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Orientador: Prof°. Dr °. Carlos José Soares

Banca examinadora:
Prof°. Dr°. Carlos José Soares
Profª. Drª. Karla Zancopé
Prof°. Dr °. Carlos Alberto Kenji Shimokawa

Uberlândia, 2022

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) 3225-8115/8108 - www.ppgoufu.com - copod@umuarama.ufu.br

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Matrícula do Discente:	12112ODO001				
Nome do Discente:	Thiago Silva Peres				
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Área de concentração:	Clínica Odontológica Integrada				
Linha de pesquisa:	Biomecânica Aplicada à Odontologia				
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P437
2022

Peres, Thiago Silva, 1997-
Efeito das fontes de luz mono e multiwave com diferentes diâmetros de ponta e métodos de fotoativação na dureza Knoop de facetas em resinas compostas [recurso eletrônico] : Effect of mono and multiwave light-curing unit with different tip diameter and light exposure protocols on the Knoop hardness of resin composite veneer / Thiago Silva Peres. - 2022.

Orientador: Carlos José Soares.
Dissertação (Mestrado) - Universidade Federal de Uberlândia, Pós-graduação em Odontologia.
Modo de acesso: Internet.
Disponível em: http://doi.org/10.14393/ufu.di.2022.325
Inclui bibliografia.
Inclui ilustrações.

1. Odontologia. I. Soares, Carlos José,1965-, (Orient.). II. Universidade Federal de Uberlândia. Pós-graduação em Odontologia. III. Título.

CDU: 616.314

Bibliotecários responsáveis pela estrutura de acordo com o AACR2:
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DEDICATÓRIA

A Deus por me guiar nesta caminhada. Que na sua infinita bondade permitiu que eu concluísse mais uma etapa da minha jornada. Que nos momentos de aflição me acalentou e acalmou meu coração. Agradeço ainda por ter colocado em minha vida pessoas incríveis que sem as quais não conseguiria chegar até aqui.

Aos meus pais, Simone e Afrânio, sem a força e amor que vocês nada disso seria possível atualmente. Por todo o zelo e dedicação todos os dias. Obrigado por participarem e me ajudarem nessa jornada. Por serem meus grandes exemplos de simplicidade, humildade, bondade e alegria. Pelos conselhos que fizeram com que pudesse ser cada dia mais forte. Vocês são tudo para mim.

A minha namorada, Lilibeth Carola também chamada por Carito ou Caro ou Carol, por ser sempre paciente carinhosa. Obrigado por me acompanhar todos os dias nos quais tive que me dedicar até o final do dia a realização do meu trabalho no CPbio. Obrigado pelos seus conselhos diários. Muchas gracias con todo mi amor, carinho e cuidado. Você faz meus dias mais felizes com seu jeito de alegre e sorridente. É como você disse uma vez sozinhos vamos rápidos e juntos vamos mais longes.

AGRADECIMENTOS

Ao meu orientador Prof. Dr. Carlos José Soares, por acreditar na minha capacidade. O senhor é um grande exemplo de pessoa, profissional e pesquisador para mim. Vejo todos os dias o seu esforço para ser cada dia melhor e tornar tudo todos a sua volta em pessoas melhores e bem sucedidas. Por isso tenho grande admiração em todos seus ensinamentos passados e busco sempre aprender mais com o senhor todos os dias. Obrigada pela sua orientação e por tudo que você me proporcionou durante o mestrado. Sou muito grato e tenho um carinho enorme por você e pela professora Priscilla.

Ao meu orientador de iniciação científica Alexandre Coelho Machado, por ter contribuído para que eu possa ter chegado no mestrado e também agora ao doutorado. Me inspiro muito em você em sua bondade e no seu jeito de ser. Admiro a pessoa que você é e como trata todos a sua volta. Saiba que mesmo tenho uma admiração e carinho muito grande por você. Muito obrigado por todos seus ensinamentos e por ter me ajudado a conquistar parte dos meus sonhos que era fazer mestrado e doutorado.

Aos amigos Helena Letícia, Maria Tereza, e a minha namorada Lilibeth Carola por estarem sempre presentes e por não negarem esforços para me ajudar. Obrigada pelos momentos de descontração, pelas conversas boa e por me ensinarem tanto.

Ao grupo BIAOR, ao qual me orgulho de fazer parte. Obrigada por contribuírem com meu aprendizado.

Aos professores do programa de Pós-graduação (PPGO/UFU), pessoas dedicadas as quais não medem esforços em compartilhar seus conhecimentos. Sou muito grata por ter tido professores tão competentes.

À Faculdade de Odontologia da UFU, onde me graduei e agora me torno mestre. Sou eternamente grata e tenho imenso orgulho em falar que sou formado nesta casa.

Ao CPbio, lugar ao qual o trabalho se tornou possível pela estrutura física e conforto que proporciona aos alunos.

Ao CNPq, pela bolsa de estudo que me proporcionou apoio financeiro durante esse tempo.

SUMÁRIO

RESUMO

Este trabalho teve por objetivo avaliar o efeito das fontes de luz (FL) mono e multiwave com diferentes diâmetros de ponta e protocolos de fotoativação na dureza *Knoop* de resinas compostas com diferentes fotoiniciadores usados para facetas diretas. Foram confeccionadas amostras em forma da face vestibular de um incisivo central com 12 mm de comprimento incisal-cervical e 9 mm de largura máxima mesio-distal e 1,5 mm de espessura usando 2 resinas compostas com diferentes fotoiniciadores: TN, Tetric N-Ceram (Ivoclar Vivadent) - e VI, Vittra APS (FGM) cor A2E; fotoativadas com 4 LCUs: 2 multiwave - GV, Grand VALO (Ultradent) e EN, Emitter Now Duo (Schuster); e 2 monowave - RX, Radii Xpert (SDI) e EL, Elipar Deep Cure (3M Oral Care); em 2 modos de fotoativação (MF): localizada 40 s no centro da amostra e dupla exposição à luz deslocando 3 mm do centro da amostra para cervical e incisal (20 s cada), totalizando 16 grupos (n=10). A dureza *Knoop* (KH, N/mm2) foi medida na parte superior e inferior da amostra nas regiões central, cervical, incisal, mesial e distal. As LCUs foram caracterizadas em: diâmetro da ponta ativa (mm), potência (mW) e perfil do feixe com e sem interposição de corpos de prova (mW/cm^2), variando os diferentes MF. Os dados foram analisados por ANOVA-3way e teste de Tukey ($\alpha = 0,05$). As FLs mono e multiwave não interferem na dureza Knoop da resina composta TN e VI. Os valores de KH no topo foram significativamente maiores do que no fundo quando a exposição à luz foi localizada no centro da amostra, especialmente nas margens do corpo de prova. Todas as LCUs não atingiram 80% da dureza máxima na parte inferior da região cervical quando a exposição de luz foi localizada no centro da amostra. VG resultou em melhor desempenho com exposição à luz localizada. A dupla exposição à luz minimizou as diferenças entre as FLs e também entre as localizações da faceta de resina composta. Todas as FLs mostraram distribuição de luz homogênea. A fotoativação deslocando a fonte de luz, e consequentemente cobrindo toda a restauração mostrou-se essencial para atingir a dureza *Knoop* adequada da resina composta. LCUs com maior diâmetro de ponta ativa resultaram em melhor distribuição de luz gerando maior dureza Knoop de resina composta nas margens das facetas de resina composta.

PALAVRAS-CHAVE: resinas compostas, dureza, métodos de fotoativação e fontes de luz.

