optical transmittance spectra, showed in Figure 6, revealed that, prior to polymerization, all materials showed high transmittance values around 350 nm, followed by a progressive decline until approximately 650 nm, and a subsequent increase up to 850 nm. This spectral behavior is characteristic of light scattering in resin-matrix composite materials with varying sizes and refractive indices of their inorganic fillers. As described by previous studies, spectral variation in highly filled materials is attributed to the complex interaction between light absorption and scattering (3,39). Materials with a high concentration of micro- or nano-sized inorganic fillers tend to exhibit increased light scattering and absorption. The particle size, distribution, and volume fraction play pivotal roles in determining optical attenuation (39,40).

The sharp decline in optical transmittance observed below 450 nm may be attributed to the overlap between the photoinitiators absorption peaks and the limited transmission of the restorative materials in this wavelength range. In particular, CQ has its maximum absorption at approximately 468 nm. Resin-matrix composite with high filler content reduces the number of photons effectively absorbed by the initiators in this range. Non polymerized specimens showed higher UV-region transmittance, which decreased significantly above 400 nm, suggesting that visible-light-induced activation may be compromised depending on material composition and thickness (39,41,42).

Following polymerization, showed in Figure 6, the spectral trend remained, but with increased transmittance values for all materials. 3YTZ demonstrated the highest optical transmittance levels surpassing resin-matrix composite (43). Previous studies reported that zirconia's translucency is directly related to its microstructure, including smaller grain sizes and absence of opacifying pigments (1,3).

The difference in mean light transmittance values before and after polymerization was significant. The greatest variation occurred in the resin-matrix composite group. Although the resin-matrix composite group showed the greatest variation in transmittance before and after polymerization, the overall light transmission remained lower compared to the 3YTZ group. This suggests that polymerization-induced structural rearrangements in the organic matrix significantly affect its ability to transmit light, but do not necessarily result in higher light transmittance than 3YTZ. This is supported by previous studies, who reported that matrix densification post-curing reduces internal radiation absorption (8,44).

During real-time light curing, radiant power values recorded by the MiniGig device showed an initial peak followed by a rapid decline in the first few seconds and then stabilized. This behavior indicates high initial light transmission followed by increased absorption by the polymerizing matrix (45). 3YTZ again exhibited the highest radiant power values, supporting the spectrophotometric findings (44).

Although initially counterintuitive, this finding is supported by more recent studies highlighting advancements in the optical properties of certain polycrystalline ceramics, including 3YTZP. Specific formulations of zirconia, particularly those processed with fine grain control, reduced porosity and lower pigmentation, may achieve translucency levels comparable to or even exceeding those of some resin-matrix composites (36,46–48).

Despite commonly being characterized as an opaque ceramic, the 3YTZP zirconia in this study transmitted more light after cementation than the resin-matrix composite. This behavior can be attributed in part to the microstructural and its highly crystalline nature characteristics of 3YTZP, which consists of zirconium dioxide (ZrO_2) stabilized with approximately 3 mol% of yttrium oxide (Y_2O_3) along with the standardized 1.5 mm thickness may have produced a light-collimating effect. This composition preserves the material in a tetragonal crystalline phase at room temperature, conferring it high mechanical strength and fracture toughness. The microstructure is densely packed with fine grains (< 0.3 µm), which reduces light scattering and allows a certain degree of light transmission, particularly when grain boundaries and impurities are minimized during sintering. The standardized 1.5 mm thickness may also have contributed to a light-collimating effect. The results suggest that this combination of material properties and thickness favored zirconia in this context (43,44).

The light transmittance values obtained for 3YTZP at 1.5 mm thickness are particularly relevant from a clinical perspective, as this is a common application for posterior onlays. According to Hardy et al. (2018)(14), even small increases in restorative thickness, from 1.0 to 2.0 mm, can significantly reduce light transmission and the DC of underlying resin-matrix cements. Other studies showed that increasing thickness from 0.3 mm to 1.5 mm leads to a progressive decrease in the DC due to limited light penetration (1). Despite this trend, 3YTZP at 1.5 mm that was used in this study still demonstrated better performance than expected, possibly due to advances in material processing like optimized grain boundaries, absence of pores, and enhanced refractive index matching, which reduce internal scattering and enhance transmittance (44).

