**Universidade Federal de Uberlândia**
**Faculdade de Odontologia**
**Programa de Pós-Graduação em Odontologia**

**Julia Dantas Mazão**

# Efetividade de fotoativação – Efeito da fonte de luz, da interposição de diferentes materiais indiretos CAD-CAM e brackets cerâmicos.

Tese apresentada à Faculdade de Odontologia da Universidade Federal de Uberlândia, como requisito parcial para obtenção do Título de Doutor em Odontologia na Área de Concentração de Clínica Odontológica Integrada.

Uberlândia, 22 de julho de 2022

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Banca Examinadora
Orientador: Prof. Dr. Carlos José Soares
Prof. Dra Karla Zancopé
Prof. Dr.  Hugo Lemes Carlo
Prof. Dra. Giselle Rodrigues dos Reis
Prof. Dr. Marcelo Giannini

Suplentes
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**UNIVERSIDADE FEDERAL DE UBERLÂNDIA**
Coordenação do Programa de Pós-Graduação em Odontologia
Av. Pará, 1720, Bloco 4L, Anexo B, Sala 35 - Bairro Umuarama, Uberlândia-MG, CEP 38400-902
Telefone: (34) 3225-8115/8308 - www.ppgoufu.com - copod@umuarama.ufu.br

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Guimarães Rosa

**SUMÁRIO**

# Resumo

## RESUMO

O processo de fotoativação é um passo importantes para garantir o sucesso e longevidade de procedimentos adesivos que empregam materiais resinosos e pode ser afetado por diversos fatores. A composição, espessura e cor da cerâmica, da resina indireta ou bráquete interposto. O objetivo geral deste estudo foi avaliar a influência da interposição de diferentes materiais na passagem de luz emita por fontes de luz LED mono e multiespectros. Este estudo foi dividido em 3 capítulos de acordo com cada objetivo específico. **Capítulo 1)** Avaliar o efeito da espessura da cerâmica de dissilicato de lítio na transmissão de luz pela cerâmica e o grau de conversão, a Dureza Knoop e o modulo de elasticidade de 4 materiais de cimentação resinosos com diferentes fotoiniciadores. **Capítulo 2)** Avaliar a potência radiante(mW), irradiância (mW/cm$^{2),}$ espectro de emissão (mW/cm$^2$/nm) e o perfil de feixe de diferentes LED's na passagem de luz por diferentes espessuras e tons de compósitos vitrocerâmicos usinados no sistema CAD-CAM. **Capítulo 3)** Avaliar a passagem da luz por 5 braquetes cerâmicos mono e policristalinos em associação com 3 fontes de luz, sendo duas monos e uma multi espectro. Os métodos experimentais utilizados foram: microdureza, grau de conversão, módulo de elasticidade, potência radiante, espectro de emissão, irradiância e perfil de feixe da luz. Os resultados encontrados mostram que: 1) O aumento da espessura da cerâmica reduziu significativamente e exponencialmente a irradiância. Esta redução foi mais nítida nos comprimentos da luz de onda mais curtos (violeta), com diminuição de 82% quando a cerâmica apresenta 1 mm de espessura. O aumento da espessura da cerâmica não afetou o grau de conversão, independente dos fotoiniciadores utilizados nos materiais de cimentação testados. A posição dos LEDs violeta e azul no corpo da fonte de luz não influenciou a dureza Knoop ou o módulo de elasticidade em nenhuma das resinas testadas. 2) A espessura do compósito vitrocerâmicos resultou em efeito significativo na redução potência radiante e irradiância para todos os LEDs testados. Resina CAD-CAM na cor A3,5 demosntrou maior atenuação na transmissão de luz que as cores Bleach ou A2. 3) O tipo de LED influencia a dispersão da luz através do braquete. A luz violeta passada pelo braquete é significativamente mais atenuada que a luz azul. A composição do braquete afeta a transmissão da luz violeta e azul. Pode-se concluir que a irradiância e potência do LED sofrem influência da espessura, composição e tom do material. A luz violeta sofre mais dispersão que a luz azul, em maiores espessuras independente da condição experimental testada.

**Palavras chaves**: LED, fotopolimerizador, fotoiniciador, cimento resinoso, bráquetes cerâmicos, espessura da restauração

# Abstract

**ABSTRACT**

The light activation process is one of the most important procedures to ensure the success and longevity of resin materials. The polymerization activated by light can be affected by several factors, such as the composition, thickness, and color of the ceramic, indirect composite, or bracket interposed. The general objective of this study was to evaluate the influence of the interposition of different materials on the light transmission through when emitted by mono and multi-peak LED LCUs. This study was divided into 3 chapters according to each specific objective. **Chapter 1)** To evaluate the effect of lithium disilicate ceramic thickness on ceramic light transmission and the degree of conversion, Knoop Hardness, and modulus of elasticity of 4 resin cementation materials with different photoinitiators. **Chapter 2)** Evaluate the radiant power (mW), irradiance (mW/cm$^2$), emission spectrum (mW/cm$^2$/nm) and the beam profile of different LEDs in the passage of light through different thicknesses and shades of CAD-CAM glass-ceramic composites. **Chapter 3)** Evaluate the light scattering by 5 different ceramic mono and policristaline brackets with 3 light sources, two mono-peak, and one multi-peak. The experimental methods used were microhardness, degree of conversion, elasticity modulus, radiant power, emission spectrum, irradiance and light beam profile. The results found showed that: 1) Increasing the ceramic thickness greatly and exponentially reduced the irradiance. This reduction was most pronounced at the shorter (violet) wavelengths of light, with an 82% decrease when the ceramic was 1 mm thick. The increase in ceramic thickness did not affect the degree of conversion, regardless of the photoinitiators used in the cementing materials tested. The position of the violet and blue LEDs within the LCU body did not influence the Knoop hardness or modulus of elasticity in any of the tested resins. 2) The thickness of the composite had a significant effect on the radiant power and irradiance for all LEDs tested; The A3.5 shade had a greater influence on light transmission than the Bleach or A2 shades. 3) The type of LED influences the light dispersion through the bracket. Violet light scatters more than blue light across the bracket. The bracket composition affects the transmission of violet and blue light. It can be concluded that the irradiance and power of the LED are influenced by the thickness, composition, and color of the material. Violet light scatters more than blue light at greater thicknesses.

**Keywords:** Light-curing unit, photoinitiator, resin cement, ceramic brackets, ceramic thickness

# Introdução
# E Referencial Teórico

# 1. INTRODUÇÃO E REFERENCIAL TEÓRICO

O processo de fotoativação é um dos passos mais importantes para garantir o sucesso e a longevidade de materiais resinosos. (Price *et al.,* 2015) Embora muitas vezes, seja um passo que não se é dado a importância devida. (Price *et al.,* 2020) Diversos fatores, como a posição do operador, o tipo, espessura e a opacidade do material, a cor, a barreira de proteção usada podem interferir na irradiância e luz transmitida da fonte de luz, interferindo diretamente no sucesso da conversão de monômeros em polímeros. (Soares *et al.,* 2017; Soares *et al.,* 2017; Delgado *et al.,* 2019; Borges *et al.,* 2021)

A fotoativação de materiais resinosos foi um avanço para a odontologia estética e restauradora. (Rueggeberg *et al.,* 2011; Soares *et al.,* 2017). As fontes de luz LEDs, caracterizada pela luz emitida por diodo, foi proposta como fonte de luz viável para fotoativação de materiais resinosos.(Shortall, 2016) Em relação as fontes de luz halógenas, os aparelhos à base de LEDs apresentam vantagens, como: durabilidade de aproximadamente 10.000 horas, ausência de filtros, não necessitam de sistema de refrigeração, são mais silenciosos, possuem maior seletividade de luz, requerem menor consumo de energia e, portanto, geram menos calor.(Shortall, 2016)

São classificados em primeira, segunda e terceira geração. (Rueggeberg, 2011) As fontes de luz LEDs de terceira geração surgiram para suprir a necessidade de inserir diferentes comprimentos de onda, com picos na luz violeta, com a proposta de fotoativar materiais resinosos que têm em sua composição fotoiniciadores alternativos, diferentes da canforoquinona. (Sampaio *et al.,* 2017) O fotoiniciador mais comumente usado em materiais odontológicos à base de resina é a canforoquinona. (de Oliveira *et al.,* 2016). Como um fotoiniciador Norrish tipo II, a canforoquinona precisa de coiniciador, como aminas terciárias, para reagir e criar radicais livres que são responsáveis por iniciar o processo polimerização. (Favarao *et al.,* 2021) Como moléculas altamente reativas, as aminas oxidam, produzindo um efeito amarelado no material resinoso a longo prazo. (Righi *et al.,* 2018) Por outro lado, os fotoiniciadores Norrish tipo I não requerem coiniciador à base de amina para gerar radicais livres. (Schneider *et al.,* 2020) O óxido de fosfina (TPO) e o fotoiniciador à base de germânio, comercialmente conhecido como Ivocerin, podem substituir a canforoquinona em materiais resinosos. Como resultado, eles reduziriam o amarelamento a longo prazo. (Delgado *et al.,* 2019) Com a tendência dos procedimentos de clareamento resultando em dentes claros, novos materiais cimentantes com estes fotoiniciadores passaram a ser cada vez mais utilizados na prática clínica. (Shin *et al.,* 2009)

Os fotoiniciadores Norrish tipo I absorvem principalmente a luz no espectro violeta, (410 nm) (de Oliveira *et al.,* 2016) e, portanto, questionou-se se a eficiência de cura de cimentos à base de resina "livres de aminas" poderia ser afetada com o uso de LEDs que possuíam só a luz azul. (Silveira *et al.,* 2016) Dessa forma, as fontes de luz de multiespectro, vêm ganhando popularidade alegando resolver este propósito por incluir também a luz violeta. (Rueggeberg *et al.,* 2011)

Os aparelhos de LED são utilizados tanto para fotoativar resinas compostas, em restaurações diretas, quanto para fotoativar materiais de cimentação, em restaurações indiretas ou na ortodontia. (Almeida *et al.,* 2018, Shimokawa *et al.,* 2020; Butterhof *et al.,* 2021) Ao se realizar a fotoativação de um compósito, deve-se levar em conta que a luz é atenuada, ao se difundir por diferentes materiais, como as cerâmicas, resinas indiretas ou braquetes cerâmicos ortodônticos. (Arana *et al.,* 2021; Borges *et al.,* 2021)

A intensidade, comprimento de onda e homogeneidade da luz emitida pela fonte de luz LED são determinantes para atingir o grau adequado de conversão e propriedades mecânicas do material de cimentação (Al Shaafi *et al.,* 2014; Sampaio *et al.,* 2017). A irradiância transmitida através do material do qual a luz está passando atenua exponencialmente seguindo a lei de Beer-Lambert. Esta lei relaciona a atenuação da luz com as propriedades do material. (Watts *et al.,* 1994) Por isso, fornecer a exposição de luz correta depende não apenas do tempo de exposição adequado, de acordo com a irradiância da fonte de luz, mas também da irradiância compensatória perdida.(Delgado *et al.,* 2019; Blunck, *et al.,* 2020) Essa perda de irradiância resulta da interposição do material a qual a luz precisa passar para atingir o material a ser fotoativado.(Pishevar *et al.,* 2019) Além disso, sua composição também irá interferir.(Aldossary *et al.,* 2018) A estrutura cristalina do material cerâmico, o tamanho dos cristais, defeitos e porosidades intrínsecas do material, espessura e tonalidade de cor também interferem na transmissão da luz. (Arrais *et al.,* 2014)

Dentro desse contexto, é importante entender o conceito de irradiância que é definida como o fluxo de energia radiante que incide sobre uma superfície, por unidade de área. (Price *et al.,* 2015) Levar somente esse valor em consideração na escolha de uma fonte de luz pode ser perigoso, visto que algumas empresas diminuem o tamanho da ponta para divulgarem um valor de irradiância aceitável. (Soares *et al.,* 2017) Outro fator que deve ser considerado é a homogeneidade da luz, que em algumas fontes de luz se localiza com maior intensidade no centro, e não em toda área da ponta ativa do aparelho. (Price *et al.,* 2015)

A escolha dos cimentos resinosos também é de extrema importância para o sucesso de restaurações indiretas. (Turut *et al.,* 2013) Atualmente no mercado, podem ser encontrados cimentos de presa química, dual ou fotoativado. (Soares *et al.,* 2016) Para cimentação de laminados ou brackets cerâmicos, os cimentos fotoativados têm sido o mais indicado. (Eliades *et al.,* 2006, do Nascimento *et al.,* 2017) No entanto, outros materiais, como resina flow ou resina termoaquecidas também podem ser utilizados. (Braganca *et al.,* 2020) A razão para escolha de cimentos fotoativados é que eles são mais estáveis quanto a cor, e permitem tempo de trabalho mais controlável, quando comparados aos cimentos resinosos químicos ou duais. (Faria-e-Silva*et al.,* 2017) Entretanto, para atingir as propriedades mecânicas desejadas destes materiais de cimentação, é necessária fotoativação adequada. (Haenel *et al.,* 2015)

Algumas metodologias de avaliação da fotoativação são encontradas na literatura, tanto para avaliar a qualidade do cimento resinoso após a fotoativação (grau de conversão, microdureza), (Calheiros *et al.,* 2008; Moreno *et al.,* 2018; Bragança *et al.,* 2020; Liporoni *et al.,* 2020) quanto para avaliar a qualidade e quantidade de luz emitida e transmitida no momento da fotoativação, bem como a homogeneidade do feixe de luz. (Price *et al.,* 2014, Michaud *et al.,* 2014) A caracterização do perfil de feixe de luz é importante para entendermos o comportamento dessa fonte de luz. (Price *et al.,* 2015)

Parece oportuno avaliar por meio da conjunção de metodologias a performance de luz emitida por diferentes fontes de luz e o efeito de atenuação da luz por materiais cerâmicos, resinosos CAD-CAM e por braquetes cerâmicos de diferentes composições.

# Objetivos

## 2. OBJETIVOS

### 2.1 Objetivo Geral

O objetivo geral deste estudo foi avaliar a influência da interposição de diferentes materiais na passagem de luz emitida por fonte de luz LED’s de mono e multiespectro.

### 2.2 Objetivos Específicos

**Capítulo 1 -** *Effect of the ceramic thickness on the light attenuation, degreeof conversion, Knoop hardness, and elastic modulus of four luting resins*

Avaliar o efeito da espessura da cerâmica de dissilicato de lítio na transmissão de luz pela cerâmica e o grau de conversão, a Dureza Knoop e o modulo de elasticidade de 4 materiais de cimentação resinosos com diferentes fotoiniciadores.

**Objetivo específico 2**

Capítulo 2 - *Effect of different thicknesses and shades of a CAD/CAM resin composite on the light transmission from different curing lights*

Determinar a potência (mW), espectro de emissão (mW/cm²/nm) e perfil de feixe de diferentes fontes de luz através de várias espessuras e tonalidades de resina vitrocerâmica CAD-CAM.

**Objetivo específico 3**

Capítulo 3 – *Effect of different thicknesses and shades of a CAD/CAM resin composite on the light transmission from different curing lights*

O objetivo deste estudo foi avaliar o espalhamento da luz por 5 diferentes braquetes cerâmicos com 3 fontes de luz, sendo duas *mono-peak* e uma *multi-peak*.

# Capítulos

# Capítulos

## 3.1 CAPÍTULO 1

**Effect of the ceramic thickness on the light attenuation, degree of conversion, Knoop hardness, and elastic modulus of four luting resins**

Artigo aceito para publicação no periódico **Operative Dentistry**

**Effect of the ceramic thickness on the light attenuation, degree of conversion, Knoop hardness, and elastic modulus of four luting resins**

Julia Dantas Mazão[1], Stella Sueli Lourenço Braga[2], Gabriel Felipe de Bragança[3], Karla Zancopé[4], Richard Bengt Price[5], Carlos José Soares[6]

[1] DDS, MSc, PhD student, Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID:0000-0002-1102-672X, julia_mazao@hotmail.com

[2] DDS, MSc, PhD student, Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: 0000-0002-6883-4648 stellabraga2@hotmail.com

[3] DDS, MSc, PhD student, Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: 0000-0002-5082-4919, gabriel.braganca@hotmail.com

[4] DDS, MSc, PhD, Professor and Occlusion, Fixed Prosthodontic and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: **Erro! A referência de hiperlink não é válida.**, karlazancope@gmail.com

[5] DDS, MS, PhD, Professor Department of Dental Clinical Sciences, Dalhousie University, Halifax, Nova Scotia, Canada, ORCID: 0000-0001-6479-1436, richard.price@dal.ca

[6] DDS, MSc, PhD, Professor and Chair Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: 0000-0002-8830-605X, carlosjsoares@ufu.br

**ABSTRACT**

**OBJECTIVES:** This study evaluated the influence of the thickness of disilicate ceramic on the light attenuation (mW/cm$^2$), degree of conversion (DC, %), Knoop hardness (KH, N/mm$^2$) and the elastic modulus (E, MPa) of four luting resins.

