UNIVERSIDADE ESTADUAL DE CAMPINAS

Faculdade de Odontologia de Piracicaba

JORGE RODRIGO SOTO MONTERO

INFLUÊNCIA DA PONTA HOMOGENEIZADORA DE UM APARELHO FOTOATIVADOR LED NA MICRODUREZA DA SUPERFICIE E DA BASE DE RESINAS COMPOSTAS

INFLUENCE OF A LED CURING UNIT BEAM HOMOGENIZATION TIP ON THE TOP AND BOTTOM MICROHARDNESS OF COMPOSITE RESINS

Piracicaba

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Dissertação apresentada à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas como parte dos requisitos exigidos para a obtenção do título de Mestre em Clínica Odontológica na área de Dentística.

Dissertation presented to the Piracicaba Dental School of the University of Campinas in partial fulfillment of the requirements for the degree of Master in Clinical Dentistry, in Operative Dentistry area.

Orientador: Prof. Dr. Marcelo Giannini.

ESTE TRABALHO CORRESPONDE À VERSÃO FINAL DA DISSERTAÇÃO DEFENDIDA PELO ALUNO JORGE RODRIGO SOTO MONTERO E ORIENTADA PELO PROF. DR MARCELO GIANNINI

Piracicaba

2019

Agência(s) de fomento e nº(s) de processo(s): Não se aplica.
ORCID: https://orcid.org/0000-0003-2257-7049

Ficha catalográfica
Universidade Estadual de Campinas
Biblioteca da Faculdade de Odontologia de Piracicaba
Marilene Girello - CRB 8/6159

So78i Soto Montero, Jorge Rodrigo, 1985-
Influência da ponta homogeneizadora de um aparelho fotoativador LED na microdureza da superfície e da base de resinas compostas / Jorge Rodrigo Soto Montero. – Piracicaba, SP : [s.n.], 2019.

Orientador: Marcelo Giannini.
Dissertação (mestrado) – Universidade Estadual de Campinas, Faculdade de Odontologia de Piracicaba.

1. Fotopolimerização. 2. Resinas compostas. I. Giannini, Marcelo, 1969-. II. Universidade Estadual de Campinas. Faculdade de Odontologia de Piracicaba. III. Título.

Informações para Biblioteca Digital

Título em outro idioma: Influence of a LED curing unit beam homogenization tip on the top and bottom microhardness of composite resins
Palavras-chave em inglês:
Photopolymerization
Composite resins
Área de concentração: Dentística
Titulação: Mestre em Clínica Odontológica
Banca examinadora:
Marcelo Giannini [Orientador]
Carlos Rocha Gomes Torres
Vanessa Cavalli Gobbo
Data de defesa: 18-02-2019
Programa de Pós-Graduação: Clínica Odontológica

Informações académicas e profissionais do aluno

Currículo Lattes: http://lattes.cnpq.br/4401345389328820

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Faculdade de Odontologia de Piracicaba

A Comissão Julgadora dos trabalhos de Defesa de Dissertação de Mestrado, em sessão pública realizada em 18 de Fevereiro de 2019, considerou o candidato JORGE RODRIGO SOTO MONTERO aprovado.

PROF. DR. MARCELO GIANNINI

PROF. DR. CARLOS ROCHA GOMES TORRES

PROFª. DRª. VANESSA CAVALLI GOBBO

A Ata da defesa, assinada pelos membros da Comissão Examinadora, consta no SIGA/Sistema de Fluxo de Dissertação/Tese e na Secretaria do Programa da Unidade.

DEDICATÓRIA

Primeiramente eu quero dedicar este trabalho aos meus pais **Jorge** e **Emilia**, por ter sido meus primeiros guias e os principais responsáveis pela formação da minha identidade. Sendo que além da educação humanista que sempre recebi deles, me deram as ferramentas e estímulos para minha formação académica e profissional antes de eu entender a importância e as oportunidades que isso traria para minha vida. Minha mãe, com uma visão excepcional, sempre me estimulou a dar cada dia um esforço maior e melhor, sabendo qual é o meu potencial como pessoa. Meu pai, o homem sereno, calmo e incondicional com a família, que sempre foram fonte de apoio, mas principalmente de amor.

A minha irmã **María Alejandra,** quem foi e sempre será minha grande protetora, mas também minha maior desafiadora, quem sempre me deu um motivo para me superar, e é por tentar ser como você que sempre busquei ser melhor, e além disso, agora, me deu mais dois motivos de alegria, **Dante e Saúl.** A ela e seu marido **Braulio,** um grande abraço na distância.

À minha avó **Nena** por todo amor e carinho que sempre teve comigo, e por ser o exemplo de ser humano que toda família pode desejar. A minha avó **Rosa,** que com seu caráter forte é um exemplo de tenacidade. Aos meus avós **Jorge** e **Rodrigo,** que apesar do pouco tempo compartilhado, marcaram minha vida com exemplos e experiências inesquecíveis.

E finalmente, mas em primeiro lugar no meu coração, eu quero dedicar este trabalho a **Alejandra** e **Kristel**, que são a motivação para tentar me superar cada dia, e são a melhor companhia que eu poderia ter nesta aventura que começamos juntos há quase dois anos. Nossa experiencia familiar me ensinou, que todos os dias aprendemos um pouco de nós mesmos e do outro, e por isso, este e todos meus futuros projetos espero que sejam exemplo e inspiração para continuar aprendendo a apoiar-nos e amar-nos mais um pouco cada dia.

Este trabalho eu dedico a vocês.

AGRADECIMENTOS

Ao meu orientador **Prof. Dr. Marcelo Giannini** por ter sido mais do que um orientador e ter se convertido em um grande amigo, mesmo tendo me recebido sem me conhecer previamente. O compromisso e dedicação com que você desenvolve seu trabalho docente, é um grande exemplo de ética profissional. Além disso, e ainda mais importante, a sua qualidade humana demostra que o sucesso profissional pode e deve sempre ser acompanhado de humildade e respeito às outras pessoas.

Agradeço também à **Universidade de Costa Rica**, na pessoa do seu Reitor **Prof. Dr. Henning Jensen Pennington**, que como instituição comprometida com o desenvolvimento da sociedade costarriquenha, sempre me deu o apoio necessário para estudar, em primeira oportunidade o curso de graduação, e depois como docente, me abriu a oportunidade de continuar meus estudos no estrangeiro, permitindo-me receber uma educação de primeiro nível. Todo esse apoio, eu espero poder devolver com meu trabalho docente. Agradeço também de maneira geral a todo o corpo docente e administrativo da **Faculdade de Odontologia** e ao **Escritório de Assuntos Internacionais**. O esforço conjunto de muitas pessoas em essas entidades, foi fundamental para conseguir completar este projeto. **#SoyUCR**.

À **Faculdade de Odontologia de Piracicaba**, na pessoa do seu Diretor **Prof. Dr. Francisco Haiter Neto,** por me abrir as portas para eu cumprir o objetivo de completar este mestrado, e fornecer as ferramentas necessárias para receber educação em um programa de excelência, como é o caso Do **Programa de Pós-Graduação em Clínica Odontológica.**

A todos os Professores da área de Dentística, **Débora Alves Nunes Leite Lima, Flavio Henrique Baggio Aguiar, Giselle Maria Marchi Baron, Luís Alexandre Maffei Sartini Paulillo, Luís Roberto Marcondes Martins e Vanessa Cavalli Gobbo,** por todos os ensinamentos e por ter propiciado o desenvolvimento profissional durante as disciplinas do mestrado.

Ao **Departamento de Bioquímica Oral**, por abrir as portas do seu Laboratório para a desenvolver parte desta pesquisa.

Ao meu colega e coautor deste trabalho **Gabriel Nima** pelo apoio, interesse e ajuda na realização deste. Você é uma pessoa admirável e tornou se um dos meus melhores amigos nesta cidade, além de ter me ensinado muito ao longo do desenvolvimento desta pesquisa.

Ao **Prof. Frederick Allen Rueggeberg**, também coautor deste trabalho, obrigado pelo suporte que propiciou o desenho e a condução deste trabalho.

Ao **Prof. Dr. Carlos Tadeu**, também coautor, obrigado pela grande contribuição e suporte na realização da análise estatística.

Aos colegas do mestrado **Beatriz, Danielle, Enrico, Giovana, Janaina, Joyce, Larissa, Marcela, Marco, María, Matheus e Priscila**, pela companhia durante estes dois anos.

Aos amigos adquiridos com o tempo, tanto na Dentística quanto em outros programas **Bruna, Carolina, Eduardo, Daylana, Maicon, Mayara, Paulo e Vitaliano,** pelos momentos compartilhados dentro e fora do ambiente de trabalho.

Aos meus grandes amigos **Fabián Murillo** e **Laura Valerio,** com eles sou eternamente grato por primeiramente ter me recebido no seu lar, e uma vez cheguei morar no Brasil, pelo apoio, orientação e companhia, mas principalmente pelo carinho e amizade. Saudades de vocês. Un abrazo y muchas gracias!

A **José Manuel** e **Luisa**, por ter me dado a primeira oportunidade no começo da minha carreira profissional. Vocês são um exemplo a seguir e espero algum dia poder devolver para vocês parte de tudo o que vocês deram para mim!

A minha maravilhosa **família** que ficou na Costa Rica, pelo amor e carinho que sempre tiveram comigo, e por ter participado da minha formação pessoal e mesmo de longe, me apoiado para alcançar meus sonhos. E principalmente dou graças a Deus pela **FAMILIA** que me permitiu formar, e que cada dia me acompanha aqui no Brasil. Agradeço a elas pela tolerância, amor, paciência e companhia, mesmo quando por algum motivo eu não pude dar para elas a atenção que merecem.

A todas aquelas pessoas que influenciaram positivamente minha vida, e de uma ou outra maneira estiveram, estão ou estarão me apoiando e torcendo por mim, eu agradeço desde o mais profundo do meu coração.

Muchas gracias!