Modern low-pigment, ultrafine-grain zirconias can outperform resin-matrix composites in terms of translucency, particularly under collimated illumination where their homogeneous microstructure allows for more efficient light propagation with minimal diffusion (46,49). These findings highlight the importance of considering not only material type but also its thickness and fabrication parameters when evaluating optical behavior in restorative dentistry (49).

This behavior may also be interpreted through the microstructural features observed by optical microscopy. As shown in Figure 11, the resin-matrix cement presented a heterogeneous filler distribution, with micro-scale barium-aluminium-silicate glass particles (1–6 µm) and nano-scale amorphous silica particles embedded within the organic matrix. In the CAD-CAM resin-matrix composite, the inorganic phase exhibited variable morphology, with irregular-shaped glass fillers of differing sizes. Such heterogeneity and particle dispersion may have contributed to increased light scattering and reduced transmittance.

In contrast, the 3YTPZ specimens revealed a more homogeneous polycrystalline structure at the observed magnification. The uniform appearance of the zirconia interface suggests a densely packed crystal arrangement. This, combined with the intrinsic optical properties of 3YTZP zirconia processed with controlled sintering, may have favored light propagation through the material. Similar findings regarding zirconia microstructure and light behavior have been described in previous studies, reinforcing the observed differences in light transmittance between the tested materials (1,41).

The reduction in light transmittance observed after cementation confirms that the presence of the resin cement layer interferes with light propagation. The standardized 60 N load was chosen to simulate clinical pressure during luting and ensure reproducibility and uniform film thickness across all specimens. Previous studies have reported that the manual pressure exerted by clinicians ranges between 12 N and 67 N (4,50). Therefore, the use of a 60 N load in this study falls within the upper limit of the clinically observed range and was chosen to improve seating of the restoration and adaptation of the resin-matrix cement. Moreover, previous investigations have shown that increasing the cementation load leads to better marginal adaptation and improved mechanical resistance at the tooth-restoration interface (4,51). This standardized pressure helps minimize the presence of voids and ensures better adaptation between interfaces, which is critical for both mechanical integrity and optical behavior.

Resin-matrix cements possess intrinsic optical properties such as refractive index, filler content, and opacity that contribute to increased light scattering and absorption at the tooth-restoration interface. Previous studies have shown that resin-matrix cement layers can significantly affect the translucency of ceramic restorations and reduce the amount of light reaching the underlying tooth structure (27,52).

The resin-matrix cement used in this study contained 73 wt% inorganic fillers, including both micro-scale barium glass and nano-scale amorphous silica particles. This combination results in a high density of matrix–filler interfaces, which enhances internal light scattering and compromises translucency. The mismatch between the refractive indices of organic monomers and inorganic particles further contributes to light deflection and attenuation at the interface. The presence of irregularly shaped and variably sized fillers ranging from 1 to 6 µm and around 40 nm limits light propagation (8,53).

Filler characteristics such as color, particle type, refractive index mismatch, and matrix homogeneity play a critical role in determining optical behavior. Resin-matrix composites containing larger or aggregated particles exhibit increased internal light scattering, which significantly reduces their final translucency (54). In this study, the resin-matrix composite demonstrated lower light transmittance in both measurement systems after cementation, due to the high filler load (89 wt%) comprising micro-scale barium glass ceramics, zirconium silicate particles (0.5–3 µm), and nano-scale amorphous silica (~40 nm) which together create a heterogeneous internal structure with numerous interfaces that disrupt light propagation (41).