**METHODS:** Three resin cements: RV, RelyX Veneer (3M Oral Care, St Paul, MN, USA); AC, Allcem Veneer APS (FGM, Joinville, SC, Brazil); VE, Variolink Esthetic LC (Ivoclar Vivadent, Schaan, Liechtenstein) and one flowable resin composite TF, Tetric N-Flow (Ivoclar Vivadent, Schaan, Liechtenstein) were all photocured for 20s. The irradiance (mW/cm$^2$) and emission spectrum (mW/cm$^2$/nm) from a broad-spectrum LED light unit (Bluephase G2, Ivoclar Vivadent, Schaan, Liechtenstein) were measured directly over the luting material (control) and through 0.3, 0.7 and 1.0 mm thick lithium disilicate discs (e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein). The effect of the ceramic thickness on the DC, KH and E was compared.

**RESULTS:** The curing light delivered 26.1 J/cm$^2$ to the surface and 6.2 J/cm$^2$ through the 1.0 mm thick ceramic. The irradiance beam profile showed that the distribution of violet and blue light across the light tip of the LCU was relatively homogeneous, but there was less light in the violet range compared to the blue range. The irradiance and spectral radiant power decreased significantly as the ceramic thicknesses increased ($P < 0.001$). The KH and E had a significant effect for the various resin luting materials ($P < 0.001$). The RV resin cement had the greatest KH and E values, and VE had the lowest. Ceramic thickness had no significant effect ($P = 0.213$) on KH and E and there was no interaction between the different ceramic thicknesses and the resin luting materials ($P = 0.151$). The KH and E were also not influenced by the location where these measurements were made across the specimens ($P= 0.165$). No significant reduction of the DC was observed as the ceramic thickness increased ($P = 0.311$).

**CONCLUSION:** Increasing the ceramic thickness greatly and exponentially reduced the irradiance. This reduction was more pronounced at the shorter wavelengths (violet) of light, with an 82% decrease when the ceramic was 1mm-thick. Increasing the ceramic thickness did not affect the DC at the top of the resin, irrespective of photoinitiators used in the resins tested. The position of the violet and blue LEDs within the body of the LCU did not influence Knoop Hardness or elastic modulus in any of the resins tested. The Knoop hardness and elastic modulus of VE were significantly lower than the other 3 luting materials tested.

**Keywords**: ceramic thickness, resin cements, luting materials, light-curing unit, photoinitiator.

**Clinical relevance**

Increasing the ceramic thickness reduced the amount of light received by the resins but had no effect on their mechanical properties provided that 6.2 J/cm2. The Knoop Hardness and Elastic modulus of Variolink Esthetic LC were significantly lower than the other tested materials.

## INTRODUCTION

Ceramic veneers cemented with light-activated resin-based materials have been widely used as aesthetic and functional conservative treatment due to their good mechanical and optical properties.[1] The longevity of these ceramic veneers is dependent on several factors, such as the light emitted by the light-curing units (LCU), the thickness of the ceramic, and the material used for cementation.[2,3] Light cured resin-based cement materials are commonly used for cementing ceramics veneers.[1,4-6] However, other materials such as flowable resins have also been used.[7] The use of light-cured resin composites is based on the premise that the ceramic will allow sufficient light to be transmitted through to the resin material.[8] The reason for choosing light-activated resin materials is because they are more color stable and offer a more controllable working time compared to dual or chemically cured resins.[2,9] Adequate photoactivation is required to achieve the desired mechanical properties of the resin luting materials.[10] The irradiance, wavelength, exposure time, and radiant exposure can all affect the degree of conversion and mechanical properties of the resin luting materials.[8] Some materials require the LCU to deliver shorter wavelengths of light (violet) to activate the photoinitiators used in these resins.[11,12]

The concept of minimally invasive dentistry for ceramic veneers is still not well defined,[13] and the ceramic can range in thickness.[14] When the ceramic is greater than 1.2 mm thick, the amount of light attenuation through the ceramic can influence its mechanical and clinical performance if an insufficient radiant exposure is delivered.[15,16] The thickness, composition, and shade of the ceramic can reduce the transmission of light through the ceramic and thus the radiant exposure. This may then affect the degree of conversion and mechanical properties of the luting material.[16,17] The homogeneity of the light source can also affect these properties.[17]

Over time, resins that use high concentrations of camphorquinone (CQ) tend to turn yellow due to the continued activation of their tertiary amines.[16] In an attempt to improve color stability, new resin luting materials have been introduced that have less CQ and include alternative photoinitiators such as trimethylbenzoyl-diphenylphosphine oxide (TPO), or Bis-acylphosphine oxide (BAPO). These initiators require light in the violet range (~410 nm) compared to resins that use only CQ which require a different wavelength of blue light (around 468–470 nm).[18] Unfortunately, LED emitters cannot provide a broad spectrum of light from 400 to 500 nm. Instead, their output is limited to a ± 25 nm range that is centered around a peak wavelength. As a result, broad-spectrum multipeak LCUs must use a combination of several different types of LED emitters to emit both the violet and blue light spectra.[3] However, it is not clear if there is any interaction between the light emitted in different spectral ranges from the multipeak LCU and the ceramic thickness, or if there is any effect on the properties of the photocured resin.[8]

Therefore, this study evaluated the effect the thickness of lithium disilicate ceramic has on the light transmission through the ceramic and on the degree of conversion, Knoop hardness, and elastic modulus of resin luting materials that use different photoinitiators. The null hypotheses were:

1) the ceramic thickness would have the same effect on the attenuation of the violet and the blue light from a multipeak LCU,

2) the ceramic thickness would have no effect on the degree of conversion of the resins,

3) the ceramic thickness and the location of the LED emitters in the body of the LCU would not influence the Knoop hardness and elastic modulus of the resins.

## METHODS AND MATERIALS

### Study design

Translucent or neutral shades of four light-activated resins were used in this study. Three were resin cements: RelyX Veneer (3M Oral Care, St Paul, MN, USA), Allcem Veneer APS (FGM, Joinville, SC, Brazil), Variolink Esthetic LC (Ivoclar Vivadent, Schaan, Liechtenstein), and one was a flowable resin composite Tetric N-Flow (Ivoclar Vivadent, Schaan, Liechtenstein). The information provided by the manufacturers of all these materials is listed in Table 1. Lithium disilicate glass-ceramic discs (IPS e.max CAD - Ivoclar Vivadent, Schaan, Liechtenstein) that were 0.3 mm, 0.7 mm and 1.0 mm thick were made (n = 5). The CAD/CAM block HT – A1 was glued to an acrylic plate with cyanoacrylate glue (Super Bonder, Loctite, Dusseldorf, Germany) and sticky wax

(Asfer, São Caetano do Sul, SP, Brazil). The ceramic block was cut using 0.4 mm thick double-sided diamond discs (Odeme Dental Research, Joaçaba, SC, Brazil) using a precision cutter (IsoMet 1000, Buehler, Il, USA) at 225 rpm under a 150g load with copious water irrigation. The cut samples were then crystallized (Programat P310, Ivoclar Vivadent, Schaan, Liechtenstein), using the P91 program. This furnace reaches a maximum temperature of 845°C, and then stabilizes for a period of 7 minutes, after which it starts to cool slowly to prevent thermal shock. The ceramic thickness was confirmed after crystallization.

**Characterization of Light Curing Unit (LCU)**

The total radiant power (mW), radiant emittance ($mW/cm^2$), emission spectrum ($mW/cm^2/nm$), irradiance ($mW/cm^2$) and light beam profile from the Bluephase G2 (Ivoclar Vivadent, Schaan, Liechtenstein) were analyzed. Five measurements of the total radiant power (mW) emitted between 350 and 550 nm and spectral radiant power (mW/nm) from Bluephase G2 and through the ceramic were accomplished using an integrating sphere (ISP-50-8-I, Ocean Insight Inc., Orlando, FL, USA) attached using a fiber-optic spectrometer (Flame, Ocean Insight Inc., Orlando, FL, USA). A radiometric calibration lamp (HL-3 plus, Ocean Insight Inc., Orlando, FL, USA) was used to calibrate the system before the measurements were made. When measuring the output from the LCU only, the tip of the LCU was positioned 0-mm from the 12.5 mm aperture into the sphere, and all the light emitted from the LCU was captured by the integrating sphere. In addition, the light transmission through 0.3, 0.7, and 1.0 mm ceramic thicknesses was accomplished positioning the LCU tip 0-mm from the 9-mm aperture into the sphere corresponding to the matrix dimensions used in the study.

The radiant power data from the Bluephase G2 were analyzed in these ranges (350 – 550 nm), violet light (350 – 430 nm), and blue light (430 – 550 nm). The LCU tip internal and external diameters were measured using a digital caliper (Mitutoyo, Tokyo, Japan). The tip area was calculated from the inner diameter of the light tip. The mean radiant exitance (tip irradiance value) for the LCU was calculated as the quotient of the average of the 5 radiant power values and the internal optical area of the Bluephase G2 tip. This result provided the averaged single tip irradiance value commonly reported by manufacturers and used in ISO 10650.[19]

The light beam profile from the LCU was examined using a laser beam profiler (Ophir-Spiricon, Logan, UT, USA). This device uses a digital camera positioned at a fixed distance from a 60-degree holographic diffuser screen (Edmund Optics, Barrington, NJ, USA). Two blue filters (HOYA UV-VIS colored glass bandpass filter, Edmund Optics, Barrington, NJ, USA) and one neutral density filter (5.0 OD reflective neutral density filter, Andover Corporation, Salem, NH, USA) were used to attenuate and flatten the spectral response of the camera. The Bluephase G2 was mounted in a fixed orientation and positioned 0 mm distance from the imaging screen or the ceramic discs, facing the camera. To evaluate the distribution of just the violet and the blue wavelength regions of light, the beam profiles were also recorded through a 400 nm or 460 nm narrow bandpass filter (Edmund Optics, Barrington, NJ, USA) that had a full width half maximum range of 10 nm. Thus, the camera captured all the images at the same distance, position, and exposure time, making them comparable. The three-dimensional images were analyzed using the beam analyzer software (BeamGage Professional version 6.14, Ophir-Spiricon, Logan, UT, USA).

**Degree of Conversion (DC)**

To prepare the resin samples, a 0.5 mm thick circular Teflon matrix that had a 5 mm diameter circular hole was placed over a mylar strip. This matrix was filled with resin, and another mylar strip was placed on top. The tip of the light source was then placed in contact with the surface of the strip. A 20 s exposure time was used for each resin cement (Table 1) through the different ceramic thicknesses and the specimens were stored dry in the dark at 25°C for 24 h.

The degree of conversion (DC, %; n = 5) was measured 24 h after light curing at the top surface of the luting materials using attenuated total reflectance/Fourier transform infrared spectroscopy (ATR/FTIR, Vertex 70, Bruker, Ettlingen, Baden-Württemberg, Germany). The post-curing spectrum was acquired at the top of the resin samples that were 0.5 mm thick after they had been stored dry at 25° C for 24 h. All the data were collected at 25°C ± 1°C and 60 ± 5% humidity conditions, shielded from ambient and room light. To obtain a reference value, a baseline measurement of each uncured (U) luting material was obtained once, by scanning the specimens 32 times over a range from 400 $cm^{-1}$ to 4000 $cm^{-1}$ with a resolution of 4 $cm^{-1}$ wavenumbers. The DC was calculated from the ratio of the area of aliphatic (1638 $cm^{-1}$) and aromatic (1608 $cm^{-1}$) curves of cured (C) and uncured (U) resin specimens. The standard formula used to calculate the degree of conversion was DC (%) = (1 - C/U) x 100.[20]

**Knoop Microhardness Test (KH) and Elasticity Modulus (E)**

The surface hardness was measured as soon as possible after 24 h at the top surface of the resin specimens using Knoop microhardness (KH, $N/mm^2$; n = 5) (Future-Tech Corp FM-700, Tokyo, Japan). The resin cement matrices were positioned on the microhardness tester, and 5 measurements were made using a 50 g indentation load applied for 15s in five different positions in each quadrant and at the center of the 5.0 mm diameter sample (Figure 1). The mean value of each quadrant was calculated and used for data analysis.

The Knoop indentations were also used to determine the elastic modulus (E).[21] The decrease in the length of the indentation diagonals caused by the elastic recovery of a material is related to the hardness/ elastic modulus ratio (H/E) according to the following empirical relationship: b'/a' = b/aea1 (H/E), where b/a is the ratio of the diagonal dimensions a and b in the fully loaded state, given by a constant 0.140647, b'/a' is the ratio of the altered dimensions when fully recovered, and a1 = 0.45 is a proportionality constant. The indentation modulus, comparable to the material's E, was calculated from the slope of the tangent of the indentation depth curve at the maximum force.[21,22]

**Statistical Analysis**

Irradiance, DC and KH data were analyzed for normal distribution and homoscedasticity using the Shapiro-Wilk and Levene's tests. Two-way ANOVA was used to compare Irradiance and DC data regarding the main factors: ceramic thickness (4) and light-cured resin-based material (4). The effect of the location of KH measurement was checked by using two-way repeated measurement for the light-curing protocol (4), light-cured resin-based material (4), and the measurement positions (5). Multiple comparisons were made using Tukey's post hoc test. All tests used a significance level of α = 0.05, and all analyses were performed using Sigma Plot 13.1 (Systat Software Inc, San Jose, CA, USA). The emission spectra (nm/mW/$cm^2$) and beam were reported descriptively.

## RESULTS

The mean and standard deviation of the irradiance transmitted through the three different thicknesses of ceramic are reported in Table 1. The irradiance decreased rapidly and exponentially ($R^2$= 0.92) as the thickness increased (Figure 2). However, the resin received at least 6.2 J/$cm^2$ (Table 2) even through 1.0 mm of ceramic. Two-way ANOVA showed a significant effect for ceramic thickness ($P < 0.001$); however, no significant effect was found for the resin luting materials ($P = 0.341$), and there was no interaction between ceramic thicknesses and resin luting materials ($P = 0.422$).

The radiant power and the emission spectra curves from the Bluephase G2 without the ceramic (control), through 0.3, 0.7 and 1.0 mm of ceramic are shown in Figure 3. Bluephase G2 beam profiles, tip diameter and average radiant output (tip irradiance in mW / cm2), distribution across the non-ceramic light tip (control) and across 0.3, 0.7 and 1.0 mm of ceramic are reported in Figure 4. Increasing the ceramic thickness exponentially reduced the amount of light transmitted through the ceramic. This reduction in light transmission was greater in the violet region (82% at 1 mm thickness) than in the blue region (76% at 1 mm thickness) of light (Table 2 and Figure 2).

The mean and standard deviation of the degree of conversion at the top of the resin luting materials activated through the different thicknesses of ceramic are shown in Table 3. Although the DC decreased as the ceramic thickness decreased, this reduction was not significant ($P = 0.311$). The choice of resin-based material had no significant effect ($P = 0.278$), and there was no interaction between the ceramic thickness and the type of resin material. ($P = 0.408$).

The mean and standard deviation of the Knoop hardness at the top of the resins photocured through the different ceramic thicknesses are shown in Figure 5. The two-way repeated-measures ANOVA showed a significant effect for the various resin luting materials ($P < 0.001$). However, the ceramic thickness had no significant effect (P = 0.213), and there was no interaction between the different ceramic thicknesses and the resin luting materials (P = 0.151). The location of the LED light emitters in the body of the LCU had no significant effect on the results (P = 0.165). The RV resin luting material had significantly higher KH values than AC and TF; the VE had the lowest KH value, irrespective of the measurement location.

The mean and standard deviation of the elastic modulus of the resins activated through the different ceramic thicknesses are shown in Figure 6. Two-way repeated-measures ANOVA showed a significant effect for the resin luting materials (P < 0.001); however, the different ceramic thicknesses had no significant effect (P = 0.113), and there was no interaction between the ceramic thickness and luting materials (P = 0.108). In addition, no significant effect was observed for the location of the LED emitters in the body of the light (P = 0.117). The RV had significantly higher E values than the other three luting materials. TF was the highest, followed by AC, and the VE had the lowest E value, irrespective of the location of the measurement.

## DISCUSSION

This study examined the effect of the thickness of lithium disilicate ceramic on the light transmission, degree of conversion, Knoop hardness and Elastic Modulus of four resin luting materials that use different photoinitiators. The ceramic thickness significantly reduced the light transmission through the ceramic, mainly in the shorter wavelengths of violet light. Therefore, the first hypothesis was rejected. Provided that the resins received at least 6.2 $J/cm^2$ (Table 2) the ceramic thickness did not significantly influence the DC at the top of the specimens. Therefore, the second hypothesis was accepted.

The Knoop hardness is a reliable method to evaluate the quality of photoactivation of a resinous material,[23] and the indentations can be made in defined locations across a specimen. The literature has previously reported that the distribution of emitted wavelengths across the surface of the light guide of some polywave LED units can be inhomogeneous.[23-27] In this study, the resin luting materials specimen was divided into quadrants to ascertain the influence of violet and blue light on the microhardness and elastic modulus of the resin luting materials. The effect of the position of violet and blue wavelengths, expressed by the location of the LEDs in the body of the LCU, had no significant influence on the emission spectrum at the 5 mm center diameter at the light tip or the properties of the resins photo-cured under this 5 mm region. Therefore, the third null hypothesis was rejected. The relatively good beam homogeneity of the LCU used in this study especially across the 5 mm diameter specimens and the photoinitiators found in the resins used in this study may explain this finding.