ABSTRACT

To evaluate the effect of mono and multiwave light-curing units (LCU) with different tip diameter and light exposure protocols on the Knoop hardness of resin composites with different photoinitiators used for direct veneers. Central incisor-shaped specimens with 12 mm of incisal-cervical length and 9 mm of mesial-distal width, and 1.5 mm thick were made using 2 resin composites with different photoinitiators: TN, Tetric N-Ceram (Ivoclar Vivadent) - and VI, Vittra APS (FGM) shade A2E; light-cured with 4 LCU: 2 multiwave - GV, Grand VALO (Ultradent) and EN, Emitter Now Duo (Schuster); and 2 monowave - RX, Radii Xpert (SDI) and EL, Elipar Deep Cure (3M Oral Care); in 2 localized light exposure (LEP): for the 40 s centered over the specimen and double light exposure shifting 3 mm from the center of the specimen to cervical and to incisal (20 s each), totaling 16 groups (n=10). Knoop hardness (KH, N/mm2) was measured at the top and bottom of the specimen in the central, cervical, incisal, mesial, and distal regions. The LCUs were characterized in: active tip diameter (mm), power (mW), and beam profile with and without specimen interposition (mW/cm²). Data were analyzed by ANOVA in 3 factors and the Tukey test (α = 0.05). Mono and multiwave LCUs do not interfere on the Knoop hardness of resin composite TN and VI. The KH values of VI and TN resin composite specimens were significantly influenced by the LCU (P <.001), by the location of the measurement (P <.001), and also by the face of the specimen (P <.001).The KH values at the top were significantly higher than at the bottom when localized light exposure was used, especially at the periphery of the specimen. All LCUs do not achieve 80% of maximum hardness to the bottom of the cervical region to localized light exposure. VG resulted in better performance with localized light exposure. The double light exposure minimized the differences among the LCU and also among the locations of the resin composite veneer. All LCUs showed homogeneous light distribution Photoactivation covering the entire restoration proved to be essential to achieving adequate resin composite Knoop hardness. LCUs with larger active tip diameter resulted in better light distribution generating higher resin composite Knoop hardness in the margins of the resin composite veneers.

KEYWORDS: Light exposure technique. Light-curing unit. Microhardness. Resin Composite.

1. INTRODUÇÃO E REFERÊNCIAL TEÓRICO

Procedimentos restauradores diretos feitos com resinas compostas em dentes anteriores fazem parte da rotina clínica do cirurgião dentista. Para realização de restaurações diretas estéticas as resinas compostas têm sido o principal material de escolha, pois oferecem adequadas características mecânicas, estéticas, necessidade de mínima intervenção e longevidade do procedimento restaurador (Demarco et al., 2015). No entanto, resinas compostas são materiais compósitos, e por isso podem ter suas propriedades dependentes dos componentes orgânicos, inorgânicos, agentes de união, inibidores e fotoativadores nelas inseridos (Ferracane, 2011). Para que resinas compostas atinjam melhores propriedades, é necessário a realização de adequada fotoativação (Cardoso et al., 2020).

Para otimizar a fotoativação diversos tipos de fontes de luz têm surgido no mercado odontológico, sendo que, algumas possuem maiores diâmetros de ponta ativa e distribuição homogênea de luz (Price et al., 2020). Fabricantes tem divulgado que essas fontes de luz permitem apenas único ponto de fotoativação em restaurações que cobre a face vestibular de dentes anteriores, pois a ponta ativa é capaz de cobrir toda a restauração entregando irradiância necessária para adequada polimerização da resina composta em toda extensão. No entanto, o custo dessas fontes de luz é elevado, quando comparado a dispositivos que possuem menor diâmetro de ponta ativa (Soares et al., 2021). Sendo assim, diversos cirurgiões-dentistas podem optar por fontes de luz com diâmetro de ponta ativa reduzidos, e consequentemente não cobrindo toda a área com apenas uma exposição.

Ademais, fabricantes de fontes de luz tem adicionado aos seus dispositivos diodos de luz no espectro do violeta (380-420 nm). Essa adição tem sido feita, pois alguns fabricantes de resinas compostas estão substituindo a canforoquinona por outros novos fotoiniciadores, como: Lucirin, BAPO, TPO e PPD. Esta substituição é feita com o objetivo de diminuir o amarelamento das resinas compostas, tornando-as mais adequas a demanda estética atual. No entanto, o espectro de absorção de luz desses novos fotoiniciadores ocorre no comprimento de onda do violeta, sendo assim, torna-se necessário a utilização de fontes de luz multi-espectro para adequada fotoativação (Santini et al., 2013).

Portanto, avaliar o efeito das fontes de luz (FL) mono e multiwave com diferentes diâmetros de ponta e protocolos de fotoativação na dureza *Knoop* de resinas compostas com diferentes fotoiniciadores usados para facetas diretas.

2. CAPÍTULO 1

ARTIGO 1

Effect of mono and multiwave light-curing unit with different tip diameter and light exposure protocols on the Knoop hardness of resin composite veneer.

***Artigo a ser enviado para o periódico Dental Materials**

Effect of mono and multiwave light-curing unit with different tip diameter and light exposure protocols on the Knoop hardness of resin composite veneer.

Thiago Silva Peres[1], Helena Letícia de Quirino Oliveira[2], Lilibeth Carola Leyton Mendoza[3], Maria Tereza Hordones Ribeiro[4], Richard Bengt Price[5], Carlos José Soares[6]

[1] DDS, MSc student, School of Dentistry, UFU – Universidade Federal de Uberlândia, Uberlândia, MG, Brazil, e-mail: thiagosilvaperes13@hotmail.com, ORCID: 0000-0002-8988-2614

[2] DDS, MSc student, School of Dentistry, UFU – Universidade Federal de Uberlândia, Uberlândia, MG, Brazil, e-mail: helena_leticia@hotmail.com, ORCID: 0000-0002-1916-8589

[3] DDS, MSc student, School of Dentistry, UFU – Universidade Federal de Uberlândia, Uberlândia, MG, Brazil, e-mail: carolaleytonm@gmail.com, ORCID: 0000-0003-1608-4299

[4] DDS, MSc, PhD student, School of Dentistry, UFU – Universidade Federal de Uberlândia, MG, Brazil, e-mail: mthribeiro.tete@gmail.com, ORCID: 0000-0002-5126-7931

[5] DDS, MSc, PhD, Professor at Dental Clinical Sciences Department, School of Biomedical Engineering, Dalhousie University – Nova Scotia, Halifax, Canada, e-mail: richard.price@dal.ca ORCID: 0000-0001-6479-1436

[6] DDS, MSc, PhD, Professor at Dentistry Department, School of Dentistry, UFU – Universidade Federal de Uberlândia, MG, Brazil, e-mail: carlosjsoares@ufu.br; ORCID: 0000-0002-8830-605X

Declarations of interest: none

All authors actively participated in the discussion of the manuscriptfindings, reviewed and approved the final version of this manuscript.

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

Phone: +55 34 3225 8119 / Cell Phone: +55 34 999713472, E-mail: carlosjsoares@ufu.br

Acknowledgments

The authors are grateful with CNPq (National Council of Scientific and Technological Development) and FAPEMIG (Foundation for Research Support of the State of Minas Gerais) for supported by grants. This research was carried out at CPBio - Biomechanics, Biomaterials and Cell Biology Research Center from Federal University of Uberlândia.

Highlight

1. The Knoop hardness was not affected by monowave and multiwave LCUs tested.
2. No LCU was capable to cover the entire area of the specimen area;
3. Emitter Now Duo designated multiwave for manufacturer was not identified peak in violet spectrum;
4. The radiant power passed through the 1.5 mm thickness of resin composite was reduced for all LCUs tested;
5. LCUs tested in this study presented a homogeneous light distribution;
6. Double light exposure protocol generated higher values of KH to the margin of the specimen to all LCUs tested than one light exposure on the center of the specimen.