The presence of nano-fillers increases the number of interfacial boundaries within the material, promoting greater light scattering due to their proximity to the wavelength of visible light. Moreover, the use of irregular-shaped or agglomerated particles further intensifies these scattering effects. The combination of nano- and micro-fillers, although beneficial for mechanical performance, often compromises optical properties due to this cumulative internal scattering (40,55). These findings are consistent with the study Balbinot et al. (2019)(23), which demonstrated that materials containing high inorganic load, especially above 80 wt%, show a significant decrease in light transmittance due to internal scattering. In that study, the authors reported that even with a reduced thickness, composites with heavy filler loads showed substantial attenuation, especially in the visible light range. This supports the hypothesis that the high filler volume in the CAD-CAM resin-matrix composite used in the present study contributed directly to its lower transmittance performance.

These numerical findings are also consistent with prior studies. In the present investigation, 3YTZP specimens demonstrated mean transmittance values consistently below 0.1 a.u. across the spectral range (350–850 nm), both before and after cementation. These results are in line with those of Sulaiman et al. (2015)(26), who reported similar values for 1.5 mm zirconia specimens. In contrast, CAD-CAM resin-matrix composites in this study exhibited broader variation, with transmittance ranging from approximately 0.0 to 0.4 a.u., especially in the longer wavelengths post-polymerization. Despite the commonly held view that composites offer superior translucency, the dense filler load and structural heterogeneity in this CAD-CAM composite appear to have mitigated light transmission efficiency.

Furthermore, the organic matrix of the resin-matrix cement typically includes a blend of dimethacrylate monomers such as Bis-GMA, UDMA, and TEGDMA. These monomers exhibit different viscosities and refractive indices (ranging approximately from 1.46 to 1.55), contributing to optical inhomogeneity when combined with inorganic fillers whose refractive indices may range from 1.53 to 1.58. This mismatch between the organic and inorganic phases enhances light refraction and scattering at the matrix–filler interface, ultimately reducing translucency Furthermore, silanized interfaces between fillers and matrix though chemically bonded can still present discontinuities or porosities, which also interfere with the light path (42,56).

In addition to the comparison between restorative materials, this study also assessed the reliability and complementarity of two distinct optical measurement techniques: a bench-top spectrophotometer and the MiniGig radiometer. The correlation between radiant power values (MiniGig) and spectral transmittance (spectrophotometry) reinforces the methodological consistency of this study. Although the units of measurement differ, both methods demonstrated similar trends, with 3YTZ allowing greater light transmission and resin-matrix composite showing lower transmittance after polymerization (57).

The MiniGig device measured radiant power in real-time during the curing process, while the spectrophotometer assessed spectral transmittance before and after polymerization. Together, these instruments provided a more comprehensive understanding of light transmission across the restorative cement complex (57,58). To further illustrate post-polymerization behavior, Figure 10 presents the ratio of transmittance between the polymerized and non-polymerized states (p/np) for both materials. The results indicate that the 3YTZP zirconia group exhibited a higher and more stable p/np ratio across the measured spectrum, whereas the resin-matrix composite group showed greater fluctuations and overall lower values. This suggests that zirconia maintains a more consistent transmittance profile after polymerization, likely due to its highly crystalline microstructure and thermal stability. In contrast, the resin-matrix composite's polymeric matrix undergoes densification and structural rearrangement, which significantly alters its optical performance (59).

The MiniGig device proved to be a reliable tool for measuring light transmission during the photopolymerization process. Radiant power, rather than irradiance, was selected as the output metric due to discrepancies between the assumed and actual tip area of the light-curing unit (10 mm² vs. 8 mm) (58). This choice resulted in more accurate and reproducible data.

The MiniGig device effectively distinguished among the three experimental conditions evaluated in this study. First, in the control group, where light was unobstructed, the highest radiant power values were recorded. Second, when light passed through the restorative material only, a reduction in radiant power was observed due to partial attenuation by the material. Third, in the most complex configuration, where light passed through both the restorative material and the resin-matrix cement an even greater reduction in radiant power was noted, particularly in the resin-matrix composite group. This stepwise decline in light intensity demonstrates the additive effect of optical attenuation across successive layers and highlights the MiniGig's sensitivity in detecting subtle differences in light transmittance between materials and interfaces (8,60).