When the resin is photoactivated through a restorative material, the increased thickness of the material directly interferes with the amount of dispersion, scattering and absorption of the light received at the top surface.[28] In this study, lithium disilicate ceramic was used as the restorative material; the light scattering and absorption by the ceramic material are directly linked to the greater crystalline content and its thickness [9]. When the emission spectrum of the light from the LCU was examined, it became evident that the light irradiance attenuation increased with increasing ceramic thickness and this effect was greater for the lower wavelengths of violet light. When the ceramic was 0.3 mm thick, there was a 61% reduction in the irradiance of the violet light at 412 nm. This reduction increased to 82% when the ceramic was 1.0 mm thick (Table 2). The amount of light scattering is directly related to the wavelength of light.[9,29] The shorter wavelengths of violet light do not penetrate as deeply as the longer wavelengths of blue light due to the phenomenon of Rayleigh scattering where the shorter the wavelength, the more the light scatters.[8,30,31] This explains the greater attenuation of violet light at greater thickness. This effect was corroborated in the beam profile (Figure 4) and shows why it is necessary to determine the wavelengths of light that are received by the resin luting materials.

Some Type 1 photoinitiators used in resin luting materials are not activated by blue light. Instead, they require wavelengths of light in the violet range.[3] However, the Ivocerin photoinitiator used in Variolink Esthetic LC absorbs light in both the violet and the blue ranges of the spectrum and it achieved adequate polymerization.[12,16] The APS system presents in Allcem Veneer uses a combination of several initiators, in addition to Camphorquinone and some co-initiators.[12] RelyX Veneer includes hexafluorophosphate diphenyl iodonium (DPIH), which reacts with the inactive CQ photoinitiator by electron reduction to produce a phenyl radical that is capable of initiating the CQ polymerization reaction. This may explain the higher mechanical properties obtained for this resin cement.[32,33] According to the manufacturer, Tetric N-Flow, is different from Variolink Esthetic because it uses both Lucirin TPO and CQ as photoinitiators. It does not contain any Ivocerin.

Although there was no difference in the 24 h DC values at the top of the specimens, a small statistical difference was found between the Knoop hardness and elastic modulus values at the top of the luting materials. The relationship between a high DC and a high material hardness is not always straightforward.[34] Other characteristics may also interfere with hardness, including the chemical structure of the monomers and the type and density of the cross-link bonds.[34] Variolink Esthetic had the lowest Knoop hardness and elastic modulus values when compared to the other luting materials evaluated. The manufacturer of the Variolink Esthetic recommends that 10 s of photoactivation is sufficient when the LCU irradiance is above 1000 mW/cm². In this study, the materials were activated for 20 s; however, a longer 40 s exposure time will produce higher KH and DC values.[12] Since lower elastic modulus and Knoop hardness values were found for Variolink Esthetic when it was compared to other materials, at thicknesses of 1.0 mm or more, a photoactivation time longer than 20 s is recommended for this resin.

This study has some limitations; the size of the specimens should be considered due to the limited capacity to identify the effect of the wavelength of light in the area that was outside the 5.0 mm diameter from the center. For example, in clinical conditions, the dimensions of the buccal face of the laminate veneer would exceed the 5.0 mm in diameter of the specimen used in this study (Figure 1). Larger diameter samples of resin may show the difference between blue and violet light positions and generate different results. Furthermore, the clinician should consider the light irradiance attenuation through the ceramic and limit the use of light-cured resin luting material to ceramic restorations such as laminate veneers.[16] Additionally, the quality of the LED LCU, the exposure time, and covering the entire surface of the restoration must also be observed to deliver an adequate amount of energy to polymerize all of the resin luting material.[17] Clinical studies are required to understand better the real influence of multi or single-peak lights on the mechanical properties of different resins that use other photoinitiators.

## CONCLUSIONS

Within the limitations of this study where all the resins received at least 6.2 $J/cm^2$, the following conclusions can be drawn:

- Increasing the ceramic thickness greatly and exponentially reduced the irradiance. This reduction was more pronounced at the shorter wavelengths (violet) of light, with an 82% decrease when the ceramic was 1mm-thick.
- Increasing the ceramic thickness did not affect the DC at the top of the resin, irrespective of photoinitiators used in the luting materials tested.
- The position of the violet and blue LEDs within the body of the LCU did not influence Knoop Hardness, Elastic modulus in any of the luting material tested.
- The Knoop Hardness and Elastic modulus of Variolink Esthetic LC were significantly lower than the other 3 luting materials tested.

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**Table 1.** Resin cements used.

| Resin luting materials | Code | Shade | Type | Exposure Time (s) | Composition | Filler (wt%) | Manufacturer |
|---|---|---|---|---|---|---|---|
| RelyX Venner | RV | TR | Light cured Resin cement | 20 s | Bis-GMA, TEGDMA, zirconia/silica filler | 66 | 3M Oral Care, St Paul, MN, USA |
| Allcem Venner APS | AV | TRANS | Light cured Resin cement | 20s | Methacrylic monomers, aluminosilicate glasses, silicon oxide | 63 | FGM, Joinvile, SC, Brazil |
| Variolink Esthetic LC | VE | NEUTRAL | Light cured Resin cement | 20s | UDMA, Bis-GMA, HEMA, TEGDMA, GDMA, barium glass, zirconia/silica filler | 60-68 | Ivoclar Vivadent, Schaan, Liechtenstein |
| Tetric N- Flow | TF | T | Light cured flowable resin composite | 20s | UDMA, Bis-GMA, Bis-EMA, TEGDMA, barium glass, ytterbium trifluoride, mixed oxide, silicon dioxide | 63 | Ivoclar Vivadent, Schaan, Liechtenstein |

**Table 2**. Mean Irradiance (mW/cm$^2$) from the Bluephase G2 measured through the different ceramic thicknesses and percentage (%) of the light attenuation at the violet and blue range of wavelengths.

| **Wavelength (nm)** | **Control** | | **0.3 mm** | | **0.7 mm** | | **1.0 mm** | |
|---|---|---|---|---|---|---|---|---|
| Radiant exposure in 20 s (J/cm$^2$) | 26.1 | (0%) | 12.5 | | 8.7 | | 6.2 | |
| Full range (350 - 550 nm) | 1408 $^A$ | (0%) | 625 $^B$ | (46%) | 435 $^C$ | (69%) | 321 $^D$ | (77%) |
| Violet light (350 - 430 nm) | 215 $^A$ | (0%) | 84 $^B$ | (61%) | 55 $^C$ | (74%) | 38 $^D$ | (82%) |
| Blue light (430 - 550 nm) | 1160 $^A$ | (0%) | 527 $^B$ | (55%) | 369 $^C$ | (68%) | 276 $^D$ | (76%) |

* Different capital letters indicate significant differences and the effect of the ceramic thickness (row) on light transmission (Tukey test, $P < 0.05$).

**Table 3.** Mean ± standard deviation Degree of Conversion (DC, %) values

| **Materials** | **Control (Without ceramic)** | **Ceramic thickness** | | |
|---|---|---|---|---|
| | | **0.3 mm** | **0.7 mm** | **1.0 mm** |
| Tetric N' Flow | 77.0 ± 1.5 $^{Aa}$ (100%) | 76.1±1.5 $^{Aa}$ (99%) | 75.4 ± 3.0 $^{Aa}$ (98%) | 75.3 ± 2.8 $^{Aa}$ (98%) |
| Variolink Esthetic | 72.6 ± 1.3 $^{Aa}$ (100%) | 69.8 ± 0.2 $^{Aa}$ (96%) | 68.8 ± 1.2 $^{Aa}$ (94%) | 65.6 ± 2.0 $^{Aa}$ (90%) |
| AllCem Veneer | 74.2 ± 3.0 $^{Aa}$ (100%) | 72.8 ± 3.5 $^{Aa}$ (98%) | 72.5 ± 0.4 $^{Aa}$ (97%) | 72.4 ± 2.3 $^{Aa}$ (97%) |
| RelyX Veneer | 76.9 ± 8.5 $^{Aa}$ (100%) | 76.2 ± 4.8 $^{Aa}$ (99%) | 72.3 ± 4.6 $^{Aa}$ (94%) | 72.9 ± 2.4 $^{Aa}$ (94%) |

Different capital letters indicate significant differences and the effect of the ceramic thickness (row); Different lowercase letters indicate significant differences in the DC among the materials (columns) (Tukey test, $P < 0.05$).

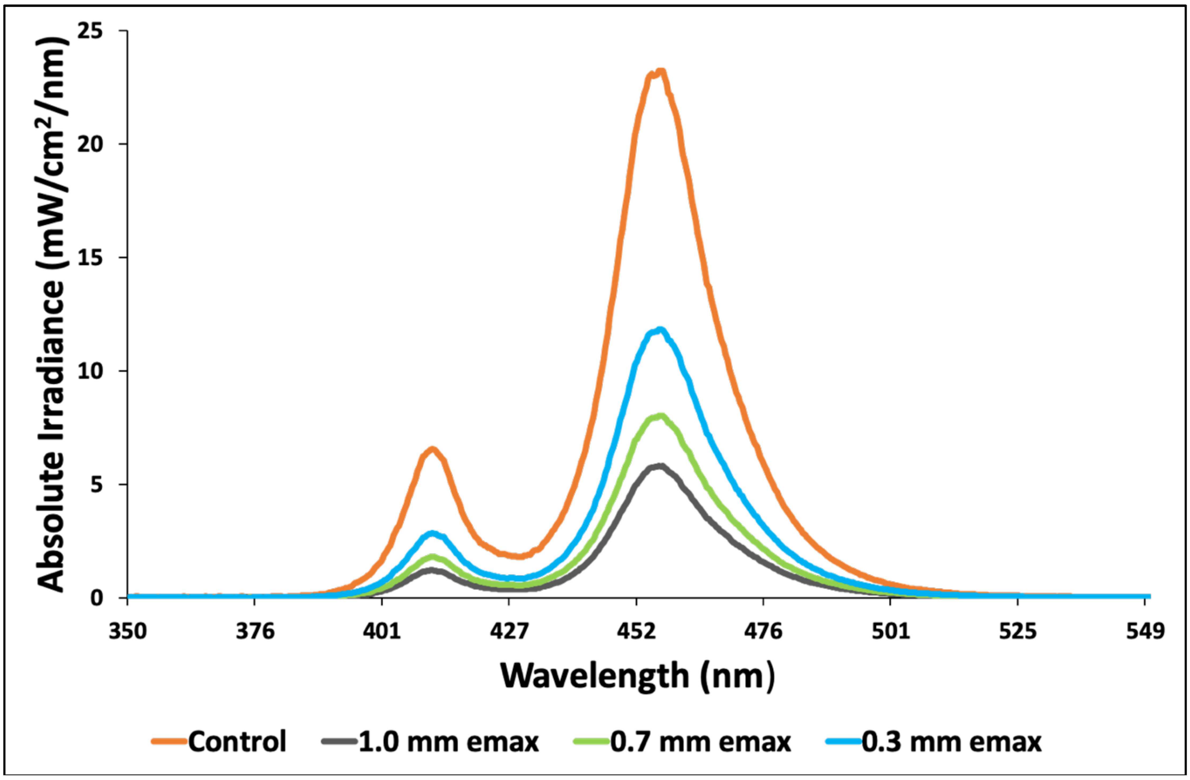


**Figure 1.** Emission spectrum (mW/nm) curves measured with Intregrate Sphere from control and through the different ceramic thickness. Orange line (control) - no ceramic interposition; Blue line - interposition of 0.3 mm ceramic thickness. Green line - interposition of 07.mm ceramic thickness. Gray line - interposition of 1.0 mm ceramic thickness.

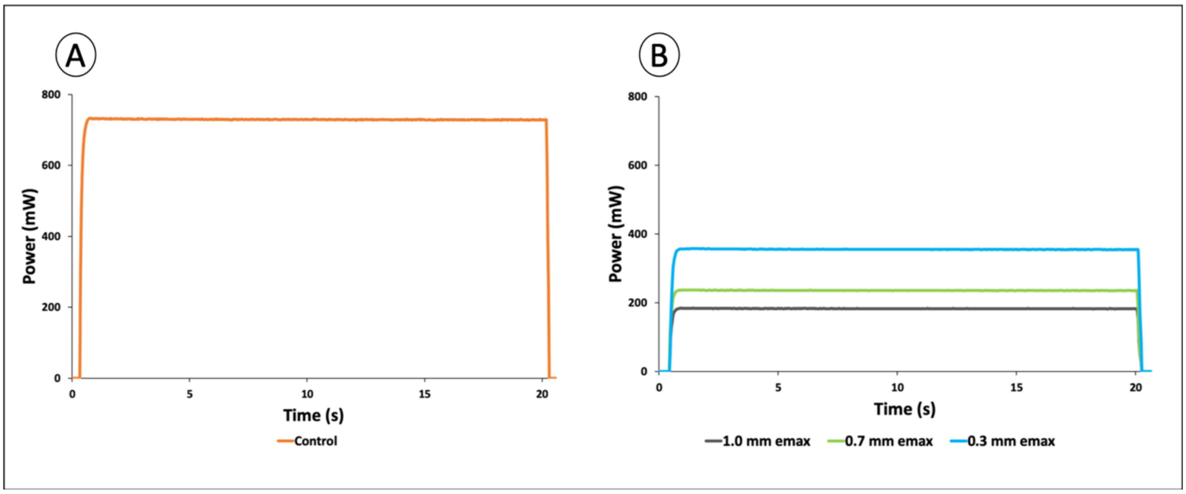

**Figure 2.** Radiant power (mW) emitted during 20s at the high mode of Bluephase G2 tested through three different ceramic thicknesses. Orange line (control) - no ceramic interposition; Blue line - interposition of 0.3 mm ceramic thickness. Green line - interposition of 07.mm ceramic thickness. Gray line - interposition of 1.0 mm ceramic thickness.

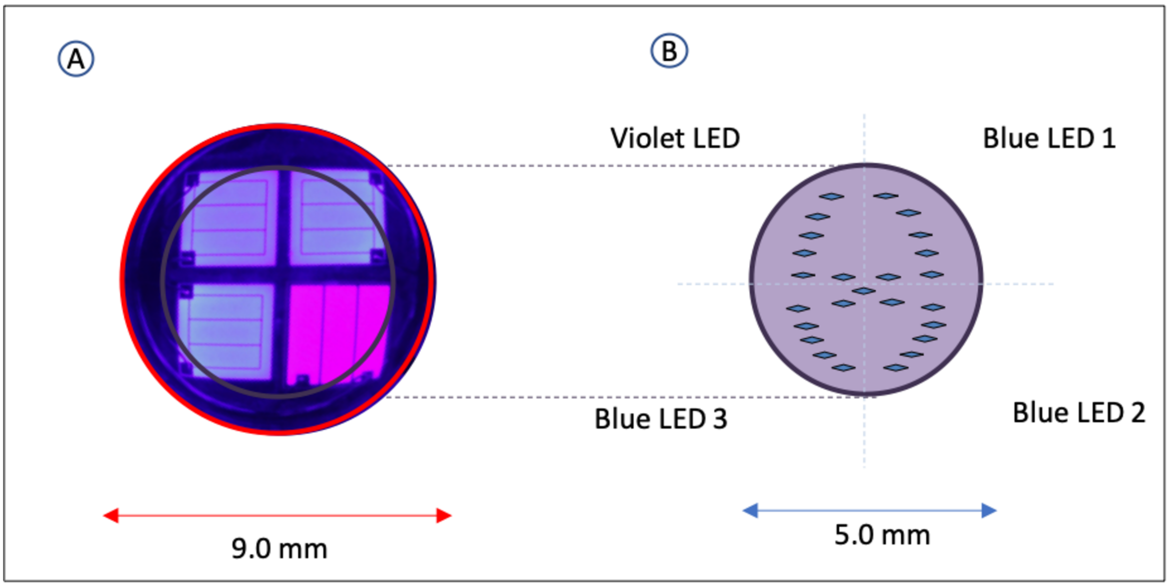


**Figure 3.** A. Location of the blue and violet LEDs within the body of the multi-spectrum Bluephase G2 light-curing unit; B. The position of the 5 indentations made on each sample correspond to the position of the LED emitters.