Effect of mono and multiwave light-curing unit with different tip diameter and light exposure protocols on the Knoop hardness of resin composite veneer

Abstract

Objectives. Evaluate the effect of mono and multiwave light-curing units (LCU) with different tip diameter and light exposure protocols on the Knoop hardness of resin composites with different photoinitiators used for direct veneers.

Methods. Central incisor-shaped specimens with 12 mm of incisal-cervical length and 9 mm of mesial-distal width, and 1.5 mm thick were made using 2 resin composites with different photoinitiators: TN, Tetric N-Ceram (Ivoclar Vivadent) - and VI, Vittra APS (FGM) shade A2E; light-cured with 4 LCU: 2 multiwave - GV, Grand VALO (Ultradent) and EN, Emitter Now Duo (Schuster); and 2 monowave - RX, Radii Xpert (SDI) and EL, Elipar Deep Cure (3M Oral Care); in 2 localized light exposure (LEP): for the 40 s centered over the specimen and double light exposure shifting 3 mm from the center of the specimen to cervical and to incisal (20 s each), totaling 16 groups (n=10). Knoop hardness (KH, N/mm2) was measured at the top and bottom of the specimen in the central, cervical, incisal, mesial, and distal regions. The LCUs were characterized in: active tip diameter (mm), power (mW), and beam profile with and without specimen interposition (mW/cm^2).The data was analyzed using Three-way ANOVA and Tukey's tests ($\alpha = 0.05$).

Results. Mono and multiwave LCUs do not interfere on the Knoop hardness of resin composite TN and VI. The KH values of VI and TN resin composite specimens were significantly influenced by the LCU ($P < .001$), by the location of the measurement ($P < .001$), and also by the face of the specimen ($P < .001$). The KH values at the top were significantly higher than at the bottom when localized light exposure was used, especially at the periphery of the specimen. All LCUs do not achieve 80% of maximum hardness to the bottom of the cervical region to localized light exposure. VG resulted in better performance with localized light exposure. The double light exposure minimized the differences among the LCU and also among the locations of the resin composite veneer. All LCUs showed homogeneous light distribution.

Significance. Photoactivation covering the entire restoration proved to be essential to achieving adequate resin composite Knoop hardness. LCUs with larger active tip

diameter resulted in better light distribution generating higher resin composite Knoop hardness in the margins of the resin composite veneers.

Keywords: light exposure technique, light-curing unit, microhardness, resin composite.

1. Introduction

The esthetic restorative procedures are present in the routine of clinicians and are essentially associated with resin-based restorative materials.[1] Direct resin composite veneers made in anterior teeth have long been used as a conservative and esthetic treatment option, due to esthetic capacity and reduction of tooth substrate removal.[2, 3] The increasing demand for aesthetics in anterior teeth, suggests that the reason to place, and especially to replace, the resin composite in anterior teeth is other than caries and fractures.[4] The evaluable resin composites used for veneer restoration have different compositions and photoinitiators and their association with different types of light-curing units (LCUs) can affect the Knoop hardness.[5, 6]

Increasing the esthetic demand for white teeth, the popularity of the resin composite with other photoinitiators than camphoroquinone (CQ) has increased.[7] It occurs because the yellow color of camphoroquinone can influence the esthetic result of the whitening teeth restoration.[6] Manufacturers have started to use 2,4,6-trimethylbenzoyldiphenylphosphine oxide photoinitiator, commercially known as Lucirin® TPO that which reduces the yellow color to the final restoration.[8] However, these photoinitiators have a different absorption peak than CQ which has the maximum peak at approximately 470nm, and the Lucirin® TPO had a maximum absorption peak in the violet region at 400nm.[1, 9] Theoretically, the use of a multiwave LCU for light activation of the resin composite with Lucirin® TPO could improve the mechanical properties.[9, 10]

Different characteristics, such as power (mW), radiant exitance (mW/cm^2), tip irradiance (mW/cm^2); emission spectrum (mW/cm^2/nm), and beam irradiance profile are parameters used to characterize of the LCUs.[11] These parameters can also affect the resin composite mechanical performance.[12, 13] Most of the LCUs in the market appear to be equivalent irradiance to the others that have a higher cost and higher tip diameter.[14] It occurs because the irradiance is calculated from the cross-sectional circular area, and when reduce the active tip diameter has an improvement on the irradiance.[14] In general, the LCUs that had higher power (mW) and greater tip diameter, which can cover larger tooth surfaces had a higher cost.[11] The LCUs with larger tip diameter and adequate irradiance are preferable because they could cover a bigger area of the restoration reducing the light activation time. However, the light should also be delivered homogeneously around overall restoration with adequate radiant exposure to cure properly the resin composites.[1] To LCUs with a reduced tip diameter a localized exposure could result in an inadequate amount of light received in the entire restoration, consequently reducing the performance of resin composite.[15]

Most LCUs that have low costs on the market have smaller active tip diameter, variating from 6 to 7 mm, whereas few LCUs that have higher costs have active tip diameters of 9 – 12 mm.[14] Otherwise, the maxillary central incisors have different dimensions, with incisal-cervical crown length ranging between 7.8 – 13.2 mm, and mesiodistal width of 7.5 – 10.1 mm.[16] Consequently, the direct resin composite veneer made in maxillary central incisors can involve a bigger area than the active tip diameter of most LCU presented on the market.[11] In the literature, there are few studies investigating the influence of tip diameters on the Knoop hardness of resin composite. [6, 15, 17] The evaluable studies showed that the LCUs with small tip diameters are associated with a reduction in the Knoop hardness at the resin composite margins.[6, 15, 17]

The impact on the margin of the anterior restoration can be associated with fracture, secondary caries, marginal leakage, and marginal discoloration.[18] However, was not found evidence in the literature evaluating the effect of LCU parameters associated with light exposure protocol on the Knoop Hardness of resin composite veneer on a maxillary central incisor, which frequently could have more diameter than the active tip diameter of LCUs.

Therefore, the aim of this study was to evaluate the effect of the mono and multiwave LCUs with different tip diameters associated with single and double light exposure technique to light activate the resin composite with different photoinitiators simulating a central incisor veneer. The null hypotheses were: 1) The use of the LCUs with different tip diameters associated with centered single or double light exposure covering the buccal surface would not influence the Knoop hardness of the resin composite simulating the central incisor veneer. 2) Knoop hardness of the resin composite with different photoinitiators would not be affected by the light activation using mono and multiwave LCUs;

2. Materials and methods

2.1 Study design

Two resin composites in shade EA2 with different photoinitiators were used. Four LCUs were used in this study, two multiwave and two monowave. The LCU were characterized by: active tip diameter (mm) with a digital caliper; power (mW), irradiance (mW/cm^2), and spectrum ($mW/cm^2/nm$) with and without resin composite veneer specimen interposition in integrate sphere; and light transmission by LCU with and without resin composite specimen in the beam profile. Two light exposure protocols were tested, a single centered and a double spot lightening for light cure the resin composite specimens produced with an impressed matrix of buccal central incisor shape. The Knoop microhardness values (KH) at the top and bottom surface were measured 24h after specimen fabrication.