RESUMO

O objetivo do estudo foi avaliar o efeito de diferentes pontas transmissoras de luz de um aparelho fotoativador na microdureza da superfície e da base de resinas compostas convencionais e do tipo *bulk-fill*, que contem diferentes fotoiniciadores como canforoquinona, Lucirin-TPO ou Ivocerin. Adicionalmente, foi analisado o perfil do feixe de luz emitido por cada ponta. Foi usado um aparelho fotoativador LED *polywave* Bluephase Style (Ivoclar Vivadent AG) e duas pontas transmissoras de luz desenhadas para uso nesse aparelho, uma ponta regular (RT) com emitância de 935 mW/cm^2 e uma ponta homogeneizadora (HT), com emitância de 851 mW/cm^2. Foram testadas duas resinas convencionais (Herculite Ultra, Kerr Corp (HER), e Tetric EvoCeram, Ivoclar Vivadent AG (TEC)) e duas resinas tipo *bulk-fill* (SonicFill, Kerr Corp (SOF). e Tetric EvoCeram Bulk Fill, Ivoclar Vivadent AG (TBF)). Foram fabricados corpos de prova em formato de disco, com 10mm de diâmetro e 2mm de espessura no caso das resinas convencionais, e 4mm de espessura para as resinas *bulk-fill*. Os discos foram polimerizados o tempo indicado pelos fabricantes, mantendo o aparelho fotoativador em uma posição fixa. A posição de saída da luz emitida por cada um dos três LED do aparelho fotoativador (sendo que dois chips emitem luz azul com um pico de emissão de 456nm, o terceiro chip produz luz violeta com um pico de 409nm) foi sinalizada na ponta e marcada nos discos, como referência para as medições posteriores. Foi medida a microdureza superficial Knoop (KHN), do topo e da base de cada disco, no ponto central de incidência da luz emitida por cada chip. Os dados da caracterização da luz foram analisados com um teste *t* de Student. Os dados de microdureza foram analisados com ANOVA de 3 fatores (LED, topo ou base, e tipo de ponta; $\alpha = 0.05$). As imagens do perfil de feixe de luz demostraram melhor distribuição da luz na ponta transmissora, quando foi usada a HT. O uso da HT também resultou em uma diminuição da microdureza de HER nas posições associadas aos LED azuis na base dos discos, mas não produz diferença no topo. Em TEC, o uso da HT aumentou a microdureza no topo nas regiões dos três LED. O uso da HT produz um aumento na microdureza de SOF na posição de um dos LED azuis, e do LED violeta, na base, e em TBF aumentou a dureza do topo nas posições de todos os LED. Em todas as resinas testadas, a dureza media da superfície dos discos foi maior, do que na base. De maneira geral, a dureza foi maior nas regiões dos LED azuis, do que na região do LED violeta, tanto no topo, quanto nas bases dos discos, independentemente da ponta transmissora usada. Os resultados sugerem que o uso da ponta homogeneizadora pode aumentar a microdureza da superfície de resinas compostas que apresentam fotoiniciadores alternativos, mas o efeito é perdido na base do material.

Palavras chave: Fotopolimerização, resinas compostas.

ABSTRACT

The purpose of this study was to evaluate the effect of a light guide (regular or homogenizing) from a light curing unit (LCU) on the top and bottom microhardness of conventional and bulk-fill composites disks, and to analyze the beam profile produced by each light guide. A polywave LED LCU Bluephase Style (Ivoclar Vivadent AG) with two different light guides were used: a regular tip (RT), with an emittance of 935 mW/cm^2, and a homogenizer tip (HT), with an emittance of 851 mW/cm^2.Two conventional composites (Herculite Ultra (HER), Kerr Corp and Tetric EvoCeram (TEC), Ivoclar Vivadent AG) and two bulk-fill composites (SonicFill (SOF), Kerr Corp and Tetric EvoCeram Bulk Fill (TBF), Ivoclar Vivadent AG). Disk-shaped composite samples, with a 10 mm diameter and 2 mm thickness for conventional composites and 4 mm thickness for bulk-fill composites were prepared. Samples were light cured according to the manufacturers recommended times, keeping the LCU in a fixed position, with external marks in the light guides to determine the areas for hardness measurements, which corresponded to the location of the three LED chips, emitting blue and violet light (two chips with emission peak at 456nm and one chip at 409nm). Knoop microhardness was measured at the top and bottom surface of each specimen in the central in irradiance spot of each chip. Microhardness data for each composite was analyzed by 3-way ANOVA ($\alpha=0.05$). Beam profile images showed better light distribution across the surface of the light guide when HT was used. Using HT decreased microhardness of HER at the position of the blue LED chips at base of the sample but had no effect at the top surface. For TEC, use of HT increased microhardness of the three LED areas at the top surface. Use of the HT increased microhardness of SOF at the position of one of the blue and the violet LED chips at the bottom surface, and for TBF, HT increased the microhardness in all the top surface. All the tested composites showed a higher mean microhardness at top than that at the bottom of the samples. In general, all composites presented a higher microhardness at the blue LED areas, regardless of the surface or the used tip. Results suggest that using a homogenizer light guide may increase the microhardness at the top of composite resins containing alternative photoinitiators; however, that effect is not the same at the bottom of the material.

Keywords: Light curing, composite resin

RESUMEN

El objetivo de este estudio fue evaluar el efecto de diferentes diseños de puntas transmisoras de luz de una lámpara de fotocurado en la microdureza del tope y la base de resinas convencionales y *bulk-fill*. Adicionalmente, se analizó el perfil del haz de luz emitido con cada punta. Fue usada una lámpara de fotocurado LED *polywave* Bluephase Style (Ivoclar Vivadent AG) e dos puntas transmisoras diseñadas para esa lámpara, una convencional (RT) con emitancia de 935 mW/cm^2 e una homogeneizadora (HT), con emitancia de 851 mW/cm2. Se probaron dos resinas convencionales (Herculite Ultra-HER, Kerr Corp y Tetric EvoCeram-TEC, Ivoclar Vivadent AG) y dos *bulk-fill* (SonicFill-SOF, Kerr Corp. y Tetric EvoCeram Bulk Fill-TBF, Ivoclar Vivadent AG.). Se fabricaron cuerpos de prueba en forma de disco, con 10mm de diámetro e 2mm de grosor para las resinas convencionales, e 4mm de grosor para las *bulk-fill*. Los discos fueron polimerizados el tiempo indicado por el fabricante, manteniendo la lámpara en una posición fija. La posición de salida de la luz emitida por cada LED (dos chips emiten luz azul con un pico de 456nm y el tercero produce luz violeta con un pico de 409nm) fue marcada como referencia para las mediciones posteriores. Se midió la microdureza Knoop (KHN), del tope y la base de cada disco, en el punto central de incidencia de la luz emitida por cada *chip*. Los datos de microdureza fueron analizados con un ANOVA de 3 factores ($\alpha = 0.05$). Las imágenes del perfil del haz de luz demostraron mayor distribución de la luz cuando se usó HT. El uso de HT resultó en una menor microdureza de HER en las posiciones de los LED azules, en la base de los discos. En TEC, HT aumentó la microdureza en el tope, en las posiciones de los tres LED. El uso de HT produjo un aumento en la microdureza de SOF en la posición de uno de los LED azules y del LED violeta en la base y en TBF aumentó la dureza del tope en todas las posiciones. En todas las resinas usadas, la dureza promedio de la superficie del tope de los discos fue más alta que la de la base. En general, la dureza fue más alta em las regiones de los LED azules que la del LED violeta, en ambas superficies, independientemente del tipo de punta usada. Los resultados sugieren usar una HT puede aumentar la microdureza superficial de resinas que presentan fotoiniciadores alternativos, sin embargo, el efecto no se mantiene en la base del material.

Palabras clave: Fotopolimerización, resinas compuestas.

SUMARIO

1. INTRODUÇÃO

Resinas compostas fotopolimerizáveis são rotineiramente utilizadas para restaurar dentes cariados, fraturados ou substituir restaurações deficientes, tornando-se o tratamento de primeira eleição para restaurações diretas de dentes anteriores e posteriores (Lynch et al., 2014). A correta polimerização dos materiais restauradores diretos, têm se tornado um requerimento para melhorar o prognóstico das restaurações diretas. O processo de polimerização, permite a formação de grandes moléculas, com alto peso molecular, chamadas de polímeros, a partir da junção de moléculas menores, chamadas de monómeros (Anusavice, Shen, & Rawls, 2013; Prosthodontics, 2005).

Em Odontologia, o uso de materiais restauradores diretos polimerizáveis começou com o desenvolvimento de materiais quimicamente ativados baseados em metil metacrilato. No entanto, o processo podia ser complexo para o dentista, por causa da necessidade de dosificar, manipular e colocar o material, e uma vez colocado, esperar para acontecer a reação de ativação química (F.A. Rueggeberg, Giannini, Arrais, & Price, 2017). Embora as taxas de sucesso clínico destas restaurações aumentaram com o desenvolvimento de resinas adesivas, a incorporação de partículas de carga (Mark, 2009) e o condicionamento ácido do esmalte (Buonocore, 1955), o dentista não podia controlar o tempo de trabalho nem a reação de polimerização (Anusavice et al., 2013).

Os avanços na ciência dos materiais odontológicos, permitiram desenvolver materiais ativados por fontes externas de energia, como por exemplo luz (Anusavice et al., 2013), que fornece fótons ao material com energia necessária para ativar a reação de polimerização. Os primeiros sistemas de foto ativação desenvolvidos nos anos 70, continham fotoiniciadores sensíveis à luz ultravioleta para começar a liberação de radicais livres (Anusavice et al., 2013; F.A. Rueggeberg et al., 2017). O desenvolvimento de resinas compostas fotopolimerizáveis, revolucionou a forma em que os dentistas confeccionavam as restaurações, permitindo controlar o tempo de trabalho do material (Anusavice et al., 2013; R. B. T. Price, 2017) e ativar a reação de polimerização quando necessário (R. B. T. Price, 2017), tornando os aparelhos fotoativadores parte do equipamento essencial no consultório odontológico (R. B. Price, 2018; R. B. T. Price, 2017). No entanto, os sistemas ultravioleta apresentavam a desvantagem de emitir luz com baixa capacidade de penetração através do material, não permitindo incrementos maiores de 1mm de espessura (R. B. T. Price, 2017).