Within the limitations of the present study, the obtained data are bringing relevant data for the clinicians once a proper selection of materials and thickness of restorative materials provide the desirable physical properties of the restorative interfaces in the oral environment. Also, the present work analyzed two different indirect restorative materials widely used in restorative dentistry and allowed to understand the optical transmittance on both materials at a controlled cementation load. The study was also improved with the novelty of the MiniGig complementary analysis which proved to be a valid light transmittance optical instrument. Further studies must explore light transmittance with different materials and different restorative thicknesses.

The findings of this study align with and contribute to the existing literature on light transmittance in indirect restorative materials. For instance, the superior transmittance observed in 3YTZP zirconia agrees with studies by Sulaiman et al. (2015)(26) and Kim and Kim (2016)(37), which reported enhanced translucency in zirconia due to reduced pigment content and optimized grain structures. Similarly, the lower transmittance values recorded for the high-filled resin-matrix composite are consistent with previous investigations by Wang et al. (2018)(9) and Fidalgo-Pereira et al. (2023)(8), who attributed such results to increased light scattering from heterogeneous filler particle distribution. These comparative insights reinforce the notion that both material composition and microstructural organization are critical in determining optical performance and, consequently, clinical outcomes in restorative dentistry.

Despite the controlled in vitro methodology, certain limitations must be acknowledged. Firstly, the number of specimens tested was limited, which may reduce the representativeness of the results. Future research should include a larger quantity of samples to enhance statistical validity and ensure more robust conclusions. Additionally, the experimental conditions did not fully replicate the dynamic oral environment, including temperature fluctuations, the presence of saliva, and masticatory forces. Moreover, only a single material thickness (1.5 mm) and one commercial formulation per material type were evaluated, which restricts the generalizability of the findings to broader clinical applications.

CONCLUSION

5. Conclusion

Within the limitations of the present in vitro study the results demonstrated that the microstructure and intrinsic optical properties of indirect restorative materials significantly influence light transmittance and, consequently, the potential degree of conversion (DC) of underlying resin-matrix cements. By comparing CAD-CAM resin-matrix composites with 89 wt% inorganic fillers and 3 mol% yttria-stabilized tetragonal zirconia polycrystal (3YTZP), both standardized at 1.5 mm thickness and bonded with the same resin-matrix cement, it was observed that 3YTZP allowed higher light transmission across all analyses, both before and after polymerization.

These findings challenge the traditional assumption that zirconia is consistently more opaque than resin-matrix composites. Recent advances in ceramic processing particularly those involving reduced pigment content, finer grain sizes, and optimized sintering protocols, have enabled certain formulations of 3YTZP to achieve light transmittance levels equal to or greater than those of high-filled resin-matrix composites. Clinically, this implies that modern zirconia materials may not only provide superior mechanical performance but also support effective photopolymerization of dual-cure resin cements, especially when proper thicknesses and curing protocols are applied.

Spectrophotometric data and real-time light measurements using the MiniGig device consistently indicated greater optical transmittance through zirconia specimens. Microscopic evaluation further supported these findings, revealing that the composite exhibited a heterogeneous filler morphology with irregularly shaped and variably sized particles, which likely increased internal light scattering. Conversely, the zirconia specimens showed a homogenous polycrystalline structure that facilitated more efficient light propagation.

Thus, material selection in restorative dentistry should be guided not only by mechanical and esthetic requirements but also by optical behavior, which directly affects polymerization efficacy and restoration longevity. The results of this study contribute to the evolving understanding of how material composition and structure influence light transmission, highlighting the potential of contemporary zirconia as a suitable option for indirect restorations requiring both strength and sufficient light transmittance.