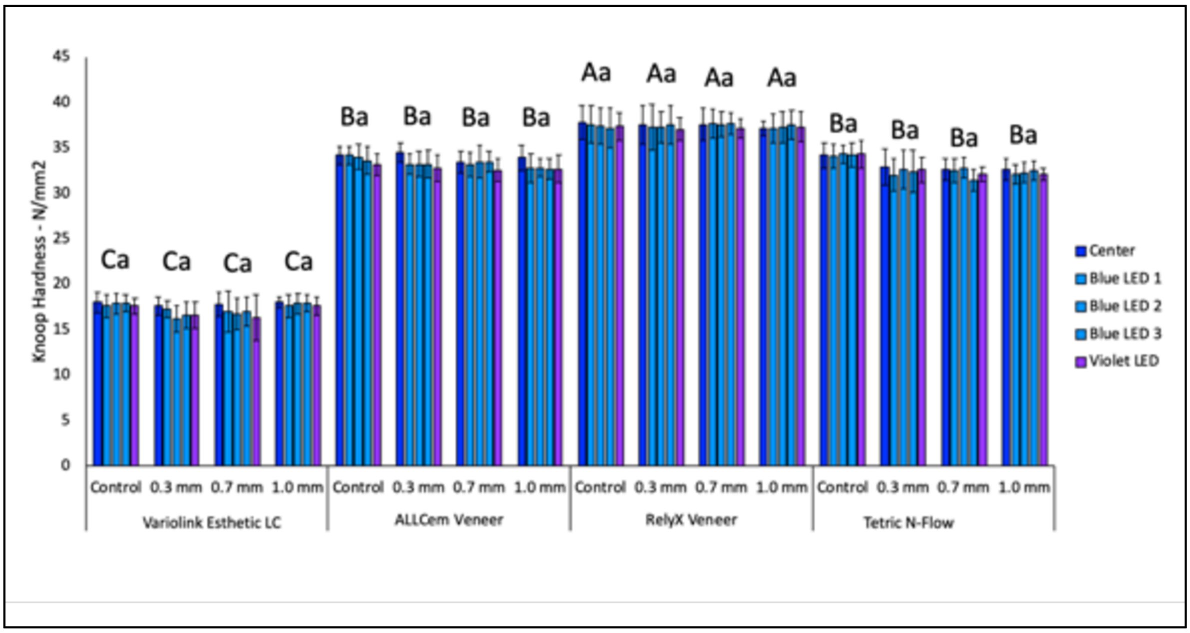


**Figure 4.** Mean Knoop hardness (N/mm$^2$) and standard deviations for all resins light activated directly by the Bluephase G2 (control) and through different ceramic thicknesses. Different letters indicate significant differences (Tukey test P <0.05). Capital letters used for comparing resin luting materials; lowercase letters compare the ceramic thickness for each resin luting materials.

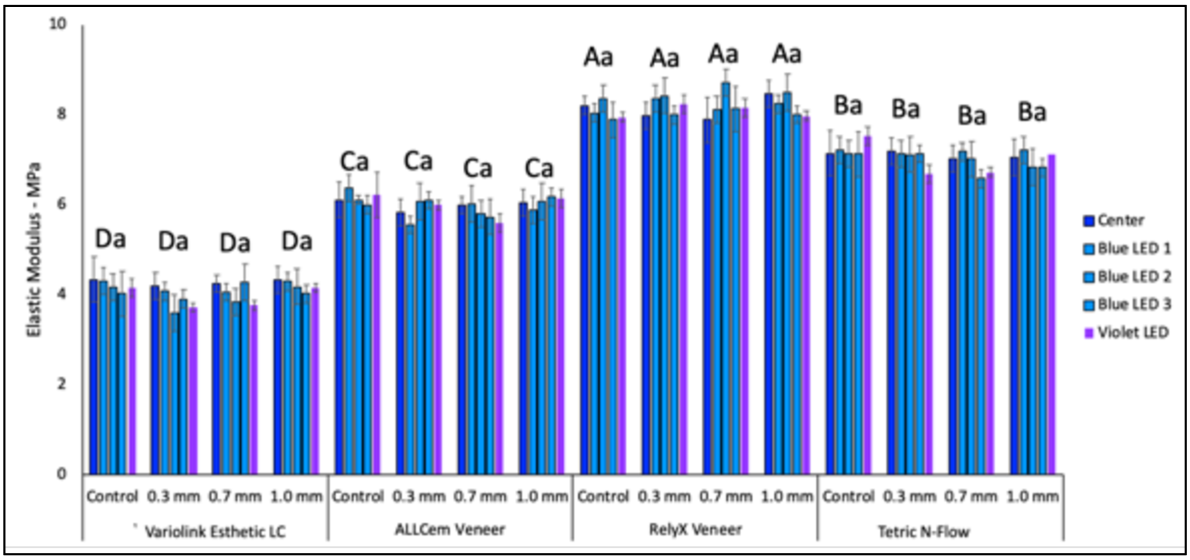


**Figure 5.** Mean Elastic modulus (MPa) and standard deviations for all resin luting materials light activated directly by the Bluephase G2 (control) and through different thicknesses of ceramic. Different letters indicate significant differences(Tukey test P <0.05). Capital letters used for comparing resin luting materials; lowercase letters compare the different ceramic thicknesses.

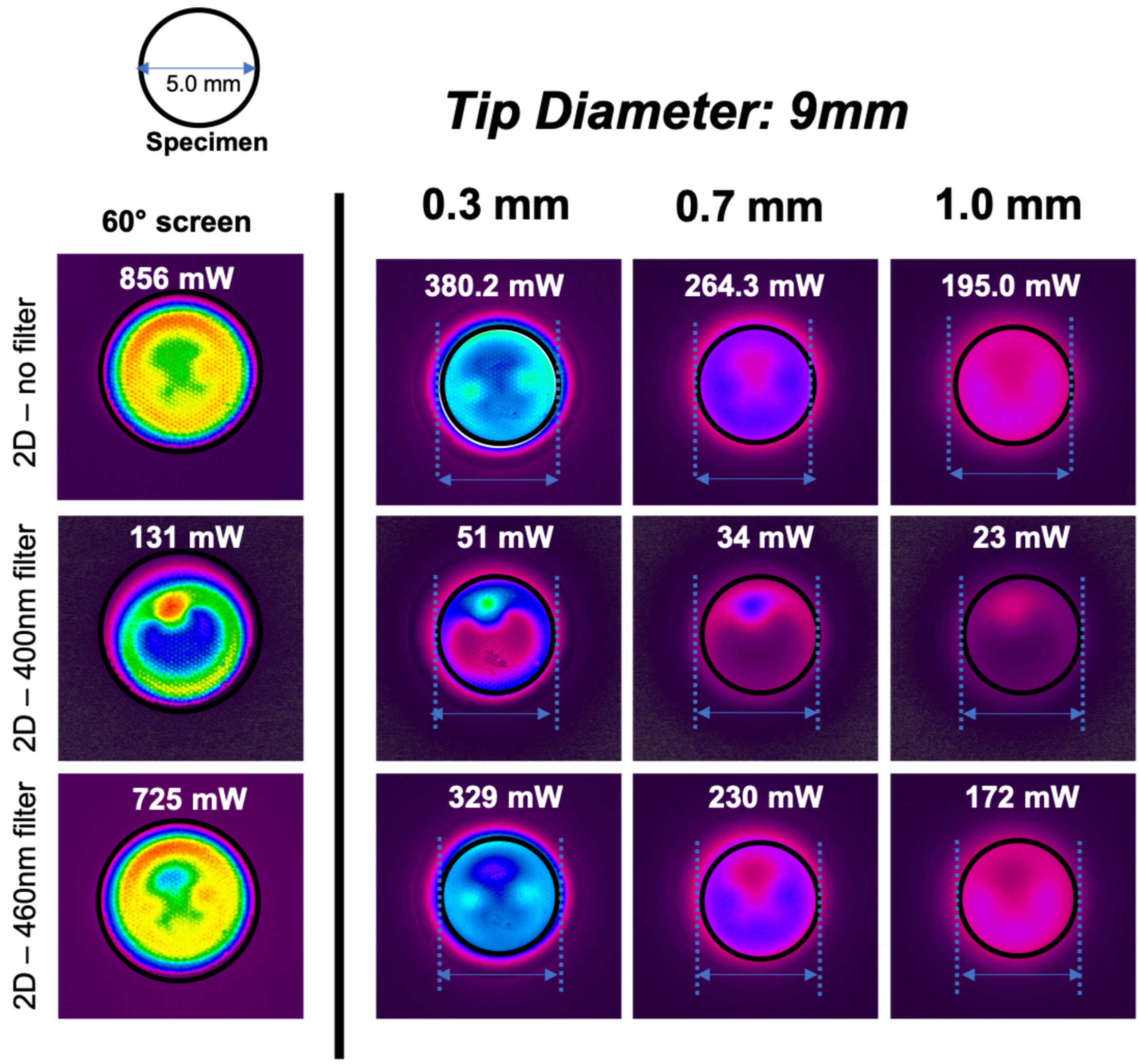


**Figure 6.** Two-dimensional images of the entire beam profile and at 400 and 460 nm superimposed over the 5 mm diameter specimens

## 3.2 CAPÍTULO 2

**Effect of different thicknesses and shades of CAD/CAM resin composite on the light transmission from different curing lights**

Artigo a ser submetido para publicação no periódico **Journal of Prosthetic Dentistry.**

**Effect of different thicknesses and shades of a CAD/CAM resin composite on the light transmission from different curing lights**

Julia Dantas Mazão[1], Maria Tereza Hordones Ribeiro[2], Stella Sueli Lourenço Braga[3], Richard Bengt Price[4], Carlos José Soares[5]

1 DDS, MSc, Ph.D. student, Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID:0000-0002-1102-672X, julia_mazao@hotmail.com

2 DDS, MSc, Ph.D. student, Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: 0000-0002-5126-7931, mt_hribeiro@hotmail.com

3DDS, MSc, PhD, Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: 0000-0002-6883-4648 stellabraga2@hotmail.com

4 DDS, MS, PhD, Professor Department of Dental Clinical Sciences, Dalhousie University, Halifax, Nova Scotia, Canada, ORCID: 0000-0001-6479-1436, richard.price@dal.ca

5 DDS, MSc, PhD, Professor and Chair Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: 0000-0002-8830-605X, carlosjsoares@ufu.br

Corresponding author:

Dr. Carlos José Soares

Federal University of Uberlândia, School of Dentistry

Avenida Pará, 1720, Bloco 4L, Anexo A, Sala 42, Campus Umuarama.

Uberlândia - Minas Gerais – Brazil CEP. 38400-902

Email: carlosjsoares@ufu.br

Phone: +55 34 3218 2255, Fax: +55 34 3218 2279

Conflict of Interest Statement

The authors confirm that they have no conflict of interest.

Keywords: CAD/CAM composite, luting materials, light-curing unit, photoinitiator, light transmission.

**Effect of different thicknesses and shades of CAD/CAM resin composite on the light transmission from different curing lights**


**ABSTRACT**

**Statement of the problem.** The thickness and the shade of the restoration may have different effects on the light transmission from different light-curing units (LCU)

**Purpose.** To determine the power (mW), emission spectrum (mW/cm²/nm), and beam profile of different LCUs through various thicknesses and shades of CAD-CAM material.

**Materials and methods.** Five thicknesses: 0.5; 0.75; 1.0; 1.5, and 2.0 mm, in three shades: Bleach; A2 and A3.5 of one brand of CAD-CAM material was used. Two single-peak LCUs: EL, Elipar DeepCure-S; and OP, Optilight Max and one multiple-peak LCU: VL, VALO Grand were used. The LCUs were positioned at 0 mm from the surface of the CAD-CAM material. The power and emission spectrum were measured using an integrating sphere and the beam profiles using a laser beam profiler. The Light Attenuation Coefficient of all LCUs and shades were evaluated in relation to the material thickness.

**Results.** There was an exponential reduction in the power and emission spectrum as the CAD-CAM thickness increased (P<.001). The light transmission through A2 CAD-CAM was affected least by the thickness (P<.001). VL and EL delivered a more homogeneous beam profile than OP. The attenuation coefficient was higher for the lower wavelengths (violet) from the VALO Grand and was higher for A3.5 shade than the A2 and Bleach shades. No violet wavelengths from the VL could be detected at the bottom of 2.0 mm of the CAD-CAM materials.

**Conclusions.** The CAD-CAM material thickness had a significant effect on the transmitted power (P<.001), irradiance (P<.001), and the wavelengths of light; the A2 shade had the least influence on the light transmission compared to the Bleach or A2 shades. VL and EL delivered a more homogenous output compared to OP.

## CLINICAL IMPLICATIONS

Increasing the thickness of the CAD-CAM/RC resulted in an exponential reduction in the power and irradiance of transmitted light from single and multi-peak LCUs. The wavelengths of violet light were more affected as the CAD-CAM thickness increased.

## INTRODUCTION

The use of computer-aided design and manufacturing (CAD-CAM) technology has increased exponentially in recent years.[1] This technology allows teeth to be prepared, scanned, the restoration designed, milled out of a CAD-CAM material, and adhesively cemented to the tooth in just one appointment.[2,3]

The two primary restorative materials are used in CAD-CAM technology are ceramic and resin composite-based materials.[4,5] Despite having inferior mechanical and aesthetic properties than ceramic materials,[6] resin composites have been proposed as a more economical alternative that can also be repaired intraorally.[2,4] Some CAD-CAM materials, also called by some a ‘hybrid ceramic’, consist of a ceramic substructure surrounded by resin.[3] These materials are available in different shades and can be milled in various thicknesses.[7]

The adhesive bonding process between the tooth and the restoration is an important step to ensure the success of the restoration.[8,9] Depending on the thickness of the restorative material two types of resin cement are recommended: a light-polymerized or a dual-cured resin cement.[10-13] To ensure the optimum properties of both types of cements, in both cases, sufficient light must pass through the restorative material to reach and photocure the resin cement.[14-16] The combination of a thicker restorative material and the use of darker or opaque shades will reduce the light transmission through the restoration. This will potentially compromise the bond to the tooth and the mechanical properties of the cement.[17,18]

The need for increasingly whiter colored luting cements has resulted in manufacturers incorporating the new generation of photoinitiators into resin cement, other than camphorquinone,[19,20] because camphorquinone has a yellow color.[21] Some of these alternative photoinitiators require light in the violet spectrum and this resulted in manufacturers developing light-emitting diode (LED) light curing units (LCUs) that emit both violet and blue light.[22-25] The wavelength of violet light is shorter than blue light, and it does not penetrate through the restorative material as well as blue light. [24-28]

The type of LCU, the combination of the shade, opacity, and the thickness of the CAD-CAM material all affect the power, irradiance, and emission spectrum of light transmitted through the indirect restorative material.[7,29-31] The irradiance value at the light tip is the radiant power (usually expressed in mW) divided by the area of the light tip (usually expressed in $cm^2$). More expensive LCUs frequently are more powerful and have a greater active tip area. However, the cost of LCU does not always correlate with the irradiance delivered and the irradiance value from the LCU can be increased by reducing the internal tip diameter.[8,32] Most studies only analyze the effect of light transmission on ceramic materials.[11,12,17] However, the characteristics and composition of the resin composite based materials can determine a different parameter of light transmission.[7,26,33-35]

The amount of light transmitted by budget cost light-curing units through the different thicknesses and shades of CAD-CAM materials is scarce, but it can have an important effect on the photo-activation of the resin luting cement.[7] Therefore, the purpose of this study was to evaluate the radiant power (mW), irradiance ($mW/cm^2$), the wavelengths of transmitted light ($mW/cm^2/nm$), and beam profile of different LCUs through CAD-CAM glass-ceramic resin composite of various thicknesses and shades. The null hypothesis was that the thickness and shade of the CAD-CAM material would not affect the light transmitted from different LCUs through the CAD/CAM material.

## MATERIAL AND METHODS

### *Study design*

Resin composite-based CAD/CAM blocks LT (BRAVA Block; FGM) that the manufacturer claims to be a glass-ceramic resin composite were used in 5 different thicknesses, in three shades. Two single-peak LCUs: EL (Elipar DeepCure-S; 3M-Oral Care) and OP (Optilight Max; Saevo) and one multiple peak LCU: VL (VALO Grand; Ultradent) were used. The specifications of these

LCUs are reported in Table 1. The LCUs were positioned at 0 mm from the resin composite surface. Power and emission spectrum were obtained using the integrating sphere (LabSphere; North Sutton) and the beam profile from the LCUs was measured (Ophir-Spiricon; Logan). The Light Attenuation Coefficient of all LCUs and shades were calculated for each thickness of the BRAVA blocks.

*CAD-CAM resin composite preparation*

The Bleach, A2, and A3.5 shades of CAD/CAM materials (Table 2) were glued to an acrylic plate with cyanoacrylate glue (Super Bonder; Loctite) and sticky wax (Sticky Wax; Asfer). The blocks were sectioned in 5 thicknesses: 0.5; 0.75; 1.0; 1.5 and 2.0 mm (n=5) using 0.4 mm thick double-sided diamond discs (Odeme Dental Research) using a precision cutter (IsoMet 1000; Buehler) at 225 rpm under 150g load with copious water irrigation.

*Total radiant power and emission spectrum*

The total radiant power (mW), radiant energy during an exposure time of 10 seconds (J), and emission spectrum (mW/cm²/nm) from the 3 LCUs were determined. Five measurements of the total radiant power (mW) emitted between 350 and 550 nm and spectral radiant power (mW/nm) from LCU's were measured using an integrating sphere (LabSphere; North Sutton) that was connected to a fiberoptic spectrometer (USB 4000; Ocean Insight). An internal calibration lamp (SCL 600; Labsphere) was used to calibrate the system. The light transmission through the control (no interposing CAD/CAM material) and the 5 thicknesses: 0.5; 0.75; 1.0; 1.5, and 2.0 mm, for the three shades of the CAD/CAM materials was measured with the LCU tip at 0-mm through a 12 mm aperture into a six-inch integrating sphere.