2.2 Specimen Fabrication

To produce the specimens the matrix was generated in bio-CAD 3D software (Rhinoceros, Miami, FL, USA) simulating the buccal face of the maxillary central incisor with 12 mm of incisal-cervical length and 9 mm of major mesial-distal width and 1.5 mm thick. The STL. model was exported to slicing software (Chitubox, Shenzhen, China) and the matrixes were printed in the 3D printer (Anycubic Photon Mono X, Shenzhen, China) using ultraviolet sensitive resin black color (Anycubic, Shenzhen, China).

Two resin composites with different photoinitiators were used. Vittra APS (FGM, Joinville, SC, Brazil) has camphorquinone plus a proprietary Advanced Photoinitiator System; and Tetric N-Ceram (Ivoclar Vivadent, Schaan, Liechtenstein) that uses Lucirin® TPO. The information provided by the manufacturer of the resin composite is summarized in Table 1. The order in which the samples were made was randomized at random.org. The matrix was positioned over a mylar strip (TDV Dental, Pomerode, SC, Brazil) and a glass plate, was filled in a single increment of the resin composite, then a second mylar strip was pressed over the top surface of resin composite. The LCU was fixed 1.0 mm above the resin composite veneer specimen.

2.3 Light exposure protocols

Four LCUs in the standard mode were tested in this study, two multiwave: VALO Grand (Ultradent Products, South Jordan, Utah, USA), and Emitter Now Duo (Schuster, Santa Maria, RS, Brazil); and two monowave: Elipar DeepCure-L (3M Oral Care, St Paul, MN, USA) and Radii xpert with (SDI, Bayswater, Vistoria, Australia) with monowave tip. The information about these LCUs is summarized in Table 2. The exposure time recommended by resin composite manufacturers was 20 s to increments until 2.0 mm of thickness however, to deliver the same energy were used two light-curing protocols:

(1) localized light exposure for 40 s centered over the specimen;

(2) double light exposure for 20 s each, being the first light exposure positioned 3 mm from the center of specimens to cervical region and the second light exposure positioned 3mm from the center of specimens to incisal region.

The specimens were stored dry for 24h at (37 $\pm$ 1°C) in dark envelopes that blocked the ambient light.

2.4 Characterization of LCUs and light transmission – Integrate sphere

A 12.5-inch integrating sphere (Labsphere, North Sutton, NH, USA) connected to a fiber optic spectrometer (USB 4000, Ocean Insight, Largo, FL, USA) was used to measure total radiant power (mW), irradiance (mW/cm^2), spectrum (mW/cm^2/nm). Initially, the LCU was fixed in a stabilization clamp device and characterized positioning the tip in the aperture of the sphere integration. The light transmitted through the resin composite veneer specimen was characterized with all LCUs. The filled matrix was centralized and stabilized at the integration sphere aperture and the tip of the LCUs was positioned 1 mm above the resin composite veneer specimen. Then the light was measured following the two light-curing protocols (localized light exposure for 40 s centered over the specimen and double light exposure for 20 s each, totalizing 40 s). Data was captured during 40 s of light curing. The measurement system, composed of the spectrometer, optical fiber, and integrating sphere, was calibrated before use.

2.5 Light transmission - Beam profiling

The beam profiles of all LCUs with and without the interposition of resin composite veneer specimen were examined touching the tip in the center of holographic diffuser (60° holographic diffuser screen, Edmund Optics). The image light beam was examined from the other side of the tip using a profile camera with a 50 mm focal length lens (SP928, Ophir-Spiricon, Logan, UT, USA) with two blue filters (HOYA UV-VIS colored glass bandpass filter, Edmund Industrial Optics, Barrington, NJ, USA) and two neutral density filters (5.0 and 0.5, Edmund Optics). All images were calibrated and extracted using the highest time found between the four LCUs used in this study. Then images were captured for all LCUs. The matrix was positioned touching the holographic diffuser, and the images were captured, for each resin composite associated with all LCU positioned 1 mm from the matrix using both light exposure protocols. Images were collected using Beam Gage Professional 6.14.0.355 software (Ophir-Spiricon, North Logan, UT, USA).

2.6 Knoop microhardness (KH)

The Knoop microhardness (KH, N/mm^2) at the top and bottom of the resin composite specimens were measured after 24 h. The resin composite specimen was positioned on the microhardness tester (Microhardness Tester FM-700, Future-Tech, Tokyo, Japan) and measurements were made in each face being five different positions (three for each location: at the center, cervical, incisal, mesial, and distal) by applying a load of 100kgf for 10 s, totalizing 30 measurements per specimen.

2.7 Statistical analysis

The KH data were analyzed for normal distribution and homoscedasticity using the Shapiro-Wilk and Levene's test. KH data were analyzed using 3-way ANOVA with repeated measurement being the study factor of the LCU type (4 levels), resin composite (2 levels) and light-curing protocol (2 levels), and repeated measurement the location at the specimens (5 levels). Multiple comparisons were made using Tukey's post hoc test. The ratio between top and bottom values was calculated for all experimental groups and locations. All tests used a significance level of α = 0.05, and all analyses were performed using Sigma Plot 12.5 (Systat Software Inc, San Jose, CA, USA).

3. Results

The radiant power and the emission spectra curves from the LCUs without the specimen (control) are shown in Figure 1, and through the resin composite veneer made with Vittra APS and Tetric N-Ceram using both light activation protocols and are shown in Figures 2 and 3.

The main characteristics of the LCUs tested in this study are shown in Figure 1. and Table 3. Three LCUs presented a single peak of light: Elipar DeepCure-L (448 nm), Radii xpert (452 nm), and Emitter Now Duo (449 nm) the VALO Grand presented a multi-peak of light (396, 443, and 463 nm). The Emitter Now Duo is named multiwave LCU however, was verified a unique light peak (Figure 1H). The radiant power curves of all LCUs transmitted through the resin composite veneer specimens are shown in Figure 3. Both resin composites blocked most of the light, and the energy that is delivered at the bottom surface is approximately 90% lower than the top surface. The main spectrum of light that reaches the bottom surface is the blue light spectrum and a lower amount of violet light passes through the resin composite in the VALO Grand LCU. The two light exposure protocols tested in this study resulted in a similar amount of energy transmitted through the resin composite veneer specimen.

Tip diameter and beam profiles distribution at the tip LCU, across the non-resin composite veneer light tip (control), and across resin composite veneer made with Vittra APS and Tetric N-Ceram using both light activation protocols are shown in Figure 4. When using one light exposure at the center Elipar DeepCure-L and mainly VALO Grand covered a higher area of the resin composite veneer. The Emitter Now Duo and Radii xpert resulted in a greater shadow area at proximal and mainly at cervical areas. Using 2 light exposures the difference between the LCUs was reduced substantially, improving the coverage area for all LCUs. The resin composite veneer reduced the amount of light transmitted through the specimen.

The KH values of the Vittra APS resin composite veneer specimens light-cured using both exposure protocols measured at different locations at the top and bottom faces are shown in Table 4 and for Tetric N-Ceram are shown in Table 5. The KH values of Vittra and Tetric N-Ceram resin composite specimens were significantly influenced by the LCU ($P < .001$), by the location of the measurement ($P < .001$), and also by the face of the specimen ($P < .001$). In general, the VALO Grand resulted in highest KH values, followed by Elipar DeepCure-L, then by Radii xpert and Emitter Now Duo LCU. The use of 1 light exposure for 40 s resulted in lower KH values at the cervical for all LCU at the bottom and for Elipar DeepCure-L, Radii xpert, and Emitter Now Duo at the top surface. In general, the incisal and mainly the cervical region were more influenced by protocol demonstrating the KH ratio between the different locations compared with the center value for both resin composites. When the 2 light exposures with 20 s were used the ratio reached almost the time values higher than 80% reducing the difference between the LCU used and different locations of the resin composite veneer restorations made with both resin composites. Vittra APS presented highest KH values. The reduction of the time of 20 s to 40 s determined a more negative influence for Tetric N-Ceram, demonstrating that the manufacture exposure time is insufficient for properly light-activated this material.