From a clinical standpoint, these findings suggest that zirconia onlays when restricted to 1.5 mm thickness and combined with high-performance light curing protocols can transmit sufficient light to ensure adequate polymerization of dual-cure resin cements. This is particularly relevant in posterior regions where mechanical strength is critical, and partial light access is still possible. On the other hand, CAD-CAM resin-matrix composites, while exhibiting lower light transmittance in this study, offer benefits such as better shock absorption, lower elastic modulus, and aesthetic flexibility. Their use may remain advantageous in situations where light access is not significantly compromised or when alternative curing strategies such as extended exposure or additional chemical polymerization can be employed. Therefore, material selection should be based on a balanced assessment of mechanical, optical, and clinical priorities.

These results emphasize the importance of selecting restorative materials based not only on mechanical and esthetic characteristics, but also on their optical performance, particularly in procedures involving light-cured resin cements. Adequate light transmittance is essential for achieving optimal polymerization and ensuring long-term restoration stability. Future investigations should assess the impact of varying thicknesses, additional material brands, and simulate intraoral conditions to better predict the clinical behavior of these restorative systems.

BIBLIOGRAPHY

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. 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.
3. 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.
4. 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).
5. 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.
6. Xu T, Li X, Wang H, Zheng G, Yu G, Wang H, et al. Polymerization shrinkage kinetics and degree of conversion of resin composites. J Oral Sci. 2020 Jul 1;62(3):275–80.
7. Santos M, Fidalgo-Pereira R, Torres O, Carvalho O, Henriques B, Özcan M, et al. The impact of inorganic fillers, organic content, and polymerization mode on the degree of conversion of monomers in resin-matrix cements for restorative dentistry: a scoping review. Vol. 28, Clinical Oral Investigations. Springer Science and Business Media Deutschland GmbH; 2024.
8. 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.

9. Wang R, Habib E, Zhu XX. Evaluation of the filler packing structures in dental resin composites: From theory to practice. Dental Materials. 2018 Jul 1;34(7):1014–23.
10. Pratap B, Gupta RK, Bhardwaj B, Nag M. Resin based restorative dental materials: characteristics and future perspectives. Vol. 55, Japanese Dental Science Review. Elsevier Ltd; 2019. p. 126–38.
11. Karabela MM, Sideridou ID. Synthesis and study of properties of dental resin composites with different nanosilica particles size. Dental Materials. 2011 Aug;27(8):825–35.
12. Issa Y, Watts DC, Boyd D, Price RB. Effect of curing light emission spectrum on the nanohardness and elastic modulus of two bulk-fill resin composites. Dental Materials. 2016 Apr 1;32(4):535–50.
13. Par M, Marovic D, Attin T, Tarle Z, Tauböck TT. Effect of rapid high-intensity light-curing on polymerization shrinkage properties of conventional and bulk-fill composites. J Dent. 2020 Oct 1;101.
14. 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.
15. Veneziani M. Posterior indirect adhesive restorations: updated indications and the Morphology Driven Preparation Technique [Internet]. Available from: https://www.researchgate.net/publication/317022052
16. Araoka D, Hosaka K, Nakajima M, Foxton R, Thanatvarakorn O, Prasansuttiporn T, et al. The strategies used for curing universal adhesives affect the micro-bond strength of resin cement used to lute indirect resin composites to human dentin. Dent Mater J. 2018;37(3):506–14.
17. Silva TM Da, Sales ALLS, Pucci CR, Borges AB, Torres CRG. The combined effect of food-simulating solutions, brushing and staining on color stability of composite resins. Acta Biomater Odontol Scand. 2017 Jan;3(1):1–7.
18. Sirovica S, Solheim JH, Skoda MWA, Hirschmugl CJ, Mattson EC, Aboualizadeh E, et al. Origin of micro-scale heterogeneity in polymerisation of photo-activated resin composites. Nat Commun. 2020 Dec 1;11(1).