Posteriormente, os sistemas fotoativadores ultravioleta, foram substituídos por sistemas emissores de luz azul visível, que permitem obter uma maior profundidade de polimerização (Anusavice et al., 2013). Os principais sistemas desenvolvidos são o arco de plasma (PAC), o halogênio (QTH), o laser de íon argônio e mais recentemente, os diodos emissores de luz (LED) (R. B. T. Price, 2017; F.A. Rueggeberg et al., 2017). Estes sistemas produzem fótons de maneiras diferentes, e emitem luz em diferentes espectros e comprimentos de onda. Embora os aparelhos do tipo QTH tenham sido os mais utilizados pelos clínicos, recentemente o uso deste tipo de aparelhos diminuiu, e foram substituídos por aparelhos LED. (Wilson & Lynch, 2014)

O desenvolvimento dos aparelhos LED, capazes de produzir luz azul em faixa espectral estreita, e o aumento no seu uso entre os dentistas, favoreceu o uso de canforoquinona (CQ) como principal fotoiniciador nos materiais restauradores (Gan, Yap, Cheong, & Cbk, 2018; R. Price, Shortall, & Palin, 2014; F.A. Rueggeberg et al., 2017). A CQ é capaz de absorver luz na faixa do espectro de 425 até 490nm, com um pico máximo de absorção próximo a 468 nm (R. Price et al., 2014). A CQ é um fotoiniciador de tipo 2, por causa da molécula não ser capaz de começar a reação de polimerização por si só, requerendo a presença de outra molécula co-iniciadora doadora de elétrons, que geralmente é uma amina terciária (Leprince, Palin, Hadis, Devaux, & Leloup, 2013; F.A. Rueggeberg et al., 2017). No geral, as reações de fotopolimerização de tipo 2, são menos foto-eficientes, do que as reações de tipo 1 (F.A. Rueggeberg et al., 2017).

Alguns outros fotoiniciadores usados em materiais odontológicos, apresentam reações de tipo 1, como é o caso do Lucirin TPO e do BAPO, que são potencialmente mais eficientes do que a CQ (Leprince et al., 2013; Pongprueksa et al., 2014). Porém, o uso destas moléculas diminuiu com o surgimento dos primeiros aparelhos LED, devido à faixa de absorção desses fotoiniciadores, que se encontra aproximadamente entre 390 e 420 nm, numa região do espectro da luz visível próxima ao violeta, motivo pelo qual não eram eficientemente ativados pela luz azul dos primeiros aparelhos LED (Leprince et al., 2013; R. Price et al., 2014; F.A. Rueggeberg et al., 2017).

Os avanços na tecnologia LED, permitiram desenvolver aparelhos que contém vários chips, capazes de produzir luz em diferentes comprimentos de onda, específicos. Estes aparelhos são comercialmente conhecidos como *multiple peak* ou *polywave®*, e apresentam faixas de emissão de luz que abrangem os picos de absorção tanto da CQ, como de fotoiniciadores alternativos como fenil-propanodiona (PPD), Lucirin TPO, BAPO, Ivocerim e outros (de Oliveira et al., 2016; Pongprueksa et al., 2014; F.A. Rueggeberg et al., 2017; Sampaio et al., 2017).

Apesar das vantagens oferecidas pelos aparelhos LED do tipo *polywave®*, existem preocupações devido à potencial falta de homogeneidade do feixe de luz que atinge a superfície do material (Sampaio et al., 2017). Algumas pesquisas mostram que o uso de aparelhos emissores de luz em diferentes comprimentos de onda, pode influenciar a polimerização dos materiais odontológicos, demonstrando menor dureza, grau de conversão, e penetração da luz nas regiões com menor energia e comprimento de onda (Frederick A. Rueggeberg, Price, Harlow, & Sullivan, 2016).

Portanto, este estudo utilizou um aparelho fotoativador LED do tipo *polywave®*, com dois tipos de pontas transmissoras de luz (regular e homogeneizadora), para estudar o efeito do feixe de luz que atinge a superfície do material, na microdureza superficial de duas resinas compostas convencionais e duas do tipo *bulk-fill*, em diferentes regiões e profundidades. Além disso, foi analisado o perfil do feixe de luz com cada uma das pontas para determinar o espectro de emissão e a quantidade de energia emitida.

2. ARTIGO

INFLUENCE OF A LED CURING UNIT BEAM HOMOGENIZATION TIP ON THE TOP AND BOTTOM MICROHARDNESS OF COMPOSITE RESINS

Running Title: Beam homogenization light tip effect on composite resin microhardness

Article submitted to Operative Dentistry

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ABSTRACT

This study evaluated the effect of curing light unit (LCU) guide type (regular or homogenizing) on top and bottom microhardness of conventional and bulk-fill resin-based composites (RBC). A polywave LCU (Bluephase Style, Ivoclar Vivadent AG) was used with two different light guides: a regular (RT, 935 mW/cm^2 emittance), and a homogenizer (HT, 851 mW/cm^2 emittance). Two conventional RBC (Herculite Ultra (HER), Kerr Corp; Tetric EvoCeram (TEC), Ivoclar Vivadent AG) and two bulk-fill RBC (SonicFill (SOF), Kerr Corp; Tetric EvoCeram Bulk Fill (TBF), Ivoclar Vivadent AG) were tested. Disk-shaped samples (10mm Ø), 2-mm thick for conventional composites and 4-mm thick for bulk-fill composites were prepared. Samples were light cured according to manufacturer-recommended times. Knoop microhardness values (KHN) were made on the top and bottom surfaces of each specimen, at locations correlated with the output of the three LED chips, emitting blue (456nm) or violet light (409nm). Beam profile analysis using both light guides was also performed. Microhardness of each composite was analyzed using 3-way ANOVA and Tukey HSD pos-hoc test (α= 0.05). Beam profile images showed better light distribution across the surface of the HT light guide. Use of the HT decreased KHN of HER at the locations of the blue LED chips at base of the sample but had no effect on the top surface. For TEC, use of HT increased KHN of all three LED locations at the top surface. Use of the HT increased KHN of SOF at locations corresponding to one of the blue and the violet LED chips at the bottom surface. For TBF, HT increased KHN at all top surface locations. All RBC showed higher mean KHN at the top compared to the bottom surfaces. In general, all composites presented a higher KHN at the blue LED areas, regardless of the surface or the used tip. Results suggest that the homogenizer light guide resulted in increases microhardness at the top, irradiated surfaces of composite resins containing alternative photoinitiators; however, that effect was not true at the bottom surfaces.

Clinical Relevance

Lack of beam homogeneity in multiwave light-curing units might produce areas of insufficient polymerization in composite restorations. Inadequate polymerization of resin composite restorations may lead to decreased mechanical properties and lessen clinical longevity of a restoration.

Introduction

In most light-curing units (LCU), radiation is transmitted from the source to the target surface using a non-flexible, removable, optic fiber light guide [1–3]. These guides maintain the emitted light spectrum (in light-emitting-diodes units, LED), preserving or enhancing the emittance [2–5]. The capability of the light guide to deliver the generated light spectrum and emittance has become important because the LED LCU has overtaken use of QTH lights in most dental practices [6–8].

LED LCUs contain one to four LED chips [3] depending on the unit´s design. Some LCUs are capable of emitting blue and violet light within specific wavelength ranges, constituting what is known as “polywave®”, “multiple peak”, or “multiwave” lights [2, 4, 7]. However, because each chip only produces light within a narrow spectral range, some authors express concern regarding possible consequences of delivering uneven irradiance and spectral profiles when polymerizing resin-based composites (RBC) [5, 6, 9, 10]. Also, because each LED is placed at a specific location within the light-generating array, and little to no mixing of the emitted beams occur, a heterogeneous light distribution is produced at the emitting end of the guide [5, 6, 9, 11–16]. This lack of uniformity within the emitted beam then exposes the target surface unevenly, producing a heterogeneous polymerization [6, 17]. Thus, the target, light-curable restorative material may not receive radiation at all the emitted wavelengths and irradiance levels [5–7, 9, 10, 12].

The problem with a heterogeneous wavelength distribution of light becomes relevant with respect to the wide variety of photoinitiators used in resin-based materials: camphorquinone (CQ), 2,4,6-trimethylbenzoyldiphenyl phosphine oxide (Lucirin-TPO), bis-acylphosphine oxide (BAPO), phenyl propanodione (PPD), Ivocerin® [2–4, 18, 19]. Each of these photoinitiators responds preferably to light at specific wavelengths [4, 9, 10, 18, 20], and a non-uniform wavelength distribution at light emitting end might result in an incomplete or inconsistent polymerization of the target material due to lack of or partial activation of some photoinitiators [6, 9, 10, 12, 21]. Thus, a heterogeneous light distribution may result in localized areas of enhanced or reduced polymerization, which might be associated with clinical longevity of a restoration [5, 7, 11, 12, 22]. However, there is literature stating that non-uniform beams do not reduce the extent of polymerization in a 2-mm thick increment of conventional RBC [14]. In addition, it has been shown that the degree of conversion of bulk fill composites is not affected by beam inhomogeneity [23]. The lack of an effect has been attributed to special polymerization modifiers in bulk fill composites, to use more efficient photoinitiator systems [24, 25], and overall enhanced light transmission in depth [24] by better matching of refractive indices between filler particles and the resin components, which increase depth of cure [25].

Clinically, an insufficient degree of monomer conversion in RBCs has been associated with surface hardness decrease [5, 12, 26, 27], discoloration [9], reduced wear resistance [5, 28], lower bond strength [9], cytotoxicity [9], and a greater susceptibility to marginal gap defects [9, 29].