The distribution of KH values to Vittra APS and Tetric N-Ceram are plotted in the box plot graphic in Figure 5 and Figure 6 respectively. To both resin composites that received 1 light exposure the values of KH in the center of the specimen were higher than the margin. Double light exposures resulted in similar values on the top and bottom in all regions of the restoration.

4. Discussion

This study evaluated the effect of mono and multiwave LCU with different tip diameters and light exposure protocol on the KH of resin composite that use different photoinitiators. According to the results of this study, the first null hypothesis was rejected, since the KH of different regions of resin composite veneer was affected by the tip diameter of LCU when photoactivated by the different light exposure protocols. Due to the results obtained in this study, the LCU Emitter Now Duo will not be considered multiwave.

The longevity of resin composite restorations is completely dependent of the adequate conversion of monomers into polymers.[19, 20] The equipment used for mediating this conversion is the LCU, which has enormous variety in the market and has increased substantially in recent years. [11, 14] These LCUs have different technical characteristics: power, irradiance, wavelength range, tip diameter, and others.[5, 11] LCUs whit different technical characteristics can impact the Knoop hardness of resin composite.[15, 20-22] The protocol and techniques used for light activation of resinous material are linked with the operator decision and also determine the Knoop hardness of resin composite.[23-25]

The annual failure rates for anterior composite resin restoration vary from 0 to 4.1% in the long term of follow-up.[4] The resin composite is the main choice in many situations because it is a versatile material, that has the capacity of adhesion to the tooth structure with conservative preparation and adequate esthetic properties. However, resin composite present in the market has a different formulation and photoinitiators [26], which results in different Knoop hardness.[27] The two resin composites that were evaluated in this study have different compositions, as described in Table 1. The Vittra APS and Tetric N-Ceram exhibited variations in KH. In general, the region localized at the top in the center of the specimen was observed highest KH to Vittra APS, which is associated with the different filler compositions presented between these two composites. Both resin composites have a similar weight and volume of filler, which suggests that this difference in the hardness occurs because these two composites have different fillers compositions. Vittra APS has particles composed main of the nanosphere of zirconia with a size average of 200 nm, this combination results in fillers with higher size and more resistance to indentation than the Tetric N-Ceram that has particles with Barium glass, ytterbium trifluoride, mixed oxide, and copolymers with a size of 40 – 3000 nm. Another factor that influenced the KH in Tetric N-Ceram resin was the light-curing time, which was observed in regions that received 20 s of light had lower KH values than that received 40 s, indicating that the time recommended for the manufacturer to 10 s for LCU with ≥ 1000 mW/cm2 is not adequate to achieve the best Knoop hardness of this material.

The four LCUs evaluated in this study are commercially available and widely used, but they have different characteristics. The active tip diameters varied between four LCUs. The Radii xpert and Emitter Now Duo had the smallest tip diameter, 7.8 mm, and 8.1 respectively and the VALO Grand had the largest 11.8 mm (Table 3). Thus, the emitting area of the VALO Grand was 1.51 and 1.47 times greater than the Radii xpert and Emitter Now Duo respectively. As a consequence, VALO Grand delivered the highest radiant power, but its radiant emittance was the lowest. It occurs because the radiant emittance was directly influenced by the active diameter tip, then small reductions in the active diameter tip the irradiance increased. In this study, the reduction of active tip diameter generated the lowest values of KH in the margins of resin composite veneer, especially when was used a localized light exposure for the 40 s centered over the specimen. However, the increase in the tip diameter size increases the price of the LCU, [11] and could result in the acquisition of LCUs with low prices and consequently lower tip diameter for many clinical.

The second null hypothesis was accepted, the resin composite that used different photoinitiators associated with the use of multiwave (VALO Grand) and monowave (Elipar Deep Cure-L, Radii Xpert, and Emitter Now Duo) had no significant effect on the KH values. The wavelength peaks from the four LCUs are observed in Fig. 1. The emission peak from the Valo GRAND in the violet spectrum delivered a lower irradiance than the blue spectrum. The violet light have lower penetration in the composite resin, and the values that reaches at the bottom of the specimen is lower than the blue light. Although the manufacturer of Emitter Now Duo indicated that is a multiwave LCUs the violet led added in this LCU does not present any peak in the violet spectrum. The results showed that in the Emitter Now Duo, even when was used the double light-cure protocol the results showed a lower degree of conversion in the margins at the bottom surface using Vittra APS. The manufacturer of Vittra APS does not recommend any special LCU, because this resin composite has only photoinitiators capable to absorb light in the blue spectrum (400 – 500 nm). The system APS according to the manufacturer presents a combination of different initiators with Camphorquinone, and this system helps the composite resin achieve more whitening results. To the Lucirin® TPO present in the Tetric N-Ceram the results agree with other studies, that do not show a difference between the mono and multiwave LCUs. [28, 29] The results found suggests that the addition of violet light in the LCU may be evaluated with caution because the power of penetration of the violet spectrum is lower than the blue light, consequently reducing the power of penetration of blue light affecting the polymerization of resin composite.

Despite the manufacturers of resin composite having different recommendations times for light-curing, this study used 40 s in the center of the specimen to evaluate the same quantities of energy delivery to the restoration in the double exposure protocol that received 20 s of light-curing in two distinct regions of the restoration. This allows comparison with more accuracy if the resin composite is influenced directly by the light exposure protocol. To evaluate the influence of the light exposure protocol, the KH was measured in five different regions (center, mesial, distal, and cervical) which represent the locations more distances to the tip of LCU, and the points more distant from the center of the specimen. KH was measured because the hardness is an important parameter to suggest that a specimen of resin composite is adequately cured when there is no more than a 20% difference between the maximum hardness.[30-35] In this study was observed that the margin of resin composite veneer had lowest values of KH when was used a localized protocol of exposure for all LCUs. These founds suggest that in the long term of follow-up the margins of the resin composite veneer that were lower polymerizate could result in fracture, secondary caries, marginal leakage, and marginal discoloration in the restoration. These results were reported in the long term of follow-up of anterior resin composite restorations, in which the main reason to change the restoration was esthetic parameters.[4] Therefore the use of double light exposure is recommended during the confection of resin composite veneer because this protocol increased the values of KH in the margins of resin composite veneer, consequently improving the mechanical properties. This results were obtained with A2E shade in the composite resins with system of two opacity, therefore, more opaque composite resins may obtain less favorable results.

The use of beam profiles has been demonstrated to be an adequate method to evaluate the distribution of radiant power that reached the surface, and studies demonstrated a positive linear correlation with microhardness.[20] In this study was possible to observe in Figure 4 that for all LCUs the light beam was homogenous, but the tip diameter was not possible to cover the complete area of the restoration, especially in cervical-incisal diameter that has 12 mm of length. The consequence of this is that the localized light-curing protocol does not cover completely the area of the restoration. That is in line with the results presented in this study which demonstrated to all LCUs the margins had a percentual of polymerization lower than the center of the specimen on the top and especially on the bottom surface. When the specimen was photoactivated using a double light exposure protocol the area covered by the tip of the LCU is greater, which results in the increase of KH values in the margins of the restoration. However, the percentage of polymerization in the mesial and distal region to Radii Xpert and Emitter Now Duo does not achieve 80% polymerization compared to the central area on the bottom surface. These results suggest that despite shifting the light-curing protocol these LCUs have an active diameter tip lower than the 9 mm of the width present in the specimen, in consequence, the mesial and distal had lower values of polymerization than the central, incisal, and cervical regions. The LCUs with a lower diameter such as Emitter Now Duo and Radii xpert can also be used with more than 2 light exposures that can cover properly all the areas. The LCU tested in the present study are equipped with efficient power value, and the reduced tip diameter does not determine that they cannot be used, clinicians can minimize the effect by increasing the light exposures and maybe using only 40 s for all resin composites in larger restorations.