19. He J, Garoushi S, Vallittu PK, Lassila L. Effect of low-shrinkage monomers on the physicochemical properties of experimental composite resin. Acta Biomater Odontol Scand. 2018 Jan 1;4(1):30–7.
20. de Lopes C de CA, Rodrigues RB, e Silva ALF, Júnior PCS, Soares CJ, Novais VR. Degree of conversion and mechanical properties of resin cements cured through different all-ceramic systems. Braz Dent J. 2015 Oct 1;26(5):484–9.
21. Kim M, Suh BI, Shin D, Kim KM. Comparison of the physical and mechanical properties of resin matrix with two photoinitiator systems in dental adhesives. Polymers (Basel). 2016 Jul 1;8(7).
22. De Souza GM, Braga RR, Cesar PF, Lopes GC. Correlation between clinical performance and degree of conversion of resin cements: A literature review. Journal of Applied Oral Science. 2015 Jul 1;23(4):358–68.
23. Balbinot E do CA, Pereira MFCC, Skupien JA, Balbinot CEA, da Rocha G, Vieira S. Analysis of transmittance and degree of conversion of composite resins. Microsc Res Tech. 2019 Nov 1;82(11):1953–61.
24. Harianawala HH, Kheur MG, Apte SK, Kale BB, Sethi TS, Kheur SM. Comparative analysis of transmittance for different types of commercially available zirconia and lithium disilicate materials. Journal of Advanced Prosthodontics. 2014;6(6):456–61.
25. 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.
26. Sulaiman TA, Abdulmajeed AA, Donovan TE, Ritter A V., Vallittu PK, Närhi TO, et al. Optical properties and light irradiance of monolithic zirconia at variable thicknesses. Dental Materials. 2015 Oct 1;31(10):1180–7.
27. de MENDONÇA LM, 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. Journal of Applied Oral Science. 2019;27.
28. Lopes-Rocha L, Mendes JM, Garcez J, Sá AG, Pinho T, Souza JCM, et al. The effect of different dietary and therapeutic solutions on the color stability

of resin-matrix composites used in dentistry: An in vitro study. Materials. 2021 Nov 1;14(21).

29. Li RWK, Chow TW, Matinlinna JP. Ceramic dental biomaterials and CAD/CAM technology: State of the art. Vol. 58, Journal of Prosthodontic Research. Elsevier Ltd; 2014. p. 208–16.
30. 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.
31. 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 1;30(4):360–8.
32. 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.
33. Rode KM, Kawano Y, Turbino ML. Evaluation of curing light distance on resin composite microhardness and polymerization. Oper Dent. 2007 Nov;32(6):571–8.
34. 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.
35. 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.
36. Blatz-Alvarez-compendium-APC-2016.
37. Kim HK, Kim SH. Optical properties of pre-colored dental monolithic zirconia ceramics. J Dent. 2016 Dec 1;55:75–81.
38. Shahmiri R, Standard OC, Hart JN, Sorrell CC. Optical properties of zirconia ceramics for esthetic dental restorations: A systematic review. Vol. 119, Journal of Prosthetic Dentistry. Mosby Inc.; 2018. p. 36–46.
39. dos Santos GB, Alto RVM, Filho HRS, da Silva EM, Fellows CE. Light transmission on dental resin composites. Dental Materials. 2008 May;24(5):571–6.