Relative comparison of the microhardness of the top and bottom surfaces of composite specimens has been proposed as an appropriate method to establish the effectiveness of light curing, as well as a way to study the polymerization of an specific material and its depth of cure using a particular curing condition [27, 30, 31]. This technique seems valid, because surface microhardness increases with its degree of conversion [10, 20, 26, 32]. An international standards organization method uses measurement of the length of remaining, non-scrapable, perceptibly hardened composite as an indicator to assess adequacy of composite curing [33]. However, it is claimed that those methods overestimate composite depth of cure values because they only measure the deepest polymerized region of the RBC, without considering the effects of differences in LED chip positions and differences in wavelengths striking the restoration surface [20, 21, 31, 34].

In response to concern about possible inadequate RBC polymerization, LCU manufacturers have developed light guides to better homogenize irradiance and emitted spectral distribution across the emitting tip end [12]: the “homogenizer light guide” [35, 36]. This item is designed to reduce the levels of light heterogeneity while maintaining the delivered power from the LCU. However, no scientific study has been performed to directly address these claims.

The purposes of this study are to analyze the effects of photopolymerizing a variety of commercial resin-based composites with the same LCU body, but using either a conventional (regular) or a homogenizing light tip. The effect of differences in the light guides is measured using microhardness of the top or bottom restoration surfaces. The research hypotheses were that: (1) light guide type would not significantly influence microhardness at either composite surface, and (2) the top and bottom surface microhardness of polymerized composite discs using either type of light guide would not be significantly different from each other.

Materials and Method

LCU characterization

A Polywave® LCU (Bluephase Style, Ivoclar Vivadent AG, Schaan, Liechtenstein) that has two blue LED chips (456 nm; B1 and B2) and one chip violet chip (V) (409 nm) was used. One regular (RT) and one homogenizing (HT) light guide each having a circular, 10 mm Ø (9.3 mm of active internal diameter) were commercially available for use in the same LCU. The spectral emittance between 350 and 550 nm of the LCU was measured using each light guide five times using a 6” NIST-tracable, calibrated integrating sphere (CTSM-LSM-60-SF, Labsphere Inc., N. Sutton, NH, USA), connected to a fiber optic spectrometer (USB 2000, Ocean Optics, Dunedin, FL, USA). Spectra were recorded using software (SpectraSuite, Ocean Optics, Dunedin, FL, USA), and data were entered into a spreadsheet program (EXCEL 2016, Microsoft Corporation, Redmond, WA).

Beam profiles of the LCU when using both light guides were measured using a laser beam profiler having a 10 mm diameter internal aperture. No imaging target was used; the light distribution across the emitting tip end was directly visualized. The LCU light guide was aligned with a profile camera having a 50 mm focal length lens (USB-L070, Ophir-Spiricon, Logan, UT, USA). Three measurements were performed using each light guide, one of the unfiltered beam profiles, another one with a custom-made violet filter (International Light Technologies, Peabody, MA, USA), that only allows the passage of blue light in a 430-550 nm wavelength range. A third measurement was made with a custom-made blue filter (International Light Technologies, Peabody, MA, USA), only allowing the passage of violet light in a 350-430 nm wavelength range. The resulting images were collected using software (Beamgage v 6.6, Ophir- Spiricon, North Logan, UT, USA).

RBC sample preparation

Four commercial RBC were tested. Two products were classified as conventional composites (indicated for use in 2-mm thick increments) (Tetric EvoCeram (TEC), Ivoclar Vivadent AG, Schaan, Liechtenstein; Herculite Ultra (HER), Kerr Corporation, Orange, CA, USA). Two other materials were classified as high viscosity, bulk fill materials intended for use in increments ranging from 4 to 5-mm thick, respectively) (Tetric EvoCeram Bulk Fill (TBF), Ivoclar Vivadent; SonicFill (SOF), Kerr Corporation, Orange, CA, USA). Product specifications are presented in Table 1.

Ten disk specimens (10 mm Ø, 2-mm thick) of each composite were fabricated using a polyvinyl siloxane impression material mold (Putty Soft, 3M Oral Care, St Paul, MN, USA) for the conventional composites: HER and TEC. For the bulk fill products (SOF and TBF), the mold was 4 mm thick. All fabricated molds had three, 0.5 mm notched extrusions, on their inner walls, separated 120° from each other, which matched the locations of the LED chips at the proximal surface of the light guide: B1, B2, and V. Composites were placed in the matrix using a single increment, and a transparent polyester film was placed on the bottom and top surfaces of the composite-filled [33]. The assembly was lightly pressed between two microscope glass slides to remove excess composite, and the glass slides were removed, the specimen was placed over a white filter paper (Grade 1, Whatman, Little Chalfont, Buckinghamshire, UK) background [33]. The LCU was fixed in a clamp and the distal end of the light guide was positioned perpendicular to the specimen at 1 mm distance from the upper polyester film surface. The light guide completely covered the specimen.

Light-activation for each composite followed the manufacturer' recommendations (Table 1). Following light exposure, the specimens were removed from the molds and locations on composite surfaces corresponding to the LED chips positions on the top and bottom surfaces were marked using a graphite pencil on the lateral wall of each specimen. The specimens were then dark-stored for 1 h in an oven (Fanen, Guarulhos, SP, Brazil) at 36 ± 1°C, and then machine-polished (Aropol, Arotec Indústria e Comércio Ltda, Cotia, SP, Brazil) using 1000 and 1200-grit abrasive paper (Wetordry, 3M, Sorocaba, SP, Brazil) for 1 minute each, under water cooling. After polishing, specimens were dark-stored and placed in the same oven for 24 h prior to microhardness testing.

Microhardness test

A microhardness tester (Future-Tech FM Corp., Tokyo, Japan) coupled to software (FM-ARS, Future-Tech FM Corp., Tokyo, Japan), was used to obtain Knoop hardness values after applying a static load of 50 g (0.49 N) for 5 s to each composite surface. The average of three indentations, spaced 100 µm distance from each other, at the central irradiant spot of each LED (Figure 1) were used to represent a single hardness value of that specific location for a given composite specimen. The location of the measurement area was determined using the notches made at the peripheral locations as reference, and from those locations, a displacement of 2.6 mm towards the center of the disc was defined as the starting point for Knoop indenter loading. The same protocol was followed at the bottom composite surfaces.

Statistical Analysis

Power output and radiant emittance of the LCU with each light guide, at different wavelength ranges was compared by Student´s t-test. Due to the different composition of the tested RBCs, statistical analysis of microhardness values was performed separately for each material, using three-way ANOVA (factors: surface (top or bottom), light guide (HT or RT), and LED wavelength (456 nm or 409 nm)), using software (SAS 9.3 for Windows, SAS Institute, NC, USA). For each disc, microhardness values were averaged among the three measurements at each location. Mean KHN was tested for normality using the Shapiro–Wilks test and for equal variance using Levene's test. Due to lack of homogeneity in the hardness data, an exponential transformation of 1.5 was applied to obtain normality. Tukey HSD post-hoc multiple comparison test ($\alpha = 0.05$) was applied to compare pair-wise group means as well as interactions among factors within each RBC.

Results

Spectral Emittance and beam profiles

Measurements of wavelength ranges and means of the total power output and radiant exitances of the LED LCU using RT and HT are presented in Table 2. In all the measured wavelength ranges, power output and radiant emittance was higher when RT was used. Figure 2 shows the emission spectra of the two wavelengths of LEDs, using the RT and HT light guides. Visual inspection of the beam profiles shows great differences in light output distribution and emittance between both light guides (Figures 3 and 4). Figure 3 shows that the individual LED chips using the RT are visible and separated from one another, through the length of the light guide. The separation among LED chips, visible at the distal end with the light off, remains when the LCU is turned on, demonstrating the non-uniformity of the light output. Beam profile using the RT is characterized by the presence of two strong areas of emission corresponding to B1 and B2 LED chips, and a weaker emission area corresponding to V in the unfiltered beam profile. Those areas of higher emittance corresponded directly with the central spot of each individual LED chip. The power concentration at these locations contrasts with that of the large surrounding areas, where the presence of emitted light was practically undetectable, even when using filters.

When using the HT, the location of the individual emitting LED chips is barely visible through at the end of the light guide (Figure 4). The separation between LED chips becomes visible when the LCU is turned on, also demonstrating an incomplete uniformity of light output. Nevertheless, as not seem when using the RT, the emitted blue and violet light is distributed across most of HT´s light emitting distal end. The beam profile using the HT is characterized by the presence of two locations of strong power emission, with a peak output of 2260 mW corresponding to B1 and B2, and a weaker emission in the area corresponding to V. Although the high power locations showed a greater concentration of light in the central spot of each 456nm LED chip, the power output remained relatively homogeneous across the whole cross section of the light guide emitting end. Filtered beam profile images showed the diffusion of energy emitted by each LED across a wide area. The areas of low power output were practically nonexistent, when using the HT.

Surface Microhardness

Table 3 presents KHN results for HER. The three-way ANOVA indicated that surface ($p<0.0001$), light guide type ($p<0.0001$), and wavelength ($p<0.0001$) significantly influenced the results, as well as the double interaction between light guide type and surface ($p<0.0001$), and light guide type and wavelength ($p= 0.0002$). The bottom to top (B/T) hardness ratio was below 0.6 with both light guides, at all the tested wavelengths.

Microhardness values of the conventional composite (TEC) are presented in Table 4. Statistical analysis showed that surface ($p<0.0001$) and wavelength ($p<0.0001$), as well as the double interaction between light guide type and surface ($p<0.0001$), significantly influenced microhardness results. However, light guide did not significantly influence the results. When using the RT, B/T hardness ratios reached 0.9 for all wavelength locations, however, none of the wavelength locations reached a B/T ratio of 0.8 when using the HT tip.

Table 5 presents KHN results for the bulk-fill composite (SOF). The three-way ANOVA results indicated that surface ($p<0.0001$), light guide type ($p<0.0001$), and wavelength ($p<0.0001$) all significantly influenced the results, as well as the double interaction between surface and wavelength ($p=0.026$). The B/T ratio was greater than 0.8 for both light guides, in the locations associated with B1 and B2 LED chips, and below 0.8, with both light guides in the areas irradiated by V LED chip.