The radiant power data from the LCU's unit were analyzed in 3 wavelength ranges: Total, 450 – 550 nm; violet light, 350 – 430 nm; and blue light, 430 – 550 nm.

*Beam profile*

The light beam profiles of light transmitted through the different thicknesses of glass-ceramic resin composite were measured using a laser beam profiler charge-coupled device (CCD) digital camera (Ophir-Spiricon; Logan) with a 50 mm focal length lens (SP620U; Ophir-Spiricon) that was fixed at the focal distance from the slice of the CAD/CAM material. For the control condition, a diffusing surface 60-degree holographic diffusing screen (Edmund Optics) was positioned at the same focal distance from the digital camera. Two blue filters (HOYA UV-VIS colored glass bandpass filter; Edmund Optics) and one neutral density filter (Edmund Optics; Barrington) were required to attenuate and flatten the spectral response of the CCD camera. The LCU's was mounted in a fixed orientation and positioned 0 mm distance from the imaging screen or the CAD-CAM resin composites, facing towards the camera simulating all the conditions of the light transmission experiment. The camera captured all the images at the same distance, position, and exposure time, thus making the images comparable. The three-dimensional images were collected using the beam analyzer software (BeamGage Professional version 6.14; Ophir-Spiricon). The control two-dimensional beam profile images were used the internal tip diameter (mm) of each LCU, the "Optical Scaling" tool in the BeamGage Professional software produced calibrated the beam profile data in millimeters. The mean radiant power values (mW) previously obtained were then entered into the beam analyzer software to produce color-coded calibrated tip irradiance in mW/cm² images. The calibrated data from BeamGage Professional (Ophir-Spiricon) were then exported into OriginPro 2019 version 9.6. (OriginLab; Northampton) where the images were all scaled to the same irradiance levels and x and y dimensions.

*Light Attenuation Coefficient*

To evaluate how the light emitted by each LCU decreases its intensity within the specimen, the attenuation coefficient (AC, $mm^{-1}$) was estimated using the measured light at different thicknesses based on Beer-Lambert law: $I(z) = Io\, e^{-\alpha z}$, where I0 is the initial light intensity, it is the measure of light in the absence of specimen, α is the attenuation coefficient, and z is the specimen thickness.

*Statistical Analysis*

Radiant power data were analyzed for normal distribution and homoscedasticity using the Shapiro-Wilk and Levene's tests. Three-way ANOVA was used to compare the interactions between study factors: LCUs (3 levels), thicknesses (5 levels), and shades (3 levels) of CAD/CAM material. Multiple comparisons were made using Tukey's post-hoc test. All tests used a significance level of α = .05, and all analyses were performed using Sigma Plot 13.1 (Systat Software Inc). The emission spectra (nm/mW/cm²) and beam profiles were analyzed descriptively.

## RESULTS

The mean and standard deviation of radiant power (mW) emitted by three LCUs and transmitted through the different thicknesses and shades of the CAD-CAM slices are reported in Figure 1. The 3-way ANOVA (Table 3) reported that the shade had a significant overall effect (*P*<.001), the thickness of CAD-CAM slice (*P*<.001), the LCU (*P*<.001), the interaction between the LCU and thickness of the CAD-CAM slice (*P*<.001), the interaction of LCU and CAD-CAM shade (*P*<.001), between the thickness and shade of CAD-CAM material (*P*<.001), and also between the LCU, thickness and shade (*P*<.001). The Tukey test showed that without a slice of the CAD-CAM material, the Valo (VL) LCU transmitted a significantly higher radiant power than BL., OP delivered a significantly lower radiant power than BL and OP (*P*<.001). The VL light delivered significantly higher radiant power than BL through the slices of CAD-CAM materials that were 0.5 and 0.75 mm thick, irrespective of the shade (*P*<.001). However, as the thickness increased to 1.0, 1.5 and 2.0 mm, the amount of light transmitted from VL was similar to BL (*P*=.321). The amount of light transmitted using OP was always significantly lower than from VL and BL, irrespective of the shade (*P*<.001).

The influence of thickness on the radiant power transmitted through the CAD-CAM resin composite for all shades and tested LCUs are shown in Figure 2. The greater the thickness, the lower the radiant power transmitted through the CAD-CAM materials, regardless of the shade and tested LCU (*P*<.001). The bleach shade transmitted the least radiant power through the CAD-CAM materials that were 0.5, 0.75 and 1.0 thick (*P*<.001). However, when the material slices were 1.5 and 2.0 thick, the Bleach and A2 shades transmitted similar radiant power values (*P*=.108). The A3.5 shade transmitted the lowest radiant power through the CAD-CAM, regardless of thickness or tested LCU (*P*<.001).

The emission spectrum (mW/cm²/nm) from the three LCUs without the interposition of a slice of CAD-CAM material (control) is shown in Figure 3. The thickness and shade of the slice of CAD-CAM material significantly affected the light attenuation for all wavelength spectra, irrespective of shade and LCU tested. The CAD-CAM slices in the A2 and Bleach shades that were 0.75 mm or greater had a lower attenuation effect on the emission spectrum than A3.5. The greater the thickness, the greater the influence on the emission spectrum transmitted through the CAD-CAM material, irrespective of the shade and LCU (*P*<.001). The violet wavelengths from by VL were undetectable when the CAD-CAM thickness was 1.0 mm or greater (Figure 3).

The beam profiles for the three LCUs at 0 mm distance are shown in Figure 4. The VL and EL had a more homogeneous beam profile than OM. The representation of the light transmitted through the slices of the CAD-CAM material for the three LCUs in all conditions are shown in Figure 5, The light beam profiles showed that the light transmission was affected by the shade of the CAD-CAM material. Light transmission through the A2 shade was greater than Bleach only for 0.5, and 0.75mm thick slices of CAD-CAM material, irrespective of the LCU tested (Figure 5). The light transmitted through the shade A3.5 slice was the most negatively affected (Figure 5).

The attenuation coefficient of the emitted for the three LCUs with the interposition of a slice of CAD-CAM material for all shades are shown in Figure 6. The attenuation coefficient was higher for lower wavelength emitted by VALO Grand and also was higher for A3.5 shade than A2 and Bleach shades

**DISCUSSION**

This study evaluated the influence of the thickness and shade of one brand of CAD-CAM material on the light transmission from single-peak and multiple-peak LCUs. The thickness and shade of the CAD-CAM material significantly influenced the radiant power, attenuation coefficient, and light spectrum attenuation. The tested LCUs performed differently regarding the radiant power, irradiance and homogeneity of the light emitted that were affected by the thickness and shade of the CAD-CAM materials. Thus, the null hypotheses were rejected.

A thickness limit should be considered for a suitable polymerization of the light-polymerized resin cement.[12] The light transmission through the indirect restorative material may be insufficient for the luting cement to be adequately polymerized.[3,7,11] Such inadequate polymerization of luting material can cause postoperative sensitivity or marginal debonding that contributes to marginal staining and secondary caries, leading to restoration failure.[15,21]

The greater the thickness, the lower the radiant power (Figure 1). Using darker shade or thicker restoration, commonly verified in endodontically treated or severally structural compromised posterior teeth, higher light attenuation will reach the luting resin-based material,[7] can negatively affect the polymerization process. The irradiance transmitted through resin composite attenuates exponentially following the Beer-Lambert law.[10,26] For perpendicular incidence and the closest exposure to the material surface, the transmitted irradiance through a CAD/CAM material decreases exponentially as the specimen thickness increases.[7] Consequently, insufficient light may reach the resin at the bottom of the proximal box margins in premolars and molars. This may cause premature failure in these areas.

The dentist must recognize that the shade of the CAD-CAM material can have a significant effect on all tested parameters and will affect the light transmission through the restorative material. This light attenuation was greater in the Bleach shade, even though it is whiter than A2, and for A3.5, that is a darker shade. Light transmission through the dark shades is diminished because the pigments attenuate the light.[30] Darker resin composites tend to absorb more light, and they require more light exposure time, especially in greater thicknesses.[14] The bleach shade also had higher light attenuation than the A2 shade. This occurred because the bleach shade has a great number of white pigments, and is consequently opaquer. These opaquers probably cause a greater light scattering and absorbance when compared to more translucent shades, such as A2.[21,29] When darker and thicker slices of the CAD-CAM material were tested, the attenuation of the light was even more evident. Longer exposure times and additional light activation from the buccal and lingual are recommended in these clinical conditions.

Many variables affect the amount of light energy transmitted through the indirect restorative material, such as the design and tip size of the LCU, power density, exposure duration, shade, and opacity of the restorative material.[15,16,25] The choice of the LCU must be carefully evaluated when associated with cementation of indirect restoration.[19] In this study, there was a significant difference in emission spectrum among the tested LCUs. With the increasing availability of brands and models of LCU's, the clinician may not know how to choose an adequate LCU. They may also base their decision on misleading data such as an averaged irradiance value.[25] The total radiant power (mW) is measured from the LCU and then divided by the area of the light-emitting tip to produce a single averaged radiant exitance value in $mW/cm^2$. It's not uncommon to see companies reduce the tip area, to deliver an irradiance that appears to be equivalent or even greater than a higher cost LCUs.[25,32] In this study, VL delivered the lowest irradiance value because its tip is 12 mm in diameter compared to OP, which has a 7mm tip. When evaluating the beam profiles, the light from VL and EL sources was more uniform than the light from OP. Radiant exposure values were also higher for LV and EL. In practice, this lack of homogeneity and power can negatively affect the photo-activation, especially at the restoration edges, leading to its failure.[9,15,27]

With the tendency to deliver lighter restorations, alternative photoinitiators different than camphorquinone were introduced on resin-based materials.[13,19] Most of them require light in the violet range (~410 nm) compared to materials that use only CQ, which requires a different wavelength of blue light (around 468–470nm).[13] Broad-spectrum multi-peak LCUs have been gaining popularity because they deliver both violet and blue light, and the manufacturers claim they will photoactive all known dental resins.[8,23,20] However, when the wavelengths of light that were transmitted through the CAD/CAM block was examined, it became evident that the light attenuation not only increased with increasing resin composite thickness, it was also much greater for the violet light. Thus, if the resin cement requires violet light for an optimal curing process, this is a problem. It may also be a problem if the clinician chooses to photo-activate a bonding agent that requires violet light only through the overlying restorative material.

This study has limitations because the light transmission was measured only through flat surfaces of the CAD-CAM material. Another limitation is that only one CAD-CAM material was tested in this study, and other products will have different outcomes.[7,23,34,35]

Because of clinical factors such as operator technique, the light source, and the light's direction, the polymerization obtained clinically may sometimes be much less than that achieved under the ideal laboratory conditions.[14] Some clinicians use flowable or heated high viscosity light-activated resin composites to cement their CAD-CAM restoration.[20] This decision should be carefully reconsidered as the thickness of the restorative material increases. Clinicians should be careful when faced with a clinical situation with greater restoration thickness in hard-to-reach locations, such as second molars, and with dark or white opaque shades.[30] If the restoration thickness is greater than 1-mm, dual activated resin cements should be used.[11] The clinician should ensure that the light of the LCU has a straight line access to all the surfaces of the restoration.[24] To ensure clinical success of the restoration, care should be taken with the choice of luting material, the shade, the thickness of the restoration, and the photo-activation time.

## CONCLUSION

Within the limitation of this study, the following conclusions can be drawn:

- As the thickness of the tested CAD-CAM material increases, the radiant power, the irradiance, and the wavelengths of transmitted light from all tested LCUs decreased exponentially.
- The A3.5 shade of the tested CAD-CAM material had higher light attenuation than the Bleach and A2 shades using any of the tested LCU;
- VALO Grand and Elipar DeepCure delivered the most homogenous light and greater radiant power when compared to Optilight Max.
- The violet light from the VALO Grand multi-peak LCU was undetectable when the CAD/CAM material was 2.0-mm thick.

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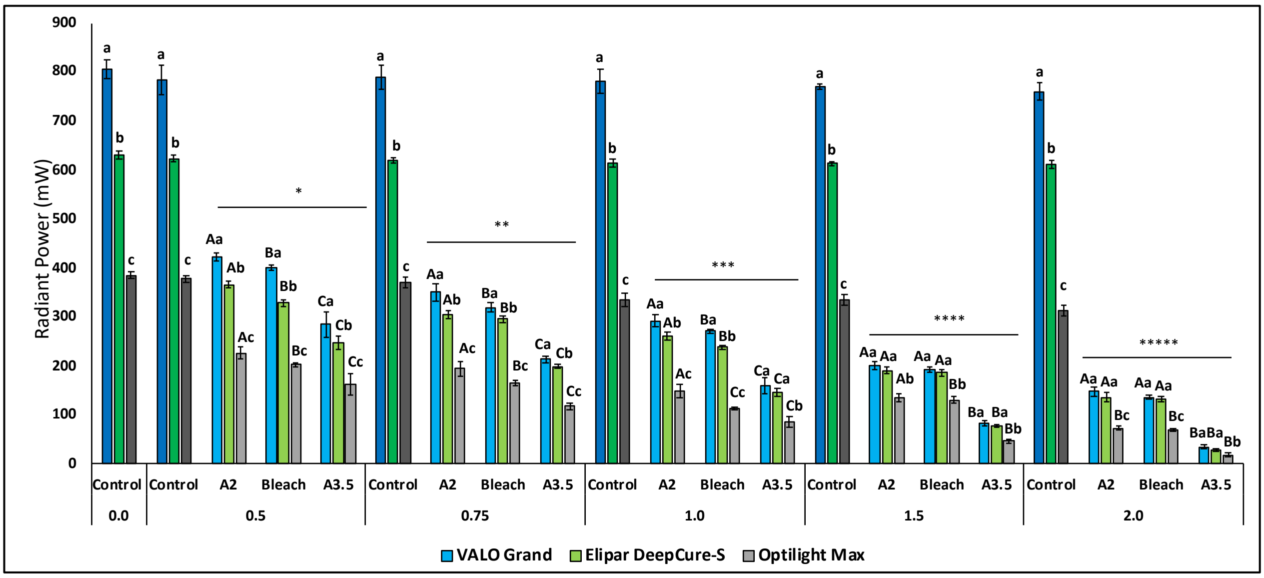


**Figure 1.** Means and standard deviations of the radiant power (mW) of each LCU measured using an integrating sphere. Control (without CAD-CAM/RC) and through three shades of CAD-CAM/RC and five different thicknesses. Different uppercase letters indicate a significant difference between shades. Different lowercase letters indicate significant difference between the LCU used (Tukey test, *P*<.005). * indicate significant difference between thickness of the CAD-CAM/RC thickness.

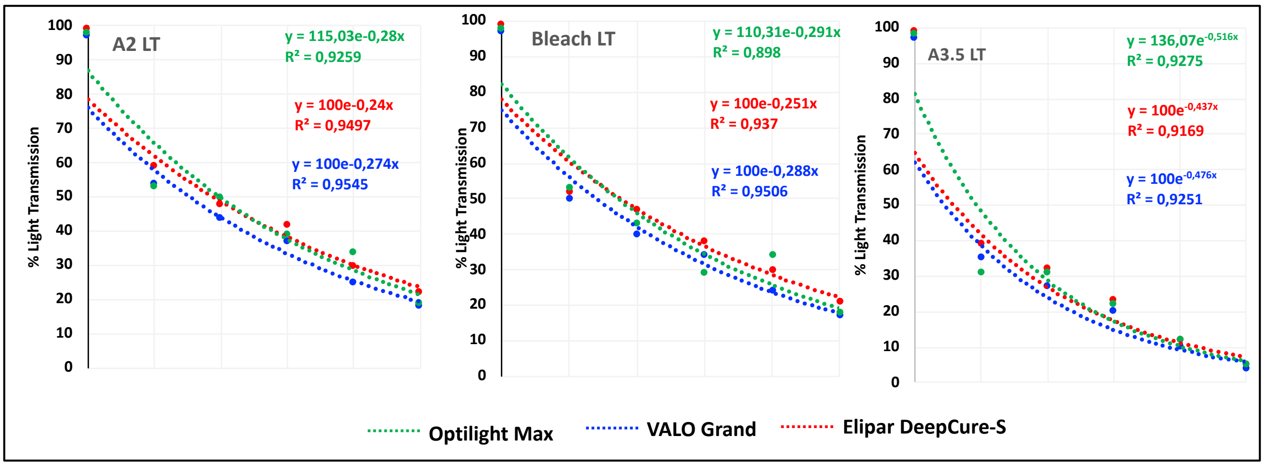


**Figure 2.** Attenuation coefficient of the emitted for the three LCUs with the interposition of a slice of CAD-CAM BRAVA Block for all shades