5. Conclusion

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. The LCUs presented a homogeneous distribution however, no LCU was capable to cover the entire area of the specimen area.
2. The radiant power passed through the 1.5 mm thickness of resin composite was significantly reduced for all LCUs tested.
3. The Emitter Now Duo designated as a multiwave for manufacture however was not identified peak of violet light.
4. The double light exposure protocol generated higher values of KH at the top and bottom in the center and the margins of the specimens, irrespective of tested resin composite;
5. The one light exposure on the center of the specimen resulted in lower values of KH in the margins for all tested resin composite veneers;
6. The KH values of resin composite that have different photoinitiators were not affected by the wavelength of the LCU, monowave (Elipar DeepCure-L, Radii Xpert, and Emitter Now Duo), or the multiwave (VALO Grand).

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Figures

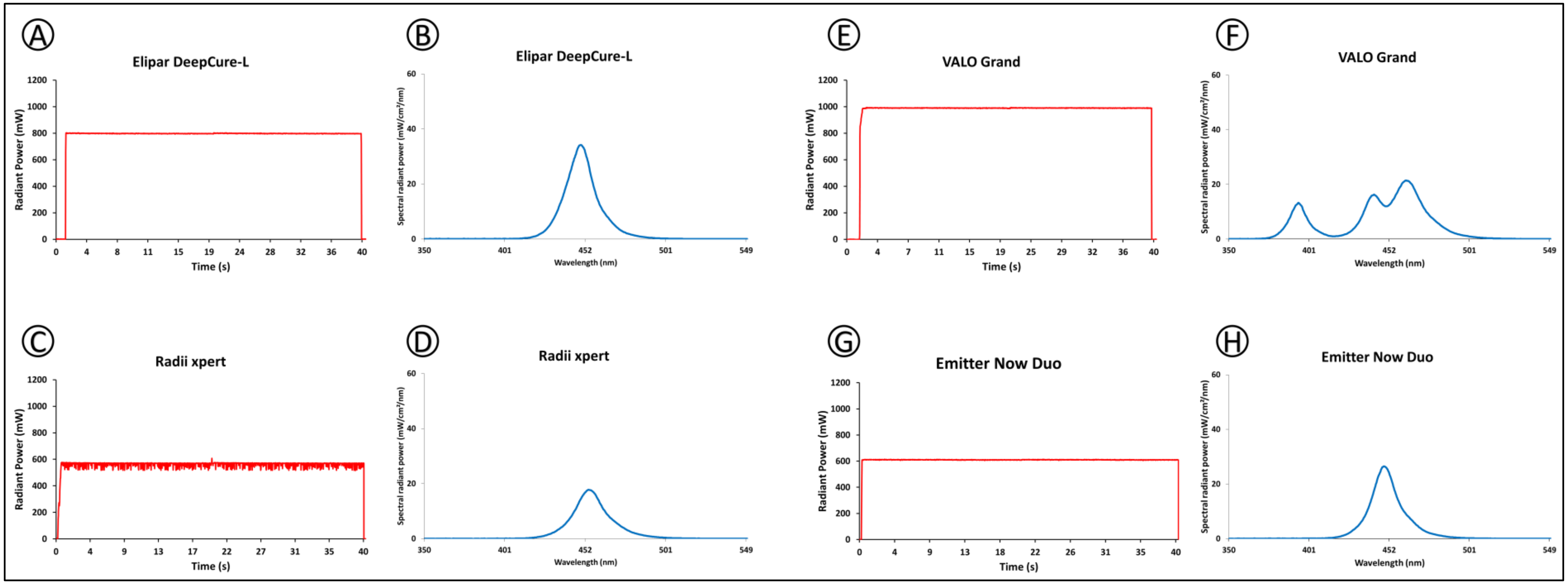


Figure 1. Radiant power and emission spectrum curves across the veneer matrix from control – non-resin composite veneer interposition. (A) Radiant Power (mW) reported over a 40 s exposure time for Elipar DeepCure-L; (B) Spectral Power (mW/cm^2/nm) for Elipar DeepCure-L; (C) Radiant Power (mW) reported over a 40 s exposure time for Radii xpert; (D) Spectral Power (mW/cm^2/nm) for Radii xpert; (E) Radiant Power

(mW) reported over a 40 s exposure time for VALO Grand; (F) Spectral Power (mW/cm²/nm) for VALO Grand; (G) Radiant Power (mW) reported over a 40 s exposure time for Emitter Now Duo; (H) Spectral Power (mW/cm²/nm) for Emitter Now Duo.