Table 6 presents the results of statistical analysis and comparisons among groups for the other bulk fill composite (TBF). Surface ($p<0.0001$), light guide type ($p<0.0001$), and wavelength ($p<0.0001$) all significantly influenced surface microhardness. None of the double, nor the triple interactions among the factors was significant. The B/T hardness ratio was greater than 0.8 when using both tips, at all the measured locations.

For all the composites, KHN was higher at the top surface (0 mm) than those obtained at the bottom (2 or 4 mm thicknesses, according to composite type). Also, for both types of light guides, within the same surface (top and bottom), higher microhardness values were observed in areas irradiated by B1 and B2 than in locations of the V LED.

Discussion

The first research hypotheses stating that using different light guides would not produce differences in the KHN was rejected. Except for TEC, surface KHN of all tested composites was significantly affected by the type of light guide used. Also, regardless of RBC and type of light guide, there were significant differences in KHN between locations irradiated mainly by the 409 nm violet LED and locations receiving blue light at 456 nm LED. The second research hypothesis, stating that microhardness of composites at the top and bottom would not be the same, was accepted, because all tested composites exhibited a significantly higher hardness at the top surface, than at the bottom.

An LCU should be able to adequately photo-polymerize up to a 2-mm thickness of conventional composites. However, the B/T hardness ratio of the CQ-based conventional composite (HER) was below 0.6 when using either light guide. This value is below the recommended 0.8 necessary to consider the material adequately cured [27, 30]. In the current study, KHN of HER was higher when the RT was used, which might be due to the high localized power delivery to the composite corresponding to the position of the LED chips [2–4, 6, 9, 11], which matched the location where the hardness measurements were performed. Also, KHN was higher on the top surface, and in the areas correlated with the output from the blue LEDs. The poorer penetration of the shorter wavelength violet light, compared to the greater penetration depth of longer wavelength blue light, might also be responsible for these findings[10, 16, 22]. The spectral absorption range of CQ ranges from 425 to 490 nm, and matches the peak emission of the blue LEDs at 456 nm, but has little sensitivity to violet light at 409 nm[3]. This result diverges from the findings of a previous study, that considered that polymerizing conventional CQ-based composites up to a 2 mm thickness, using a non-homogeneous, multiple-peak LCU, did not influence the curing profile of the material [14]. However, it must be considered that the samples in that study were smaller (5 x 5 mm blocks with 3 mm thickness), and they were polymerized using a LCU producing a beam profile, that despite not being completely homogeneous, spreads light in the absorption spectrum of CQ across most of the LCU output area [14, 37]. That aspect differs from the beam profiles of tips in the current study: the Bluephase Style LCU with both types of light guide.

The results for TEC showed that KHN was higher at the top surface, and in locations corresponding with the positions of the blue LEDs, while the selection of light guide type had no significant influence on hardness at the bottom surface, although the HT produced a higher KHN at the top surface at all measured locations. Because TEC contains both CQ and TPO photoinitiators, an improved sensitivity to violet light was expected, and confirmed by the results. Using the RT produced a B/T ratio above 0.8 at all LED positions, and when using the HT, the B/T ratio was between 0.78 and 0.75. As explained previously, the higher B/T ratio observed using the RT might be a result of the power concentration at the locations correlated with the LED chips [2–4, 6, 9, 11]. However, it was unexpected that the HT tip failed to reach an acceptable B/T ratio at any of the measured locations, despite being used on a composite from the same manufacturer of the LCU, where a high sensitivity of the photoinitiators to the LCU emission spectrum is expected [3, 11, 12]. However, because KHN at the top surface was higher using the HT but showed no significant difference in hardness at the bottom surface using the RT, the increase in top surface hardness influences the B/T ratio calculation. Moreover, the effect of the HT in spreading the light beam, produced a higher KHN at the top surface due to better activation of the photoinitiators, but the reduced concentration of irradiance in the measured locations, along with the low penetrability of violet light [22] to activate TPO at a 2 mm thickness might be responsible for this result. The effect of a curing light on composite resin photopolymerization highly depends on the extent of localized emittance and the spectral homogeneity of the light beam [12]. Finally, the manufacturer of TEC recommends a maximum increment thickness of 1.5 mm for dentin shades, instead of the 2 mm used in the present study, and as a result of that difference, KHN at the bottom might have been diminished, producing also a B/T ratio below the recommended value.

Based on these findings, clinicians should take care when polymerizing 2-mm thick increments of conventional composites using a multi-wave LCU, because insufficient energy might reach the bottom surface of the composite to adequately photocure the material. The reduced activation of photoinitiators due to light beam inhomogeneity is known [3, 10, 21]. Therefore, it is recommended that clinicians match the emission spectrum of their LCU to the photoinitiator sensitivity of their chosen RBC [2, 3, 19].

Analysis of the results using bulk fill composites produced different findings than those of the conventional composites. Microhardness of SOF was higher at the bottom surface when using the HT, in the location of the violet and one of the blue LEDs. Surface microhardness was also higher at the top surface, which is an expected result, because the top surface received higher irradiance than did the bottom surface. Using both light guide types, the B/T ratio was above 0.8 at the locations of the blue LEDs and below 0.8 at the area of the violet LED (0.78 with HT, and 0.7 with RT). Because SOF is a CQ-based composite, it could benefit from the better distribution of blue light when using the HT, even in the area of the V LED. As expected from a bulk fill composite, SOF obtained a near optimal B/T ratio, despite being a CQ only based composite, also, the manufacturer of SOF recommends a maximum increment thickness of 5 mm, and therefore a thinner increment like the one used in this study, should reach an adequate polymerization. The obtained results of KHN for SOF could be explained because this composite demonstrates better light transmission [24, 34], and higher penetrability of blue light [10, 22, 25, 37].

Surface microhardness measurements of TBF showed higher KHN values on the top surface when the HT was used, near the locations of the blue LEDs. This composite contains CQ, TPO, and Ivocerin photoinitiators, which means that the material should have an improved sensitivity to light at shorter wavelengths, especially at the top surface. That assumption was confirmed by the presence of higher KHN values observed at the top of the specimens when using HT, because the greater light distribution could produce greater activation of these photoinitiators. For TBF, the beneficial effect of using an LCU matching the spectral sensitivity of the RBC was confirmed [2, 3, 19], because the B/T ratio of TBF was above 0.8 at all the measured locations. An appropriate resin formulation may thus enhance reactivity and allow for greater depths of cure [25].

A previous study about depth of cure of bulk fill composites determined that SOF and TBF had a satisfactory depth of cure when polymerized using a monowave, blue LED LCU [25]. That result corroborates the findings of this study, where the depth of cure of both materials was satisfactory at the locations of the blue LEDs. Nonetheless, regarding the effects of beam heterogeneity in bulk fill composites, results differ from those of another study [23] that considered the effect of beam inhomogeneity in bulk fill RBCs as “minor.” However, the authors of that paper polymerized specimens using twice the recommended exposure duration and using a high-power setting. In addition, that work did not measure beam profile of the LCU used, nor mention the characteristics of the light-guide, leaving doubts about the homogeneity of the light beam, and how those factors could have influenced their results.

Spectral emission measurements confirm that both light guides succeed in transmitting and preserving the emission spectrum of the LEDs in the LCU [1–5, 36]. In the current study, the HT performed better in TBF. Nevertheless, the non-homogeneous beam profile of the multi-wave LED LCU used, with both light guide types, affected the B/T ratio of all composites, and therefore the depths of cure of all RBCs, regardless of their photoinitiator composition. This result agrees with other studies that indicate that lack of beam homogeneity might affect polymerization in restorative materials [5–7, 9–12, 37]. As a consequence, the mechanical properties [12, 16, 30, 32], and clinical performance [5, 9, 12, 25, 29] of restorations placed using less than ideal beam homogeneity might be a reality, even if the composite appears to be adequately polymerized at the top, irradiated surface [10, 12].

Light beam heterogeneity is therefore shown to affect the depth of cure of composites, by the fact that almost all the tested composites (except for TBF) had a higher B/T ratio in the location of the blue LEDs than in the area of the violet LED. Another important finding was that TEC and TBF showed a higher KHN at the top surface when using the HT, proving that a more homogeneous light beam might be beneficial for the polymerization of superficial composite layers as well. The study results confirm the sensitivity of the microhardness test and the B/T ratio method to detect differences among the surfaces of materials, and can be described with ease, allowing for a more exact and detailed approach to evaluate depth of cure than other proposed techniques, just as the composite scraping test used in ISO 4049 [10, 26, 27, 30–34].

A limitation of the present study is that microhardness measurements were restricted to specimen locations receiving the highest irradiance from the LCU with each light guide tip, to evaluate differences produced by each LED. Future research should consider hardness “mapping” the complete top and bottom surfaces of RBCs and calculating the depth of cure in the regions receiving the lowest irradiance with each light guide type, to determine a potential clinical implication produced by the presence of areas receiving very low values of light in the polymerization of restorative composites. Also, less translucent dentin shades of conventional RBC were used in this study, which might influence the differences between top and bottom microhardness, especially for TEC. On the other hand, if enamel or translucent shades of RBC are used, differences between top and bottom microhardness could have been reduced.

Conclusions

Within the limitations of the experimental design and based on the findings of the present in vitro study, the following conclusion can be made:

1. Use of a homogenizing tip allows spreading light across the tip end, which reduces localized concentrations of power and delivers more power to areas receiving lower irradiance values, when using the conventional light guide.
2. Regardless of the light guide type used and photoinitiator composition, there are significant differences in microhardness between the top and bottom surfaces of conventional and bulk fill RBCs.
3. In general, within the bulk fill materials tested, use of a homogenizing tip tends to produce higher microhardness at the bottom surfaces of the specimens.
4. Using a homogenizing top does not completely compensate the non-uniformity of light emitted by a multi wave LCU, because power differences are still observed at tip locations correlated with the fixed positions of LED chips present at the proximal tip end. However, the homogenizing tip shows better distribution of emittance than that observed using a conventional light guide, as observed for hardness values obtained at the top surfaces of TEC and TBF, and
5. Regardless of the light guide type used, violet light produced lower microhardness at the top and bottom surfaces of the tested RBC, except for the conventional CQ-containing composite (HER) at the bottom when the homogenizing tip was used.