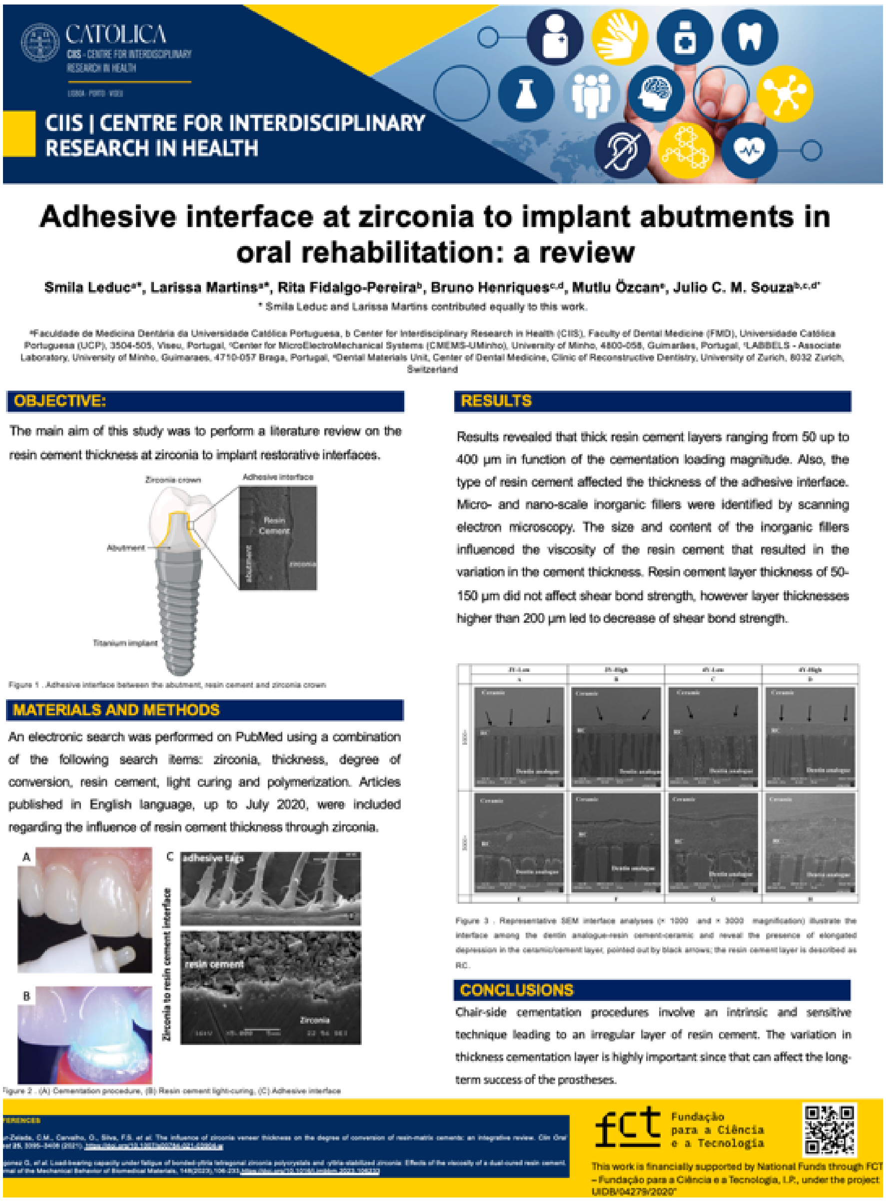
40. Souza Queiroz R, Martins De Lima P, Menezes DA, Malta P, Nara De Souza Rastelli A, Cuin A, et al. Changes on Transmittance Mode of Different Composite Resins. Vol. 12, Materials Research. 2009.
41. Pais RC, Pereira F. Light transmission through different resin-matrix composites and cements under polymerization as performed in dental practice.
42. Oivanen M, Keulemans F, Garoushi S, Vallittu PK, Lassila L. The effect of refractive index of fillers and polymer matrix on translucency and color matching of dental resin composite. Biomater Investig Dent. 2021 Jan 1;8(1):48–53.
43. Yousry M, Hammad I, Halawani M El, Aboushelib M. Translucency of recent zirconia materials and material-related variables affecting their translucency: a systematic review and meta-analysis. Vol. 24, BMC Oral Health. BioMed Central Ltd; 2024.
44. Farah RI. Dental zirconia generations: a comparative study of translucency parameters and light transmittance across varying thicknesses. Braz Dent Sci. 2024 Jul 1;27(3).
45. Par M, Repusic I, Skenderovic H, Klaric Sever E, Marovic D, Tarle Z. Real-time light transmittance monitoring for determining polymerization completeness of conventional and bulk fill dental composites. Oper Dent. 2018 Jan 1;43(1):19–31.
46. Fathy SM, Al-Zordk W, E Grawish M, V Swain M. Flexural strength and translucency characterization of aesthetic monolithic zirconia and relevance to clinical indications: A systematic review. Vol. 37, Dental Materials. Elsevier Inc.; 2021. p. 711–30.
47. Yousry M, Hammad I, Halawani M El, Aboushelib M. Translucency of recent zirconia materials and material-related variables affecting their translucency: a systematic review and meta-analysis. Vol. 24, BMC Oral Health. BioMed Central Ltd; 2024.
48. Sen N, Isler S. Microstructural, physical, and optical characterization of high-translucency zirconia ceramics.
49. Zhang F, Reveron H, Spies BC, Van Meerbeek B, Chevalier J. Trade-off between fracture resistance and translucency of zirconia and lithium-