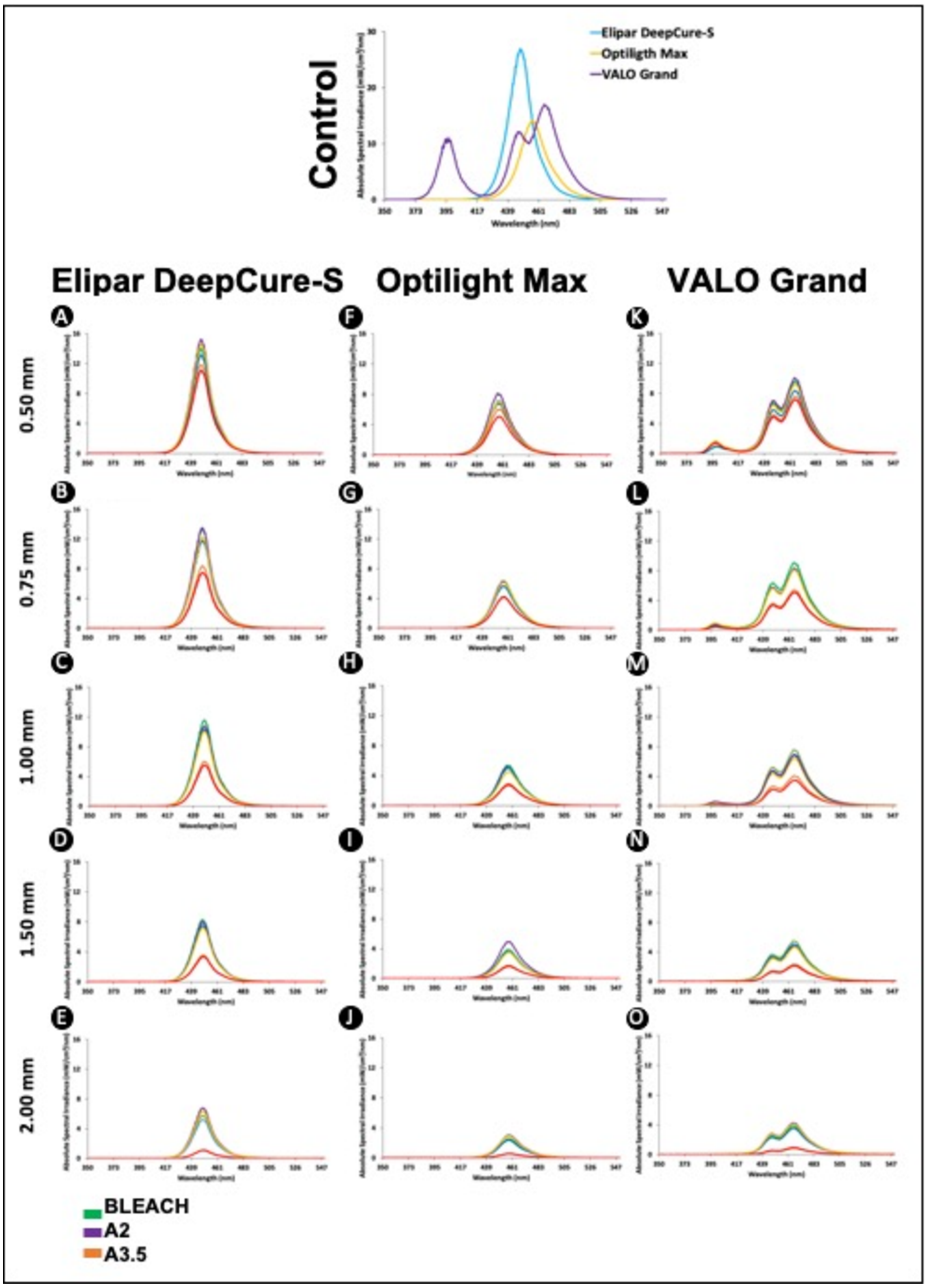


**Figure 3.** Wavelengths of light (mW/nm) from the LCUs through five different thicknesses of CAD-CAM/RC in three shades (Bleach, A2 and A3.5): A-E: Elipar DeepCure-S; F-J: Optilight Max; K-O: VALO Grand. Note the images control are in different scales.

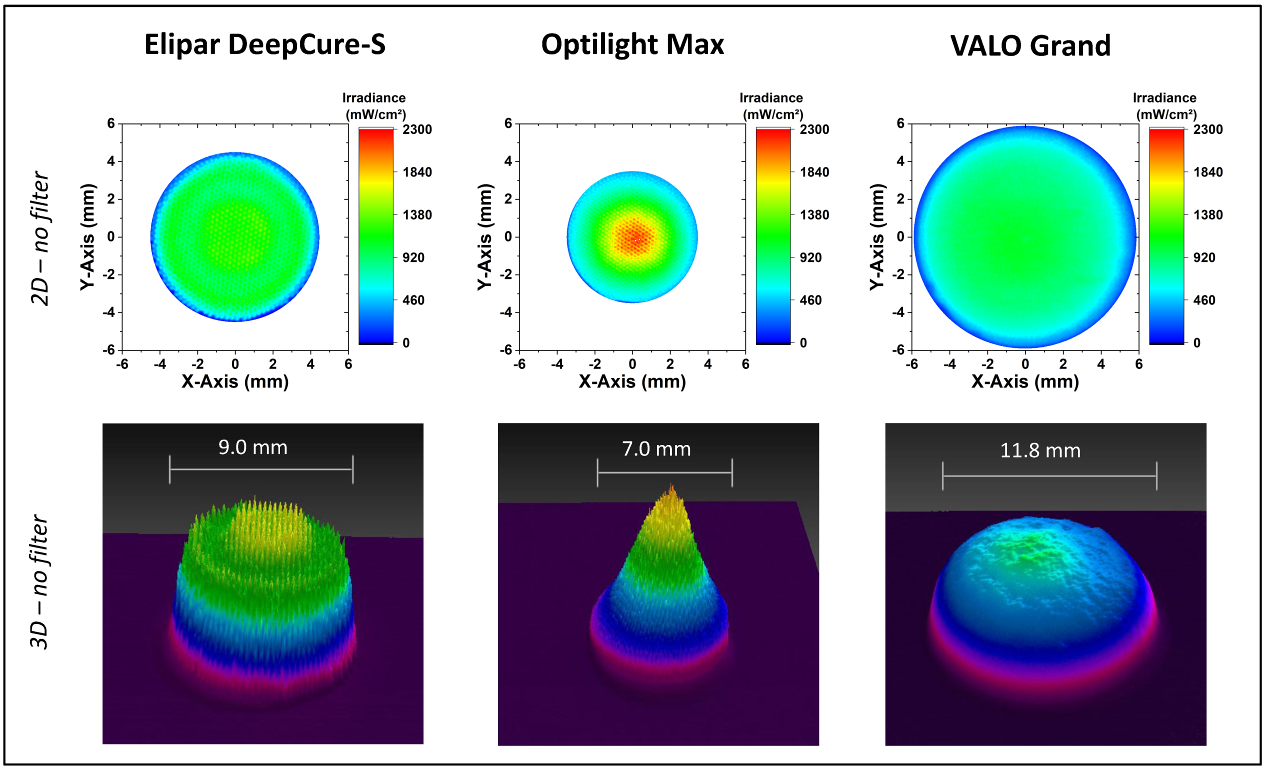


**Figure 4.** Two- and three-dimensional light beam profiles from the LCUs show the tip diameter and the irradiance (mW/cm$^2$). All the figures are on the same scale. The images represent the 0 mm distance from the light source tip to the 60° holographic screen. The same scale was used from the brightest light source. Note the difference in tip diameters from the 3 LCUs and the 'hot spot' of high irradiance from the Optilight Max.

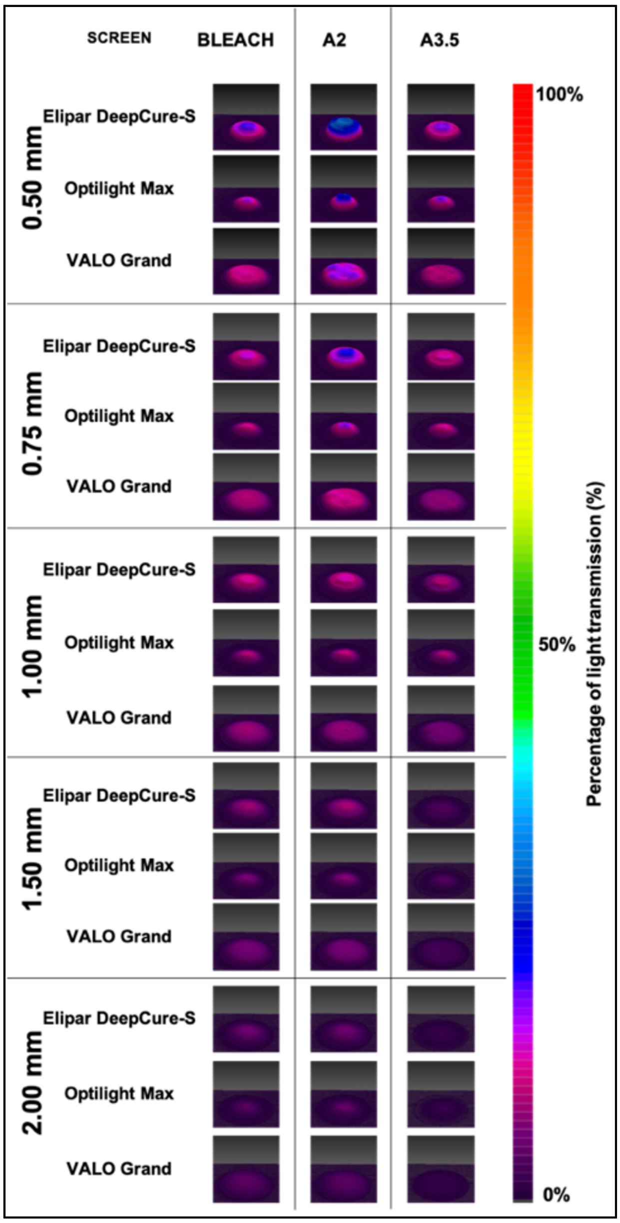


**Figure 5.** The three-dimensional representations of the beam profile captured using the standard mode of the LCUs through five thicknesses of CAD-CAM/RC in three shades (Bleach, A2 and A3.5 shades). The control images without CAD-CAM/RC (0 mm of distance) are presented at the top. Note the images taken are on the same percentage scales.

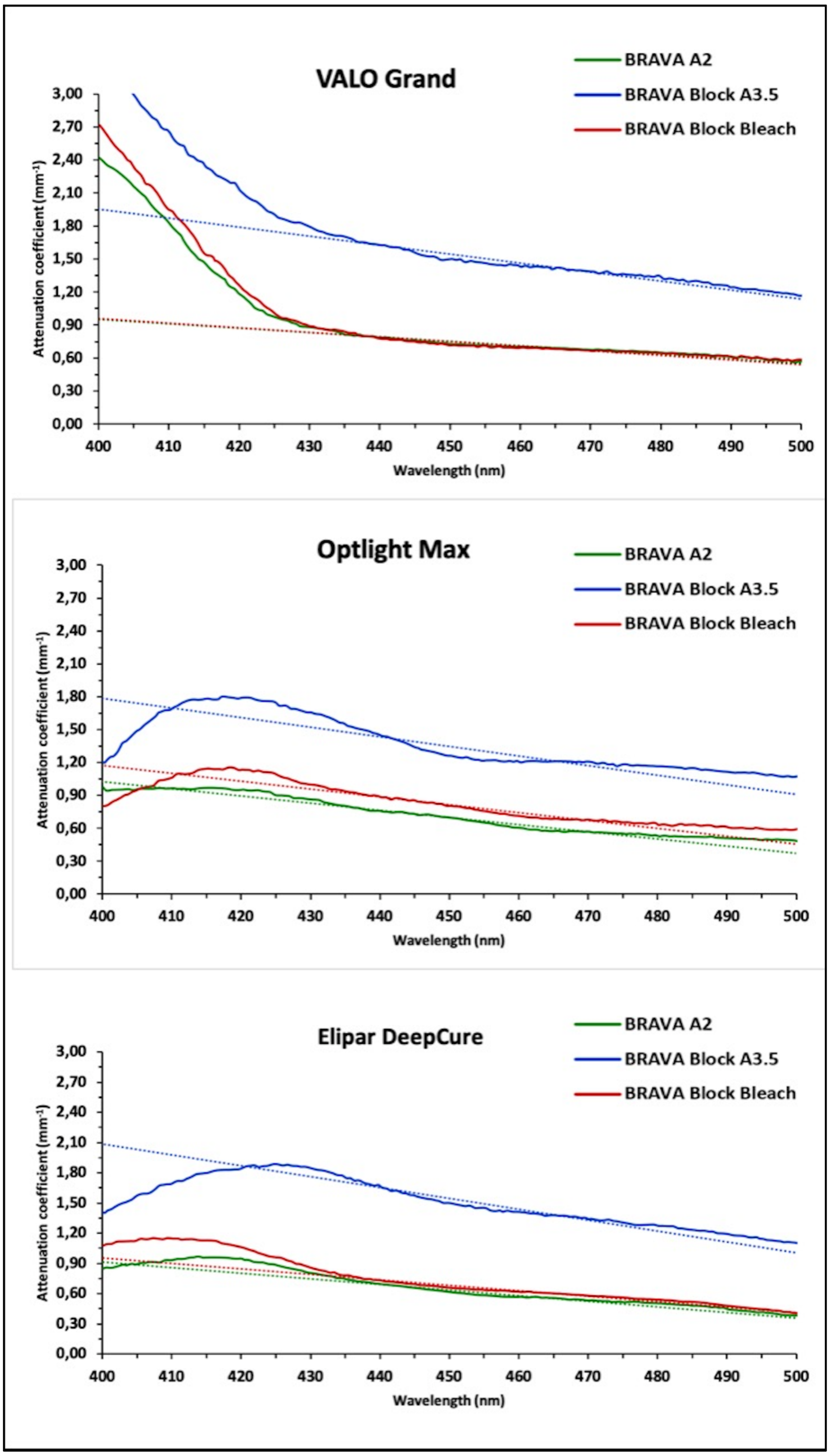


**Figure 6.** Light Attenuation Coefficients of the LCUs evaluated in relation to the thickness of the CAD/CAM blocks.

**Table 1.** The specifications of light-curing units (LCUs) used in this study.

| LCUs | Serial Number | LED LCU / wavelength emission | External Tip Diameter (mm) | Internal Tip Diameter (mm) | Manufacturer |
|---|---|---|---|---|---|
| Elipar DeepCure-S | 1521087817 | single-peak | 9.8 | 9.0 | 3M Oral Care, St Paul, MN, USA |
| Optilight Max | 881778249 | single-peak | 7.9 | 7.0 | Gnatus, Ribeirão Preto, SP, Brazil |
| VALO Grand | MFG3227-5 | multi-peak | 15.1 | 12.0 | Ultradent, South Jordan, UT, USA |

**Table 2.** The specifications of CAD-CAM resin composite blocks used in this study.

| LCUs | Composition | Shade | Serial Number | Manufacturer |
|---|---|---|---|---|
| BRAVA Block | Methacrylate monomers, initiator, co-initiator, stabilizers, silane, glass-ceramic particles, silica, and pigments. | A2 LT/14L | A2LT051220 | FGM, Joinvile, SC, Brazil |
| | | Bleach LT/14L | BLLT071120 | |
| | | A3.5 LT/14L | A35LT081220 | |

**Table 3.** Thee-way ANOVA for the emitted radiant power values (mW) emitted by 3 LCUs through the CAD-CAM/RC made in three shades and at five different thicknesses.

| **Source of Variation** | **Sum of Squares** | **DF** | **Mean of Squares** | **F** | ***P*** |
|---|---|---|---|---|---|
| LCU | 1028674.158 | 2 | 514337.079 | 4996.926 | < 0.001 |
| Thickness | 560630.625 | 4 | 140157.656 | 1361.670 | < 0.001 |
| Shade | 5076031.355 | 3 | 16438.346 | 6405.920 | < 0.001 |
| LCU x Thickness | 31114.954 | 8 | 3889.369 | 37.786 | < 0.001 |
| LCU x Shade | 496749.326 | 6 | 82791.554 | 804.343 | < 0.001 |
| Thickness x Shade | 93334.303 | 12 | 7777.859 | 75.564 | < 0.001 |
| LCU x Thickness x Shade | 14603.146 | 24 | 608.464 | 5.911 | < 0.001 |
| Error | 12145.823 | 118 | 102.931 | | |

## 3.3 CAPÍTULO 3

**Light transmission emitted by monowave and polywave® light-curing units through ceramic brackets**

Artigo a ser submetido para publicação no periódico **Angle Orthodontics**

**Light transmission emitted by monowave and polywave® light-curing units through ceramic brackets**

Julia Dantas Mazão[1], Maria Tereza Hordones Ribeiro[2], Stella Sueli Lourenço Braga[3], Guilherme de Araújo Almeida[4], Richard Bengt Price[5], Carlos José Soares[6]

[1] DDS, MSc, Ph.D. student, Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID:0000-0002-1102-672X, julia_mazao@hotmail.com

[2] DDS, MSc, Ph.D. student, Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: 0000-0002-5126-7931, mt_hribeiro@hotmail.com

[3]DDS, MSc, PhD, Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: 0000-0002-6883-4648 stellabraga2@hotmail.com

[4] DDS, MS, PhD, Professor Department of Orthodontic and Pediatric Dentistry, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: 0000-0002-5408-4268 guilhermealmeida@ufu.br

[5] DDS, MS, PhD, Professor Department of Dental Clinical Sciences, Dalhousie University, Halifax, Nova Scotia, Canada, ORCID: 0000-0001-6479-1436, richard.price@dal.ca

[6] DDS, MSc, PhD, Professor and Chair Operative Dentistry and Dental Materials Department, School of Dentistry, Federal University of Uberlândia, MG, Brazil. ORCID: 0000-0002-8830-605X, carlosjsoares@ufu.br

**Corresponding author:**

Dr. Carlos José Soares

Federal University of Uberlândia, School of Dentistry

Avenida Pará, 1720, Bloco 4L, Anexo A, Sala 42, Campus Umuarama.