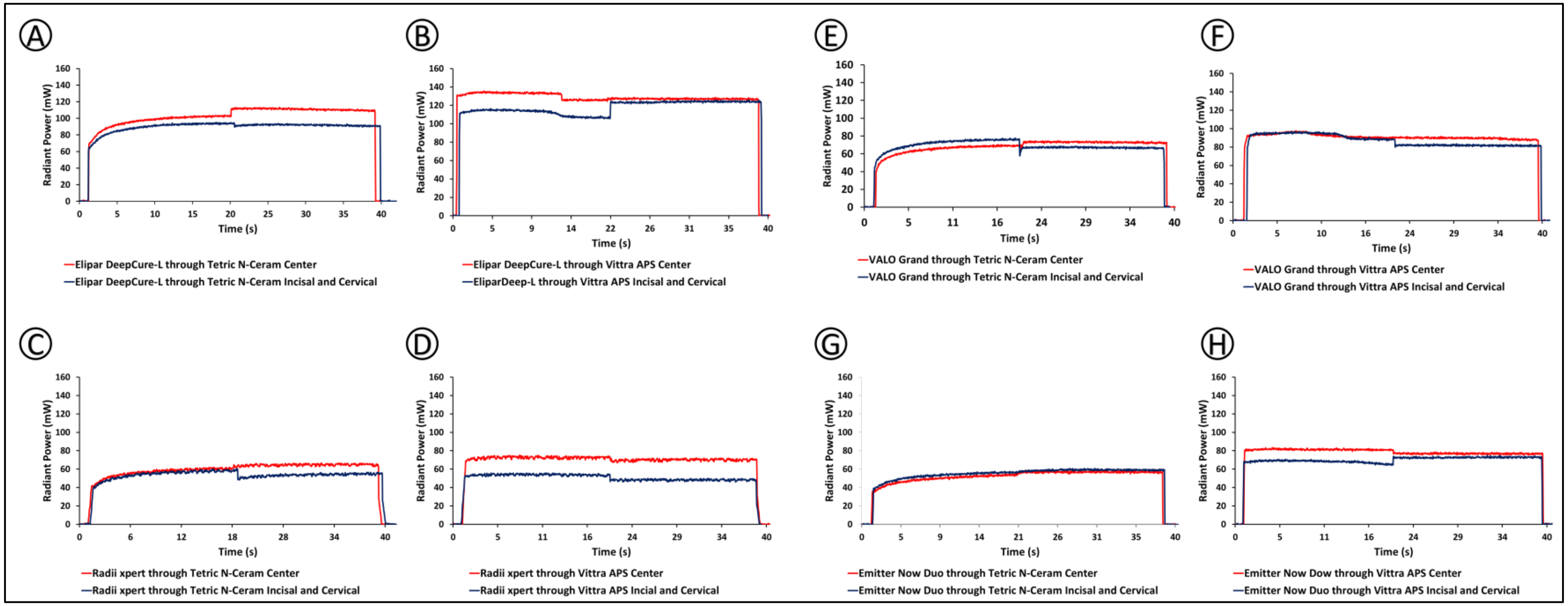
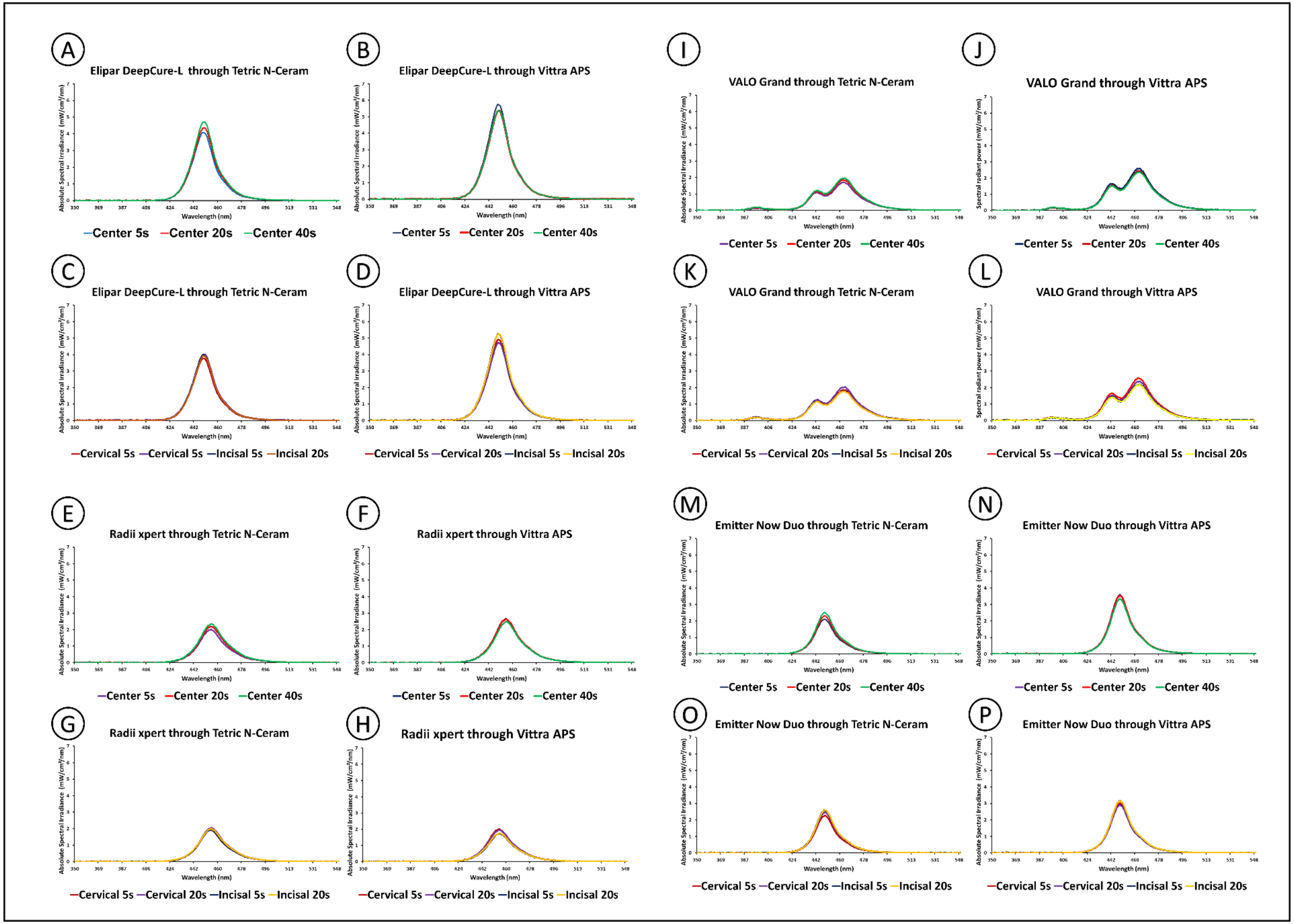


Figure 2. Radiant power (mW) curves from resin composite veneer interposition made with Vittra APS and Tetric N-Ceram using both light-curing protocols. (A) Elipar DeepCure-L through Tetric-N Ceram; (B) Elipar DeepCure-L through Vittra APS; (C) Elipar Radii xpert through Tetric-N Ceram; (D) Elipar Radii xpert through Vittra APS; (E) VALO Grand-L through Tetric-N Ceram; (F) VALO Grand through Vittra APS; (G) Emitter Now Duo through Tetric-N Ceram; (H) Emitter Now Duo through Vittra APS;


A
Elipar DeepCure-L through Tetric N-Ceram
Center 5s Center 20s Center 40s
B
Elipar DeepCure-L through Vittra APS
Center 5s Center 20s Center 40s
C
Elipar DeepCure-L through Tetric N-Ceram
Cervical 5s Cervical 5s Incisal 5s Incisal 20s
D
Elipar DeepCure-L through Vittra APS
Cervical 5s Cervical 20s Incisal 5s Incisal 20s
E
Radii xpert through Tetric N-Ceram
Center 5s Center 20s Center 40s
F
Radii xpert through Vittra APS
Center 5s Center 20s Center 40s
G
Radii xpert through Tetric N-Ceram
Cervical 5s Cervical 20s Incisal 5s Incisal 20s
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Radii xpert through Vittra APS
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VALO Grand through Tetric N-Ceram
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Emitter Now Duo through Vittra APS
Cervical 5s Cervical 20s Incisal 5s Incisal 20s

Figure 3. Emission spectrum (mW/cm^2/nm) curves from resin composite veneer interposition made with Vittra APS and Tetric N-Ceram using both light-curing protocols. (A) Elipar DeepCure-L through Tetric-N Ceram using localized light exposure protocol; (B) Elipar DeepCure-L through Tetric-N Ceram using double light exposure protocol; (C) Elipar DeepCure-L through Vittra APS using localized light exposure protocol; (D) Elipar DeepCure-L through Vittra APS using double light exposure protocol; (E) Radii xpert through Tetric-N Ceram using localized light exposure protocol; (F) Radii xpert through Tetric-N Ceram using double light exposure protocol; (G) Radii xpert through Vittra APS using localized light exposure protocol; (H) Radii xpert through Vittra APS using double light exposure protocol; (I) VALO Grand through Tetric-N Ceram using localized light exposure protocol; (J) VALO Grand through Tetric-N Ceram using double light exposure protocol; (K) VALO Grand through Vittra APS using localized light exposure protocol; (L) VALO Grand through Vittra APS using double light exposure protocol; (M) Emitter Now Duo through Tetric-N Ceram using localized light exposure protocol; (N) Emitter Now Duo through Tetric-N Ceram using double light exposure protocol; (O) Emitter Now Duo through Vittra APS using localized light exposure protocol; (P) Emitter Now Duo through Vittra APS using double light exposure protocol;