disilicate glass ceramics for monolithic restorations. Acta Biomater. 2019 Jun 1;91:24–34.
50. s-0039-1697857.
51. Goracci C, Cury AH, Papacchini F. Microtensile bond strength and interfacial properties of self-etching and self-adhesive resin cements used to lute composite onlays under different seating forces [Internet]. Article in The Journal of Adhesive Dentistry. 2006. Available from: https://www.researchgate.net/publication/6715648
52. 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.
53. Arikawa H, Kanie T, Fujii K, Takahashi H, Ban S. Effect of Inhomogeneity of Light from Light Curing Units on the Surface Hardness of Composite Resin. Vol. 27, Dental Materials Journal. 2008.
54. Ilie N, Hickel R. Correlation between ceramics translucency and polymerization efficiency through ceramics. Dental Materials. 2008 Jul;24(7):908–14.
55. 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 1;34(2):296–305.
56. Co-Ordinates (I C. Translucency Parameter Light Transmission. Vol. 87, J Dent Res. 2008.
57. Shimokawa CAK, Harlow JE, Turbino ML, Price RB. Ability of four dental radiometers to measure the light output from nine curing lights. J Dent. 2016;54:48–55.
58. de Cássia Romano B, Soto-Montero J, Rueggeberg FA, Giannini M. Effects of extending duration of exposure to curing light and different measurement methods on depth-of-cure analyses of conventional and bulk-fill composites. Eur J Oral Sci. 2020 Aug 1;128(4):336–44.
59. Farah RI. Dental zirconia generations: a comparative study of translucency parameters and light transmittance across varying thicknesses. Braz Dent Sci. 2024 Jul 1;27(3).

60. Ueda K, Güth JF, Erdelt K, Stimmelmayr M, Kappert H, Beuer F. Light transmittance by a multi-coloured zirconia material. Dent Mater J. 2015 Apr 23;34(3):310–4.

Appendix

7. Appendix



CATOLICA
CIIS - CENTRE FOR INTERDISCIPLINARY RESEARCH IN HEALTH
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Adhesive interface at zirconia to implant abutments in oral rehabilitation: a review
Smila Leduc[a*], Larissa Martins[a*], Rita Fidalgo-Pereira[b], Bruno Henriques[c,d], Mutlu Özcan[e], Julio C. M. Souza[b,c,d]
* Smila Leduc and Larissa Martins contributed equally to this work.
[a]Faculdade de Medicina Dentária da Universidade Católica Portuguesa, b Center for Interdisciplinary Research in Health (CIIS), Faculty of Dental Medicine (FMD), Universidade Católica Portuguesa (UCP), 3504-505, Viseu, Portugal, [c]Center for MicroElectroMechanical Systems (CMEMS-UMinho), University of Minho, 4800-058, Guimarães, Portugal, [d]LABBELS - Associate Laboratory, University of Minho, Guimaraes, 4710-057 Braga, Portugal, [e]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.
Zirconia crown
Adhesive interface
Resin Cement
abutment
zirconia
Abutment
Titanium implant
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.
A
B
C
adhesive tags
resin cement
Zirconia
Zirconia to resin cement interface
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.
Ceramic
RC
Dentin analogue
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.
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