Acknowledgments

This study was supported by the International Affairs Bureau of the University of Costa Rica, and the Coordination for Improvement of Higher Education (CAPES – Brazil, Code 001)

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Tables

Table 1. Classifications, brand names, compositions, and lot numbers of tested materials.

Classification	Composite (Abbreviations)	Composition	Photoinitiators	Exposure time (s)	Shade	Lot number
Incremental Fill (2-mm thick or less)	Herculite Ultra (HER)	Bis-GMA, TEGDMA, Bis-EMA, silica and barium glass, prepolymer filler, titanium oxide, 4-methoxyphenol, BPO, trimethylolpropane triacrylate.	CQ	20	A2 Dentin	5444587
	Tetric EvoCeram (TEC)	Bis-GMA, UDMA, barium glass, ytterbium trifluoride, prepolymer filler, mixed oxide.	CQ, TPO	10	A2 Dentin	T22777
Bulk Fill (4- 5-mm thick increments)	Sonic Fill (SOF)	Bis-GMA, TEGDMA, Bis-EMA, TMSPMA, barium glass, alumino-borosilicate glass.	CQ	20	A2	5376244
	Tetric EvoCeram Bulk Fill (TBF)	Bis-GMA, Bis-EMA, UDMA, alumino-borosilicate glass, prepolymer filler (ytterbium trifluoride), mixed oxides	CQ, TPO, Ivocerin	10	IVA	S51408

Abbreviations: Bis-EMA: Bisphenolglycidyl ethyl-methacrylate; Bis-GMA: Bisphenolglycidyl methacrylate; BPO: Benzoyl Peroxide; TEGDMA: Triethylene glycol dimethacrylate; TMSPMA, 3-trimethoxysilylpropyl methacrylate; UDMA: Urethane dimethacrylate, CQ: Camphorquinone, TPO: Diphenyl (2,4,6-trimethylbenzoyl)phosphine oxide.

Table 2. Wavelength range, power output, and radiant emittance of the LCU measured when using the different types of light guide.

Wavelength Range (nm)	Light Guide	Power Output (mW)	Radiant Emittance (mW/cm^2)
350 – 550	RT	635.8 ± 1.3 A	935.0 ± 2.1 A
	HT	578.0 ± 1.0 B	850.6 ± 1.9 B
350 – 430	RT	112.4 ± 1.1 A	165.8 ± 1.8 A
	HT	101.4 ± 1.3 B	148.8 ± 1.1 B
430 – 550	RT	523.0 ± 1.0 A	750.2 ± 0.4 A
	HT	476.4 ± 0.5 B	683.8 ± 1.1 B

Abbreviations: RT: Regular tip; HT: Homogenizer tip. Different characters indicate significant difference among light guides, for the same wavelength range, within a same column, by Student *t*-test ($p > 0.05$).

Table 3. Microhardness of HER according to LED wavelength, surface (top and bottom) and tip type (regular (RT) or homogenizer (HT)).

Composite	LED	Tip Type	Surface		B/T
	(Wavelength)		Top	Bottom	Ratio
HER	Blue A (456nm)	RT	59.1 ± 3.3 Aa	33.9 ± 9.6 Aa*	0.57
		HT	58.5 ± 1.3 Aa	20.4 ± 3.3 Ba*	0.35
	Violet (409nm)	RT	47.0 ± 4.4 Ab	16.9 ± 4.8 Ab*	0.36
		HT	50.4± 2.4 Ab	14.2 ± 2.9 Ab*	0.28
	Blue B (456nm)	RT	59.4 ± 5.1 Aa	32.5 ± 6.3 Aa*	0.55
		HT	57.9 ± 2.1 Aa	19.7 ± 2.7 Bab*	0.34

Means followed by similar characters indicate no significant difference. Upper case letters compare microhardness within the same LED and surface, using different light guides. Lower case letters compare LED chips, within the same light guide and surface. *indicates difference between the top and bottom within the same LED and tip.

Table 4. Microhardness of TEC according to LED wavelength, surface (top and bottom) and tip type (regular (RT) or homogenizer (HT)).

Composite	LED (Wavelength)	Tip Type	Surface		B/T Ratio
			Top	Bottom	
TEC	Blue A (456nm)	RT	51.5 ± 4.0 Ba	46.6 ± 4.2 Aa*	0.90
		HT	55.5 ± 3.4 Aa	43.1 ± 2.9 Aa*	0.78
	Violet (409nm)	RT	43.5 ± 5.5 Bb	36.0 ± 5.7 Ab*	0.82
		HT	49.8 ± 3.2 Ab	37.3 ± 2.5 Ab*	0.75
	Blue B (456nm)	RT	51.7 ± 5.0 Ba	46.3 ± 5.9 Aa*	0.90
		HT	55.4 ± 3.3 Aa	42.3 ± 3.6 Ba*	0.76

Means followed by similar characters indicate no significant difference. Upper case letters compare microhardness within the same LED and surface, using different light guides. Lower case letters compare LED chips, within the same light guide and surface. *indicates difference between the top and bottom within the same LED and tip.

Table 5. Microhardness of SOF according to LED wavelength, surface (top and bottom) and tip type (regular (RT) or homogenizer (HT)).

Composite	LED	Tip Type	Surface		B/T
	(Wavelength)		Top	Bottom	Ratio
SOF	Blue A (456nm)	RT	63.2 ± 1.4 Aa	53.2 ± 4.4 Aa*	0.84
		HT	65.8 ± 4.8 Aa	54.6 ± 2.2 Aa*	0.83
	Violet (409nm)	RT	58.9 ± 2.3 Ab	41.1 ± 5.2 Bb*	0.70
		HT	61.1 ± 2.4 Ab	47.6 ± 3.0 Ab*	0.78
	Blue B (456nm)	RT	63.4 ± 2.6 Aa	50.6 ± 4.5 Ba*	0.80
		HT	66.0 ± 3.0 Aa	53.8 ± 1.6 Aa*	0.82

Means followed by similar characters indicate no significant difference. Upper case letters compare microhardness within the same LED and surface, using different light guides. Lower case letters compare LED chips, within the same light guide and surface. *indicates difference between the top and bottom within the same LED and tip.

Table 6. Microhardness of TBF according to LED wavelength, surface (top and bottom) and tip type (regular (RT) or homogenizer (HT)).

Composite	LED (Wavelength)	Tip Type	Surface		B/T Ratio
			Top	Bottom	
TBF	Blue A (456nm)	RT	57.5 ± 3.5 Ba	50.8 ± 4.1 Aa*	0.88
		HT	62.8 ± 4.7 Aa	52.5 ± 4.4 Aa*	0.84
	Violet (409nm)	RT	52.9 ± 4.0 Bb	45.1 ± 2.5 Ab*	0.85
		HT	57.2 ± 4.8 Ab	48.5 ± 3.0 Ab*	0.85
	Blue B (456nm)	RT	57.0 ± 4.0 Ba	49.0 ± 3.6 Ba*	0.86
		HT	63.6 ± 5.5 Aa	53.9 ± 2.9 Aa*	0.85

Means followed by similar characters indicate no significant difference. Upper case letters compare microhardness within the same LED and surface, using different light guides. Lower case letters compare LED chips, within the same light guide and surface. *indicates difference between the top and bottom within the same LED and tip.

Figures

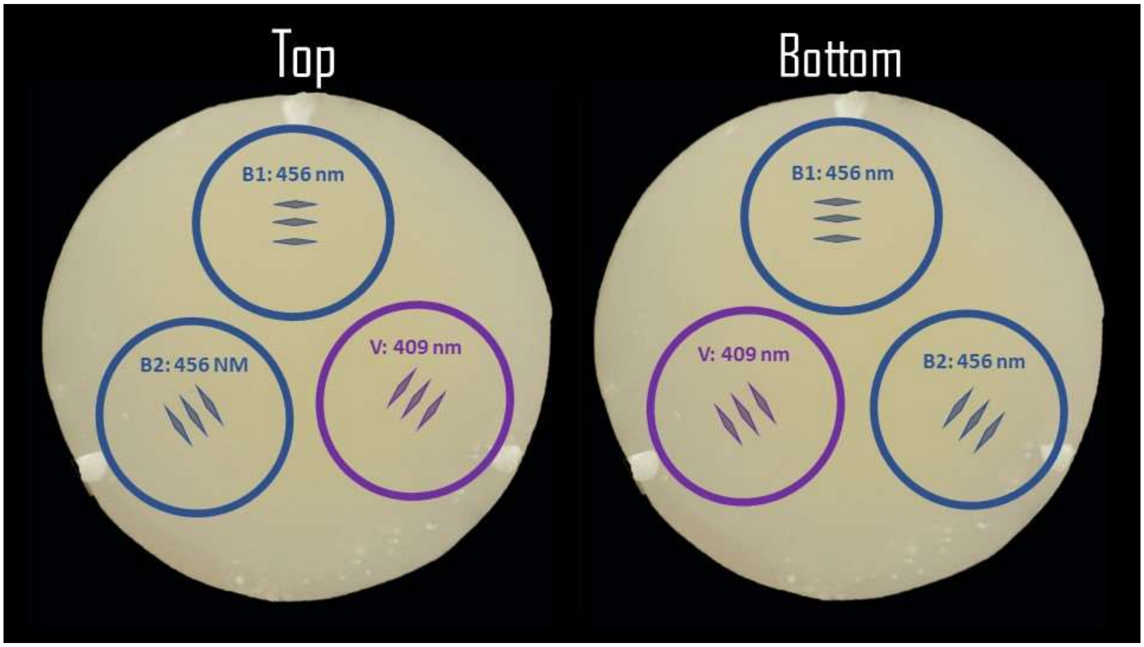

Figure 1. Schematic representation for locations of microhardness measurements with respect to the specific LED chip that is emitting toward the proximal light guide end, and from which light is emitted at the distal tip end.