Uberlândia - Minas Gerais – Brazil CEP. 38400-902

Email: carlosjsoares@ufu.br

Phone: +55 34 3218 2255, Fax: +55 34 3218 2279

**Conflict of Interest Statement**

The authors confirm that they have no conflict of interest.

**Keywords:** ceramic brackets, light transmission, light curing unit, light spectrum.

**Light transmission emitted by monowave and polywave® light-curing units through ceramic brackets**

**ABSTRACT**

**Statement of the problem**.

**Purpose.** Evaluate the light transmission trough the mono and polycrystalline ceramic brackets when light activated by monowave and polywave light curing units (LCUs).

**Materials and methods.** Two monowave LCUs: EL, Elipar DeepCure-S (3M Oral Care); OP, Optilight Max (Gnatus); and one polywave LCU: BF, Bluephase G4 (Ivoclar Vivadent) were tested in association with 5 brackets: 1 Monocrystalline Ceramic: ZE, Zetta (Eurodonto) and 4 polycrystalline alumina ceramic: CR, Ceramic Roth (Morelli); Iceram Safyra (Orthometric); PS, Poly Safyra (Morelli); TR, Translux (Aditek). The power (mW), emission spectrum (mW/cm²/nm) of LCU. The LCUs were positioned at 0 mm from the surface of the CAD-CAM material. The power (mW) and emission spectrum (mW/cm²/nm) were obtained using an integrating sphere and the beam profiles using a laser beam profiler.

**Results.** There was a significant reduction in the power and emission spectrum emitted by all LCU irrespective of the ceramic brackets ($P<.001$). The light transmission through PS bracket was significantly higher and through ZE was significantly lower than other tested brackets ($P<.001$). The violet wavelengths emitted by polywave LCU was more attenuated irrespective of tested brackets ($P<.001$).

**Conclusions.** The composition of the brackets influenced significantly on the light transmission emitted by mono and polywave LCUs. EL had better performance than OP and BF LCUs.

**CLINICAL IMPLICATIONS**

The use of polywave LCU used to fix ceramic brackets had no benefit since the violet wavelengths is almost totally blocked by mono and polycrystalline ceramic brackets.

## 1. Introduction

The force required for teeth moving is mediated by the orthodontic wires connected to the brackets.(Ribeiro et al., 2016) The bonding integration between orthodontic resin composites with enamel and metal or ceramic brackets are essential for the force transferring for periodontal ligament and bone tissues.(Goyal et al., 2013, Li et al., 2021)

Bracket bonding is one of the most time-consuming procedures in orthodontics.(Almeida et al., 2018) Light-cured, self-cured, or dual-cured orthodontic resin composites have been used in clinical practice.(Mandall et al., 2018; Arana et al., 2021) Light-cured materials have received the clinical preference due the faster procedure than self-cured materials,(Eliades et al., 2006) and also due the considerably reduction on time consuming, increasing treatment efficiency, and better patient comfort.(McCusker et al., 2013; Almeida et al., 2018) Bracket bonding can failure due to the inefficient orthodontic resin composites light-curing process, impacting on treatment effectiveness.(Alexopoulou et al., 2020)

Ceramic brackets have better color stability and esthetics perception than metallic. (Russel et al., 2005) The ceramic brackets are composed of aluminum oxide structured in polycrystalline or monocrystalline. (Russel et al., 2005) Monocrystalline brackets are composed of a single crystal produced from the combination of particles of aluminum oxide fused at a higher temperature (2100°C) and cooled slowly.(Mohamed et al., 2016) The crystallization process is controlled, which gives it a more translucent appearance. (Oliveira et al., 2014) Polycrystalline brackets are made of sintered or fused aluminum oxide particles. The translucent ceramic brackets allow direct irradiation for activating the light-cured orthodontic resin composites underneath the brackets. (Aldossary et al., 2018). The composition of the ceramic bracket can influence the light transmission and, consequently the light activation of orthodontic resin composites.(Alexopoulou et al., 2020) Enough light must pass through the bracket to determine adequate polymerization.(Lim & Lee, 2007) Some factors can interfere with light scattering during the bracket cementation, such as the bracket composition and the power of the LCU.(Niepraschk et al., 2007; Soyland et al., 2020)

The efficiency of the orthodontic resin composites polymerization depends on the power of the LCU used, tip irradiance, the distance from the LCU to the bracket, and the exposure time.(Heravi et al., 2013; Santini et al., 2016; Lee et al., 2016; Gupta et al., 2018; Aldossary et al., 2018) Recently, the use of polywave LCU in dentistry has been increased, including in orthodontics practice.(Faria-e-Silva et al., 2017) The light attenuation of the short wavelengths present in polywave LCU can also compromise the polymerization of luting materials mainly when they are light-activated using short-time activation.(Yilmaz et al., 2020)

Is scarce the information of the light transmission emitted by mono and polywave LCUs through the ceramic brackets with different compositions. Therefore, the aim of the study was to evaluate the light scattering through 5 different ceramic orthodontic brackets, with 3 different LCUs, two single-peak, and one multipeak LCUs. The null hypotheses were: 1) the ceramic brackets' composition would not influence the light transmission; 2) The monowave and polywave LCU would have no influence on the light attenuation through the orthodontic brackets.

## 2. Material and methods

### *2.1. Study design*

For evaluating the light transmission through the mono and polycrystalline ceramic brackets when light activated by monowave and polywave LCUs, 5 different ceramic orthodontic brackets were used: ZE (Zetta, Eurodonto, Curitiba, PR, Brazil), TR (Translux, Aditek, Cravilhos, SP, Brazil), PS (Poly Safyra, Morelli, Sorocaba, SP, Brazil), IR (Iceram Roth, Orthometric, Marília, SP, Brazil), CR (Ceramic Roth, Morelli, Sorocaba, SP, Brazil). The compositions of the tested brackets are described in Table 1. Two monowaveLCUs: EL (Elipar DeepCure-S; 3M-Oral Care, St Paul MN, USA) and OP (Optilight Max; Saevo, Ribeirão Preto, SP, Brazil) and one polywave LCU: BF (Bluephase G4, Ivoclar-Vivadent, Schaan, Liechtenstei) were used. The characteristics of the tested LCUs are described in Table 2. The power (mW) and emission spectrum (mW/cm$^2$/nm) of the LCUs were obtained using an integrating sphere (LabSphere; North Sutton) and the beam profiles using laser beam profiling (Ophir-Spiricon; Logan) whit and without the interposition of different tested brackets.

### *2.3 Total radiant power, irradiance, and emission spectrum*

The total radiant power (mW) and emission spectrum (mW/cm$^2$/nm) of the 3 LCUs were analyzed. Five measurements of the total radiant power (mW) emitted between 350 and 550 nm and spectral radiant power (mW/nm) from LCU's were measured using an integrating sphere (LabSphere; North Sutton) that was connected to a fiberoptic spectrometer (USB 4000, Ocean Insight). A radiometric calibration lamp LS-1-CAL-INT (Ocean Insight) was used to calibrate the system before the measurements were made. To measure the light transmitted only through each ceramic bracket, the ceramic brackets (n = 5) were individually positioned into the center of the 12mm external diameter and 8mm internal diameter black opaque plastic ring that was filled with silicone impression material (Take 1 Advanced, Kerr, Orange, CA, USA) exposing only the top and base of the brackets to the light. When measuring the output from the LCU only, the tip of the LCU was positioned 0-mm from the 12.0 mm aperture into the sphere, and all the light emitted from the LCU was captured by the integrating sphere. In addition, the light transmission through each ceramic bracket was accomplished positioning the LCU tip 0-mm from the matrix positioned over sphere aperture centralizing the center of LCU tip with the bracket. The light captured by the integrating sphere was only that passed through the brackets.

The LCU tip internal and external diameters were measured using a digital caliper (Absolute Digimatic Caliper, Mitutoyo). The tip area of each LCU was calculated from the inner diameter of the light tip. The mean radiant exitance (tip irradiance value) for the LCU was calculated as the quotient of the average of the five radiant power values and the internal optical area of the LCU's tips. These data provided the averaged single tip irradiance value that is commonly reported by manufacturers and used in ISO 10650. (ISO)

### *2.4 Beam profile*

The light beam profiles of light transmitted through the 5 different ceramic brackets were measured using a laser beam profiler charge-coupled device (CCD) digital camera (Ophir-Spiricon, Logan, UT, USA) with a 50 mm focal length lens (SP620U; Ophir-Spiricon) that was fixed at the focal distance from the orthodontic bracket. Two blue filters (HOYA UV-VIS colored glass bandpass filter, Edmund Optics, Barrington, NJ, USA) and one neutral density filter (Edmund Optics; Barrington) were required to flatten the spectral response of the CCD camera. The LCU's was mounted in a fixed orientation and positioned 0 mm distance from the bracket surface embedded into the plastic ring. All the images were captured by the camera at the same distance, position, and exposure time, making them comparable. The three-dimensional images were collected using the beam analyzer software (BeamGage Professional version 6.14; Ophir-Spiricon). The control two-dimensional beam profile images were used the internal tip diameter (mm) of each LCU, the "Optical Scaling" tool in the BeamGage Professional (Ophir-Spiricon) software produced calibrated the beam profile data in millimeters. The mean radiant power values (mW) previously obtained were then entered into the beam analyzer software to produce color-coded calibrated tip irradiance in $mW/cm^2$ images. The calibrated data from BeamGage Professional (Ophir-Spiricon) were then exported into OriginPro 2019 version 9.6. (OriginLab, Northampton, MA, USA) where the images were all scaled to the same irradiance levels and x and y dimensions.

### *2.5. Statistical Analysis*

Radiant power and irradiance data were analyzed for normal distribution and homoscedasticity using the Shapiro-Wilk and Levene's tests. Two-way ANOVA was used to compare the interactions between study factors: LCUs (3 levels) and orthodontic brackets (5 levels). Multiple comparisons were made using Tukey's post-hoc test. All tests used a significance level of $\alpha = 0.05$, and all analyses were performed using Sigma Plot 13.1 (Systat Software Inc). The emission spectrum ($nm/mW/cm^2$) and beam profile were analyzed descriptively.

### 3. Results

The mean and standard deviation of radiant power (mW) emitted by three LCUs transmitted through the ceramic brackets are shown in Figure 1. Two-way ANOVA showed significant effect for LCU factor ($P < 0.001$), for bracket factor ($P < 0.001$) and also for interaction between LCU and bracket ($P < 0.001$). The EDC and BG4 had significantly higher power than OPM when measured without the interposition of brackets (control – $P < 0.001$). However, the BG4 had significantly lower power passed light than the other 2 LCUs irrespective of testes brackets. The EDC had higher power than OPM only for the bracket with higher translucency – PolySafyra. The Dunnet test showed that the interposition of brackets significantly reduced the light transmission through all tested brackets compared with the control group, irrespective of LCU ($P < 0.001$). The PolySafyra bracket had significantly higher and the Zetta bracket had significantly lower light transmitted than all tested brackets, irrespective of light transmission.

The radiant power (mW) during the 10 s exposure time transmitted without the interposition of brackets (control) and through the ceramic brackets for each LCU is shown in Figure 2. Without brackets interposition, the Optilight Max had significantly lower radiant power than Elipar Deep Cure S and Bluephase G4 ($P < 0.001$). When the radiant power was recorded under the ceramic brackets, the light attenuation was significantly higher for polywave LCU Bluephase G4 than Elipar Deep Cure S. The ceramic brackets attenuated significantly the light emitted for all LCUs ($P < 0.001$). The ceramic bracket composition influenced significantly the radiant power emitted by LCU ($P < 0.001$). PS had the higher and ZE bracket had the lower values of radiant power, irrespective of the LCU evaluated.

The emission spectrum (mW/cm²/nm) for the three LCUs without the interposition of bracket (control) and through the five ceramic brackets are shown in Figure 3. The bracket composition influenced significantly the light transmission emitted for all LCU evaluated ($P < 0.01$). The light distributions measured by beam profile for the three LCUs with the interposition of five brackets are shown in Figure 4. The light beam profiles showed the significant effect of different ceramic brackets on the transmitted light, irrespective of LCU.

Light transmission was affected by the type of ceramic bracket. PS had the higher and Zetta had the lower light transmitted, irrespective of the LCU.

## 4. Discussion

This study evaluated the influence of the bracket on the light transmission emitted by single-peak and multiple-peak LCUs. The composition of the bracket had a significant influence on the radiant power and light spectrum attenuation; thus, the first null hypotheses were rejected. The findings of this study also showed that the polywave LCU had significantly higher light attenuation than monowave LCUs, irrespective of composition of the ceramic brackets; thus, the second null hypotheses were also rejected.

Monocrystalline and polycrystalline alumina brackets from different brands were tested in this study. The composition of the bracket influenced light transmission, demonstrating that the ceramic composition expressed by the crystallization process during bracket fabrication influences the translucency and consequently the light attenuation. The PolySafira, which is a polycrystalline alumina ceramic bracket, had a significantly lower light attenuation compared with another also polycrystalline alumina ceramic bracket. This can be explicated by the composition and the treatment design of the bracket. The grain boundaries and impurities present in ceramic brackets refract light, resulting in opacity and consequently in light scattering.(Swartz et al., 1988; Santini et al., 2016) The Zetta, which is a monocrystalline bracket, had a higher light attenuation than all tested brackets. However, in the literature, it is known that monocrystalline ceramic brackets allow a greater passage of light.(Santini et al., 2016; Mohamed et al., 2016) This demonstrates that the passage of light cannot be defined only by the basic composition (mono or polycrystalline ceramic). This is dependent on the specific material and the way it was used in manufacturing.  The clinician should seek specific information and manufacturers should report this in the guidelines

When LCUs were compared without the bracket interposition, Bluephase G4 and Elipar Deep Cure demonstrate higher power and a more homogeneous light emission profile than Optilight Max (Figure 2). While Bluephase G4 and Elipar Deep Cure have a large tip, with a more homogeneous light, Optilight Max presents a smaller diameter tip and the light was concentrated on the center area of the LCU tip (Figure 4). The irradiance value from the LCU can be increased without increasing the power output simply by reducing the internal tip diameter.(Soares et al., 2021) This generates a false sensation of high irradiance.(Shimokawa et al.,2016) However, this irradiance is basically concentrated in the center with an inhomogeneous light distribution across the tip, which may compromise the polymerization process across different bracket sizes.

The interposition of the ceramic brackets promoted great light attenuation due to the absorption and scattering of the light caused by ceramic brackets. The brackets designs are a complex and great amount of the transition of the surface and irregularities, necessary to adapt the wires and create specific forces for resulting in tooth movement. However, these complex shape variations cause more light scattering.(Mohamed et al., 2016) The effect of attenuation was significantly more evident for the multi-peak light source - Bluephase G4. This can be explained by the phenomenon of Rayleigh scattering.(Huang et al., 2020) The amount of light scattering is directly related to the wavelength of light.(Mazao et al., 2022) The shorter wavelengths of violet light do not penetrate as deeply as the longer wavelengths of blue light.(Sampaio et al., 2017) As the thickness of the bracket is large, the attenuation of violet light is even more evident.

A quality bracket cementation depends on several factors.(Niepraschk et al., 2007; Lim 2007) The type of bracket, its composition, the cementing material, and the expousuring time. (Lee, 2016) For effective cementation, enough light must reach the adhesive-tooth interface.(Aldossary et al., 2018) Some manufacturers recommend a light activation time of 5 seconds for each bracket. (Santini et al., 2016) However, a light-curing time of 20 seconds delivers more effective energy, creating better and more stable bracket fixation.(Santini et al., 2016, Hooshmand et al., 2009) Usually, by extending the irradiation times beyond the manufacturer's recommendations, an adequate curing result can be achieved.(Santini et al., 2010)

The cementation of metallic brackets is limited to the edges of the bracket base.(Sunna et al., 1999) The curing of the resin composite layer under metallic brackets can be performed from mesial and distal aspects for 20 s each.(Oesterle et al., 1995) The trans-illumination technique also has been proposed for this intention.(Heravi et al., 2013) For the cementation of ceramic brackets, it is assumed that light passes through the bracket.(Lim et al., 2006) Even so, a proper combination of light-activated resin-based orthodontic adhesive, and LCU should offer an optimum polymerization that allows more uniform and greater bond strength during the bonding of ceramic brackets. (Santini et al., 2016) It might be a problem, depending on the luting material used to fix the ceramic brackets.(Mohamed et al., 2016) The main photoinitiator used in orthodontic resinous composites is camphorquinone (CQ), a dark yellow compound which, at high concentrations in the resin formulation, may result in an undesirable yellowing effect. (Delgado, 2019) To optimize the aesthetic effect, different photoinitiators, such as Bis-acylphosphine oxide (BAPO) and phenylpropane (PPD) have been tested.(Roseira et al., 2022) These photoinitiators are more sensitive to violet light. (de Oliveira et al., 2016) The results of this study demonstrated that the use of monowave LCU tend be more adequate for light curing resin composite material used to fix ceramic brackets. Also, the results suggested that industry tendency to produce resin composite materials indicated for cementing ceramic brackets using more camphorquinone photoinitiator tend to be adequate.