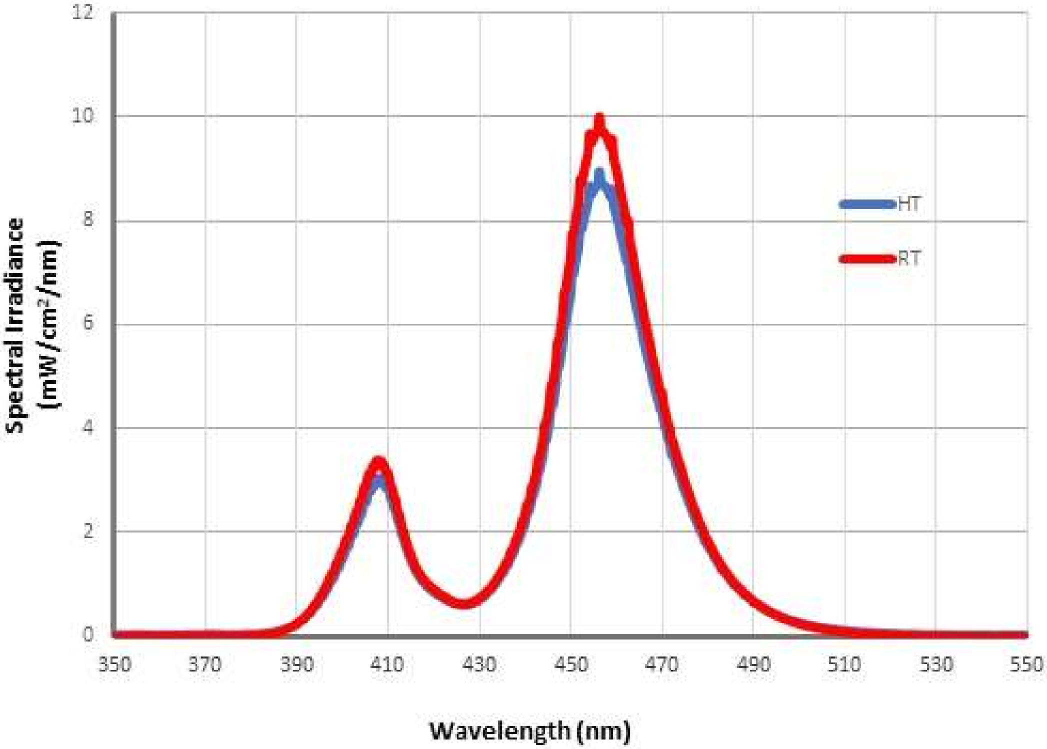

Figure 2. Spectral irradiance profiles (mW/cm^2/nm) of the Bluephase Style LCU using the two different types of light guide tips (RT = regular tip; HT = homogenizing tip).

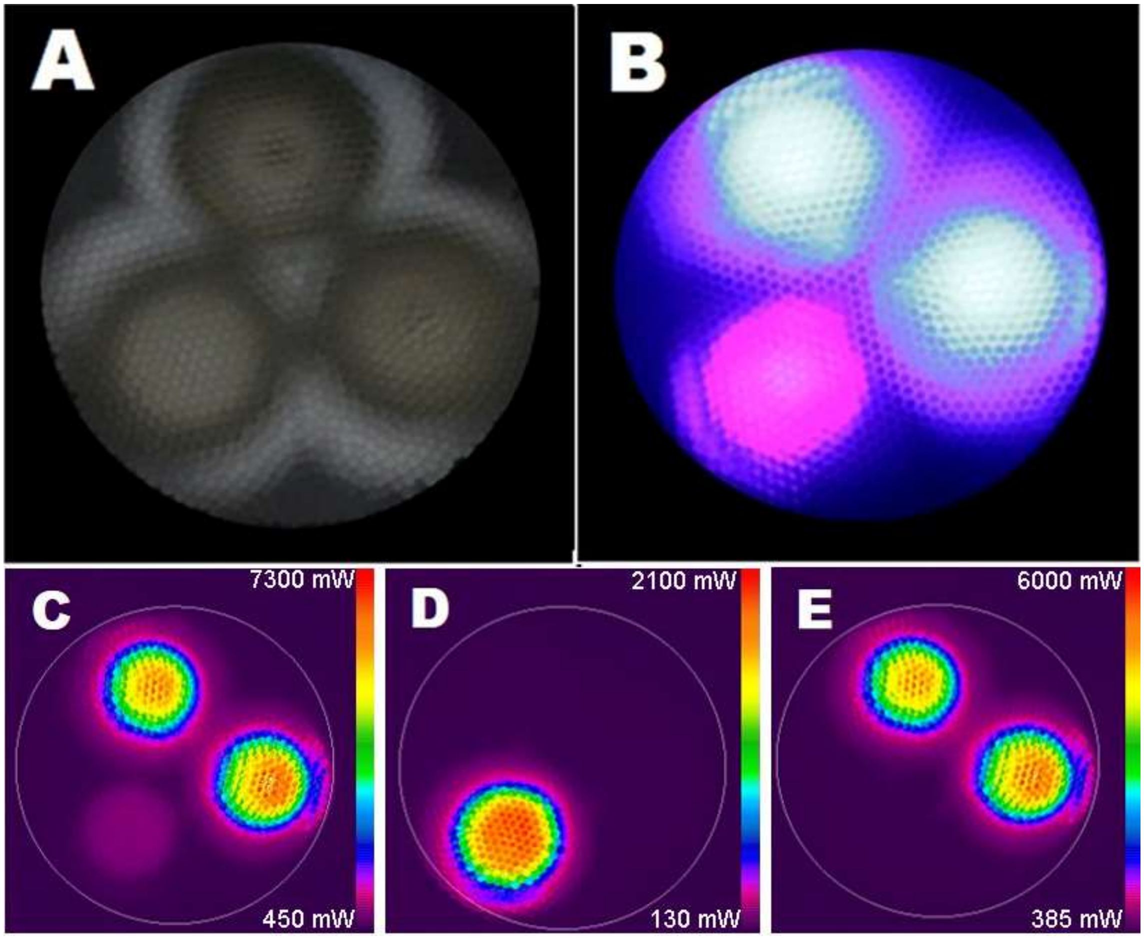

Figure 3. Images of the distal end of the Regular Tip when inserted into the body of the Bluephase Style LCU A. LED with chips off. The location of the three LED chips can be seen through the light guide. B. Light distribution from the LED chips across RT when the LCU is on. Areas of blue and violet light emission can be distinguished, as well as areas of lower light levels. C. Color-coded, scaled beam power profiles of the light emitted without using any bandpass filter. D Power distribution of only the violet chip using a 430-550 nm blue spectral filter, and E. Power distribution of only the blue light, using a 350-430 nm violet spectral filter placed in front of the camera lens of the beam profiler.

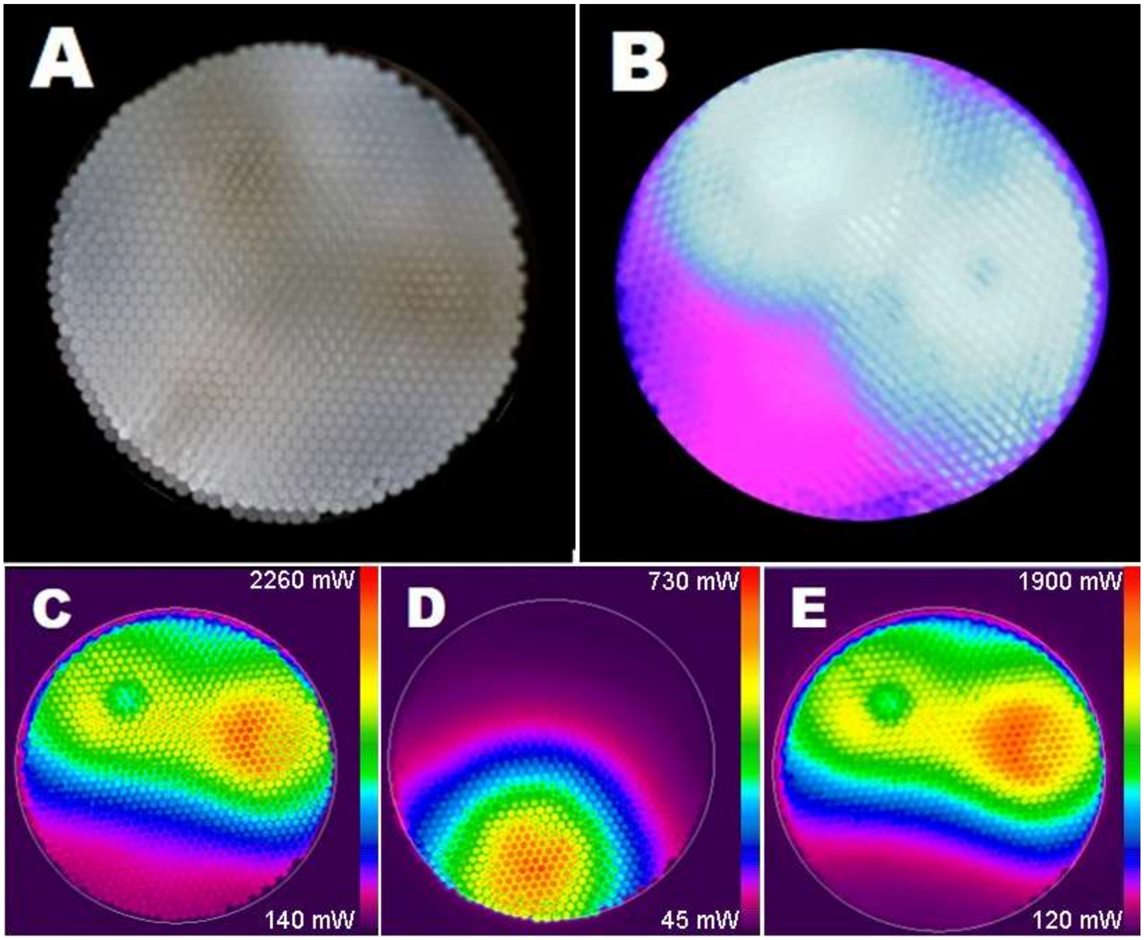

Figure 4. Images of the distal end of the Homogenizer Tip when inserted into the body of the Bluephase Style LCU A. LED with chips off. The location of the three LED chips cannot be easily seen through the light guide. B. Light distribution from the LED chips across HT when the LCU is on. Areas of blue and violet light emission can be distinguished. C. Color-coded, scaled beam power profiles of the light emitted without using any bandpass filter. D Power distribution of only the violet chip using a 450-550 nm, and E. Power distribution of only the blue light, using a 350-430 nm blue spectral filter placed in front of the camera lens of the beam profiler.