This study has some limitations, the light transmission was calculated only passed through the ceramic brackets. In clinical situation the light applied obliquely to the base of the brackets can minimize the light attenuation caused by ceramic brackets. Clinical studies are required to understand better the real influence of multi or single-peak lights on the cementation of different ceramic brackets.

## 5. Conclusion

Within the limitation of this study the following conclusions can be drawn:

- The use of polywave LCU resulted in significantly higher light attenuation caused by different ceramic brackets;
- The composition of the bracket affects the light transmission of violet and blue light;

- The Polysafyra brackets had the lowest light attenuation and Zetta bracket had the highest light attenuation irrespective of tested LCU;
- The great difference of the light emitted by tested LCU was significantly reduced when the ceramic brackets were interposed;
- The violet light scatters more than the blue light through the bracket.

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**Table 1.** The specifications of light-curing units (LCUs) used in this study.

| LCUs | Serial Number | LCU / wavelength emission | External Tip Diameter (mm) | Internal Tip Diameter (mm) | Tip - light conductor | Manufacturer |
|---|---|---|---|---|---|---|
| Elipar DeepCure-S | 1521087817 | Single-peak | 9.8 | 9.0 | Optical fiber - translucent | 3M Oral Care, St Paul, MN, USA |
| Optilight Max | 881778249 | Single-peak | 7.9 | 7.0 | Optical fiber - black | Gnatus, Ribeirão Preto, SP, Brazil |
| Bluephase G4 | 1404000004 | Multi-peak | 9.9 | 9.0 | Optical fiber with mixer - black | Ivoclar-Vivadent, Schaan, Liechtenstei |

**Table 2.** The specifications of brackets used in this study.

| Brackets | Code | Composition | Size (mm) | Manufacturer |
|---|---|---|---|---|
| Ceramic Roth | CR | Polycrystalline Alumina Ceramic | 3.9 | Morelli, Sorocaba, SP, Brazil |
| Iceram Safyra | IR | Polycrystalline Alumina Ceramic | 3.5 | Orthometric, Marilia, SP, Brazil |
| Poly Safyra | PS | Polycrystalline Alumina Ceramic | 3.9 | Morelli, Sorocaba, SP, Brazil |
| Translux | TR | Polycrystalline Alumina Ceramic | 3.5 | Aditek, Cravinhos, SP, Brazil |
| Zetta | ZE | Monocrystalline Ceramic | 3.5 | Eurodonto, Curitiba, PR, Brazil |

**Table 3.** Means and standard deviations of the radiant power (mW) of each LCU measured using integrate sphere of control (without bracket) and through the five different ceramic brackets.

| **Groups** | **Elipar Deep Cure** | **Bluephase G4** | **Optilight Max** |
|---|---|---|---|
| **Control – no bracket** | 608.5 ± 1.9 $^{a}$ | 588.0 ± 3.2 $^{a}$ | 375.9 ± 4.2 $^{b}$ |
| **Poly Safira** | 85.0 ± 0.8 $^{Aa*}$ | 54.2 ± 0.6 $^{Ac*}$ | 61.5 ± 0.7 $^{Ab*}$ |
| **Translux** | 44.6 ± 0.6 $^{Ba*}$ | 28.7 ± 0.2 $^{Bb*}$ | 45.2 ± 0.2 $^{Ba*}$ |
| **Ceramic Roth** | 41.8 ± 0.5 $^{Ba*}$ | 30.3 ± 0.4 $^{Bb*}$ | 33.4 ± 2.1 $^{Bb*}$ |
| **Iceram Roth** | 39.5 ± 0.7 $^{Ba*}$ | 25.6 ± 0.3 $^{Bb*}$ | 37.7 ± 0.4 $^{Ba*}$ |
| **Zetta** | 23.9 ± 0.7 $^{Ca*}$ | 15.5 ± 0.3 $^{Cb*}$ | 23.0 ± 0.5 $^{Ca*}$ |

Different letters indicate a significant difference calculated using two-way ANOVA (P < 0.05); upper caser letters were used for comparing LCUs; lower caser letters were used for comparing restorative material (Tukey Test); *indicate difference significant for comparison between each bracket with control group (Dunnet test).

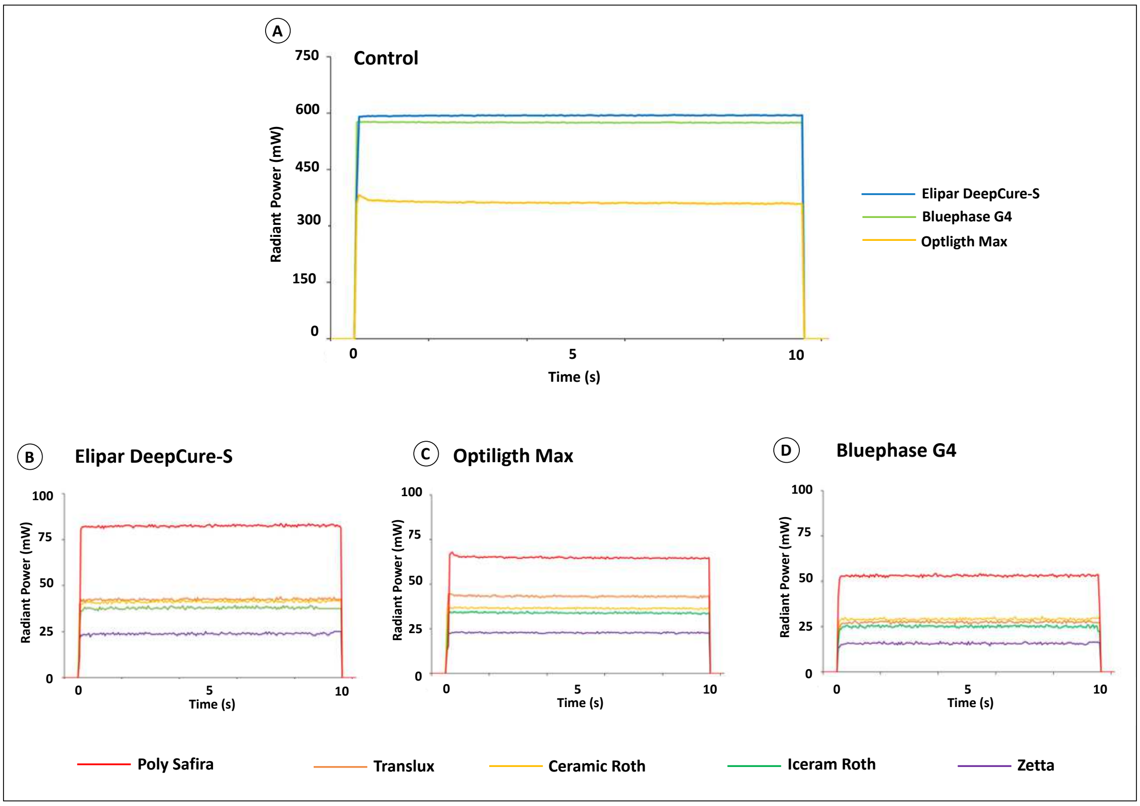


**Fig 1.** Radiant power (mW) emitted during 10s at the standard output mode of Elipar DeepCure-S, Optilight Max and Bluephase G4 tested without ceramic brackets and through five different brackets. Note the image control are in different scales.

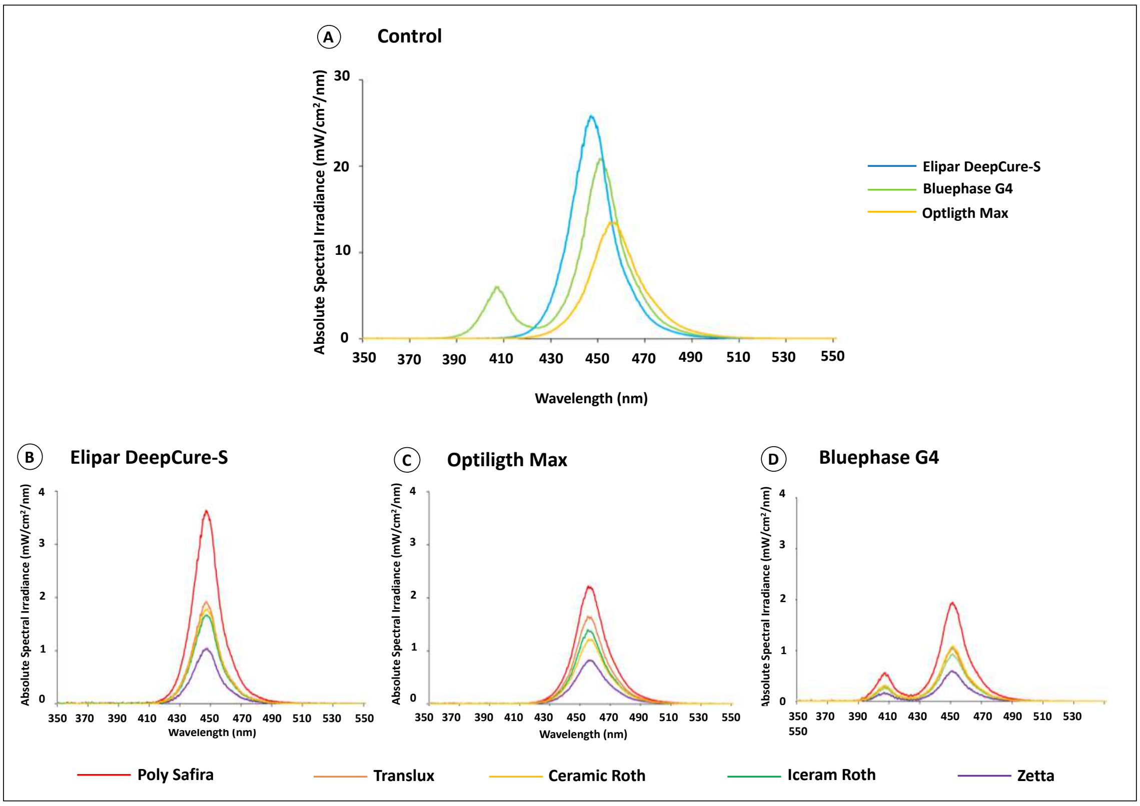


**Fig 2.** Emission spectrum (mW/nm) emitted from the LCUs tested through the five different ceramic brackets. Note the images control are in different scales.

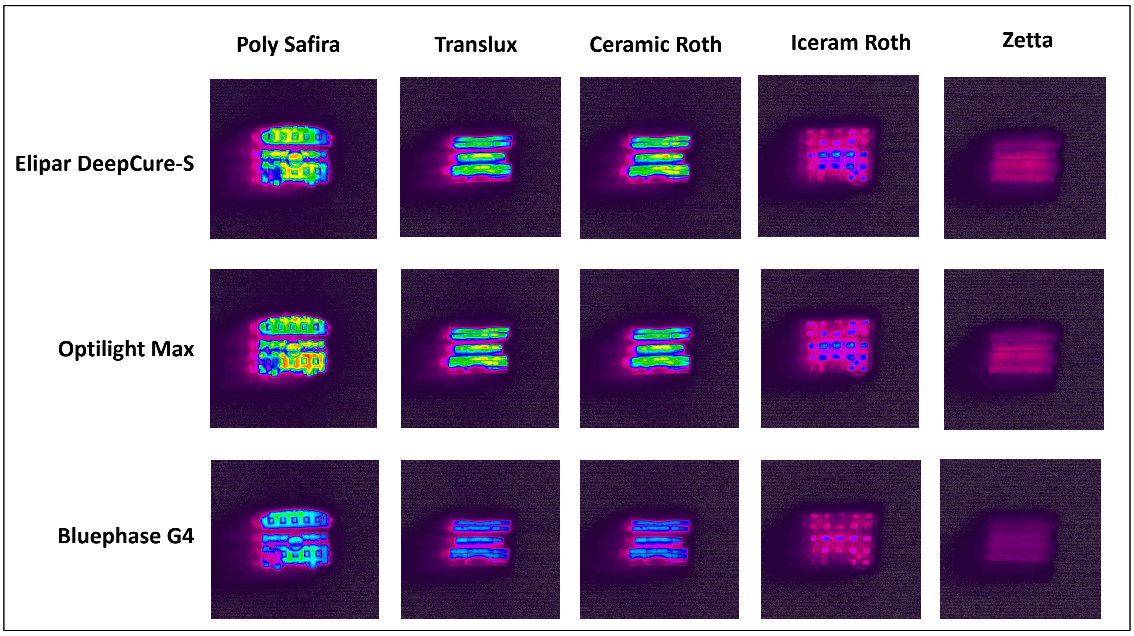


**Fig 3.** The three-dimensional representations of the beam profile captured using the standard mode of the LCUs through five different ceramic brackets. The images are in same scale.

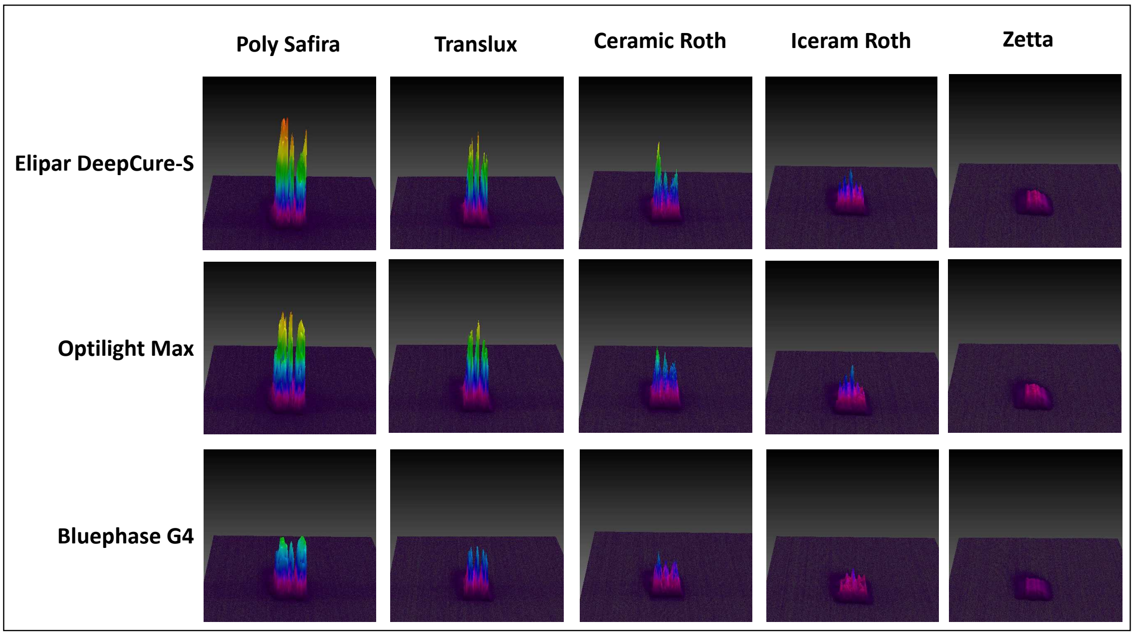


**Fig 4.** The two-dimensional representations of the beam profile captured using the standard mode of the LCUs through five different ceramic brackets. The images are in same scale.

# Considerações Finais

# 4. CONSIDERACÕES FINAIS

Considerando as limitações metodológicas deste estudo, pode-se concluir que:

O aumento da espessura da cerâmica reduziu grandemente e exponencialmente a irradiância. Esta redução foi mais nítida nos comprimentos de onda mais curtos (violeta) da luz, com uma diminuição de 82% quando a cerâmica tinha 1 mm de espessura. O aumento da espessura da cerâmica não afetou o grau de conversão, independente dos fotoiniciadores utilizados nos materiais de cimentação testados. A posição dos LEDs violeta e azul dentro do corpo da fonte de luz não influenciou a dureza Knoop ou o módulo de elasticidade em nenhuma das resinas testadas.

A espessura do compósito teve um efeito significativo sobre a potência radiante, a irradiância para todos os LEDs testados; A cor A3,5 teve maior influência na transmissão de luz do que as cores Bleach ou A2.

O tipo de LED influencia a dispersão da luz através do braquete. A luz violeta se espalha mais do que a luz azul pelo braquete. A composição do braquete afeta a transmissão da luz violeta e azul. Pode-se concluir que a irradiância e potência do LED sofrem influência da espessura, composição e tom do material. A luz violeta sofre mais dispersão que a luz azul, em maiores espessuras.

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# Anexos

### 6.1 Normas dos periódicos

1. Operative Dentistry

https://www.jopdent.com/authors/authors.php

2. Journal of Prosthetic Dentistry

https://www.thejpd.org/content/authorinfo

3. Angle Orthodontics

https://progressinorthodontics.springeropen.com/submission-guidelines