3. CONCLUSÃO

Dentro das limitações do desenho experimental e baseado nos resultados deste estudo *in vitro*, pode se concluir que:

1. O uso da ponta homogeneizadora permitiu a distribuição das luzes em toda a superfície da ponta, o que reduziu a concentração de energia em pontos localizados e a presença de outras áreas que recebem pouca energia do aparelho fotoativador quando é usada a ponta regular.
2. Independentemente da ponta transmissora de luz utilizada e do tipo de fotoiniciador, diferença significativa entre a microdureza do topo e da base foi observada tanto em resinas convencionais como para as *bulk fill*.
3. No geral, dentro dos materiais *bulk fill* testados, o uso da ponta homogeneizadora tende a produzir uma maior microdureza na base dos espécimes.
4. O uso da ponta homogeneizadora não elimina por completo a falta de homogeneidade do feixe de luz do aparelho fotoativador *multi wave*, uma vez que ainda é possível perceber diferenças nas regiões que transmitem a luz produzida por cada LED. No entanto, o uso da ponta homogeneizadora produz uma melhor distribuição da emitância do que a ponta regular, como foi observado na microdureza obtida nas superfícies do topo de TEC e TBF.
5. Sem importar o tipo de ponta transmissora utilizada, a luz violeta produziu microdureza mais baixa nos topos e nas bases dos materiais testados, com a exceto na superfície da base do compósito convencional baseado em CQ (HER), quando a ponta homogeneizadora foi utilizada.

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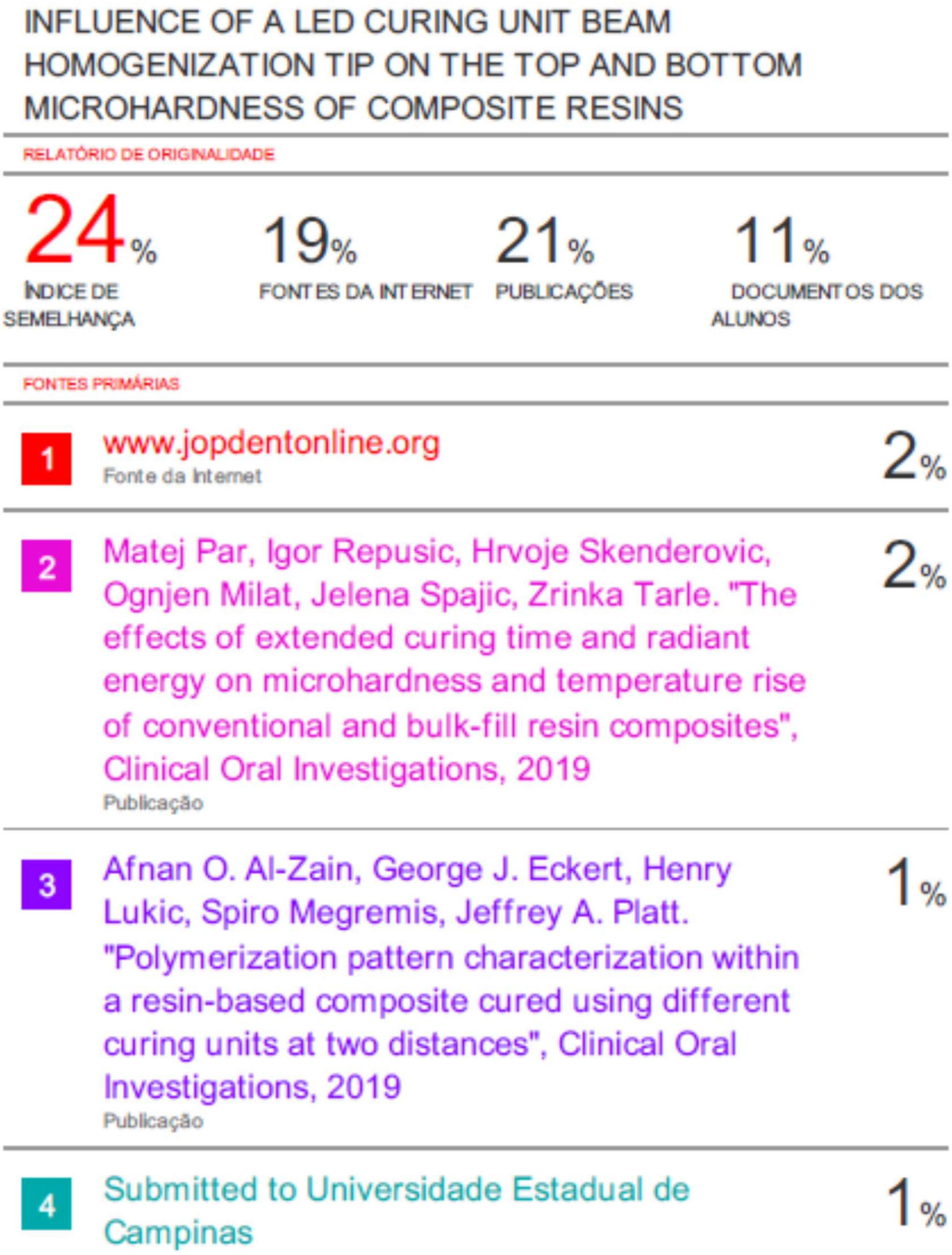
ANEXOS

ANEXO 1. VERIFICAÇÃO DE ORIGINALIDADE E PREVENÇÃO DE PLÁGIO

INFLUÊNCIA DA PONTA HOMOGENEIZADORA DO FEIXE DE LUZ DE UM APARELHO FOTOATIVADOR LED NA MICRODUREZA DA SUPERFICIE E DA BASE DE RESINAS COMPOSTAS



INFLUENCE OF A LED CURING UNIT BEAM HOMOGENIZATION TIP ON THE TOP AND BOTTOM MICROHARDNESS OF COMPOSITE RESINS

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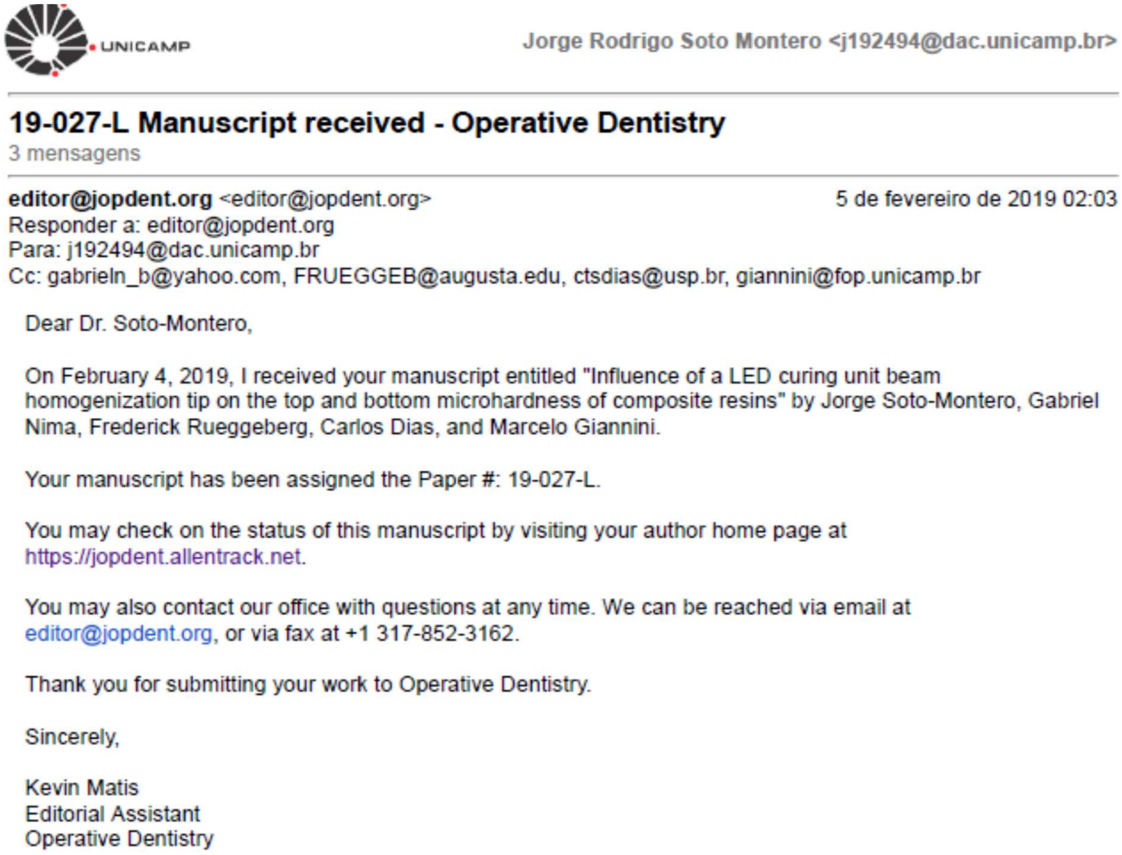
ANEXO 2. COMPROVANTE DE SUBMISSÃO DO ARTIGO AO PERIODICO OPERATIVE DENTISTRY



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