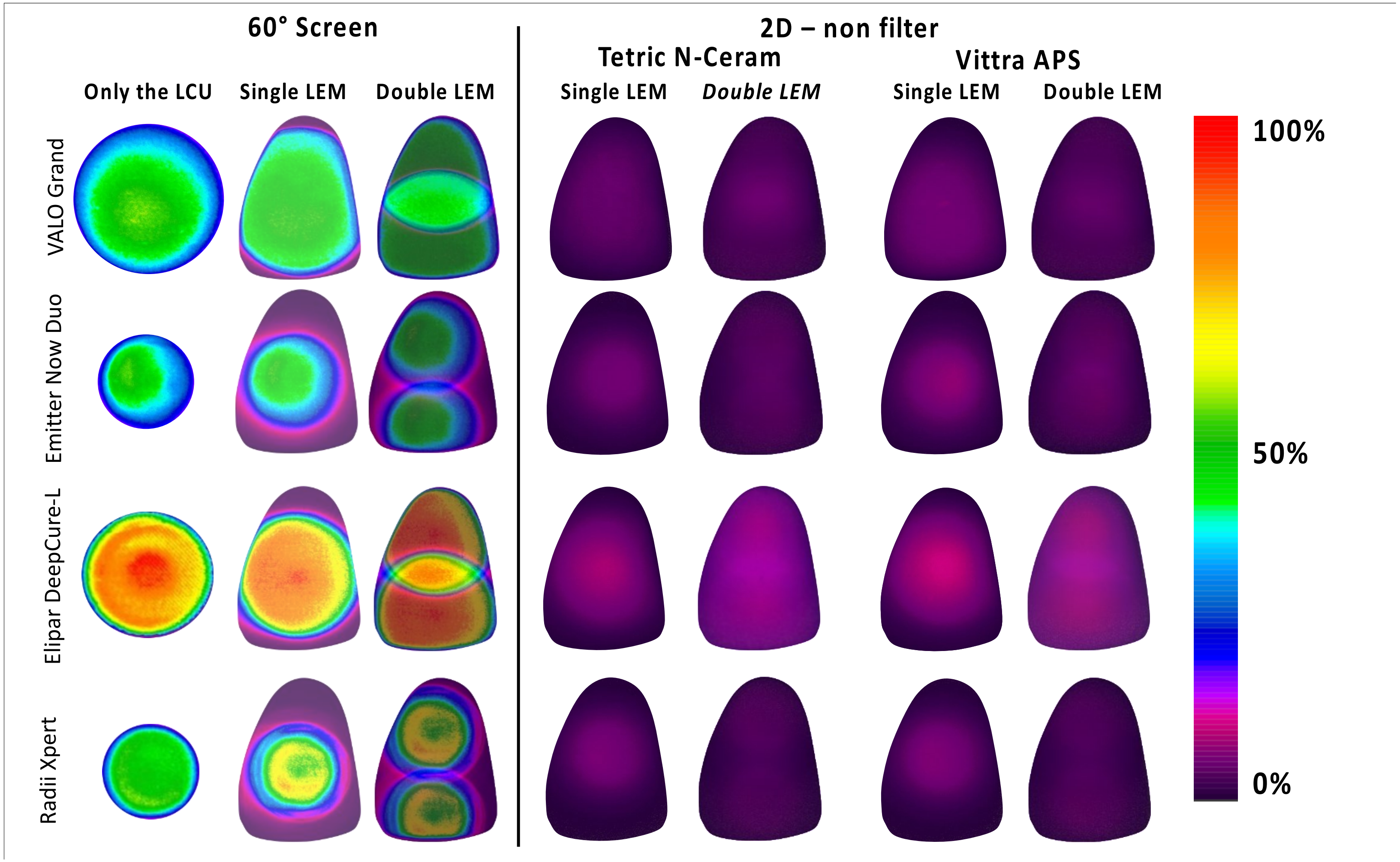

Figure 4. Two-dimensional images of the light beam profile of all LCUs and across the resin composite veneer specimen and tip diameter: VALO Grand 11.8 mm, Emitter Now Duo 8.1 mm, Elipar DeepCure-L 9 mm, and Radii xpert 7.8 mm

Tables

Table 1. Resin composite used in this study. Information was provided by the manufacturers.

Resin composites/ Manufacture	Shade	Organic matrix	Photoinitiator system	Filler	W(%)	Recommended light activation time
Tetric N-Ceram (Ivoclar Vivadent, Schaan, Liechtenstein)	EA2	Bis-GMA, UDMA, TEGDMA,	lucirin® TPO	barium glass, barium glass, and aluminum, highly disperse silica, mixed oxides, prepolymers	80-81	≥ 500 mW/cm^2 – 20 s ≥ 1000 mW/cm^2 – 10 s
VIT, Vittra APS (FGM, Joinville, SC, Brazil)	EA2	UDMA, TEGDMA	Camphorquinone and APS System*	Zircon load, silica and pigments.	72-82	20 s

Composition provided by manufacturers. Abbreviations: Bis-GMA, bisphenol A diglycidylmethacrylate; UDMA, urethane dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate; lucirin® TPO* - photoinitiator dibenzoyl germanium derivative. APS system*- according to the manufacturer it is an Advanced Polymerization System.

Table 2. The specification of light-curing units (LCUs) used in this study.

Light Curing Units/ LCU	Serial Number	LED LCU wavelength emission	Battery/ mains	Tip/light conductor	Manufacture
VALO Grand	C33856	multiwave	Battery	Direct by LED	Ultradent Products, South Jordan, Utah, USA
Emitter Now Duo	04802346	multiwave	Battery	Direct by LED	Schuster, Santa Maria, RS, Brazil
Elipar DeepCure-L	932125	monowave	Battery	Optical fiber/ black	3M, St Paul, MN, USA
Radii xpert	16536	monowave	Battery	Direct by LED	SDI, Bayswater, Vistoria, Australia

Table 3. Characteristics of the light-curing units used in this study

Light Curing Units/ LCU	Measured external tip diameter (mm)	Measured effective tip diameter (mm)	Calculated effective tip area (mm^2)	Measured radiant power (mW)	Irradiance (mw/cm^2)
VALO Grand	15.0	11.8	109.3	1029.4 ± 6.7	938.9
Emitter Now Duo	12.8	8.1	51.5	628.1 ± 16.8	1213.7
Elipar DeepCure-L	9.7	9.0	63.6	830.8 ± 5.1	1303.7
Radii xpert	12.1	7.8	47.7	500.0 ± 22.8	1032.0

Table 4. Mean and standard deviation values of Knoop hardness (N/mm^2) measured at the center of incisor central veneer Vittra APS specimens when 1 light exposure (40 s) and 2 light exposures (20 s) using different LCUs and the correspondent ratio value of different locations (cervical, incisal, mesial and distal)

TOP								
Location	**1 light exposure (40 s)**				**2 light exposures (20 s)**			
	Elipar Deep Cure	**Radii Xpert**	**Now Duo**	**VALO Grand**	**Elipar Deep Cure**	**Radii Xpert**	**Now Duo**	**VALO Grand**
Center	**66.7 ± 4.1 Aa**	**59.2 ± 5.3 Ba**	**60.3 ± 3.6 Ba**	**68.3 ± 4.3 Ab**	**61.4±5.8 Bb**	**54.2±3.8 Cb**	**55.8 ±3.8 Cb**	**75.3±4.8 Aa**
Cervical	57%	42%	52%	80%	90%	85%	87%	98%
Incisal	65%	48%	58%	90%	96%	95%	82%	95%
Mesial	79%	76%	87%	86%	84%	80%	89%	88%
Distal	88%	81%	72%	97%	84%	75%	76%	93%

BOTTOM								
Location	**1 light exposure (40 s)**				**2 light exposures (20 s)**			
	Elipar Deep Cure	**Radii Xpert**	**Now Duo**	**VALO Grand**	**Elipar Deep Cure**	**Radii Xpert**	**Now Duo**	**VALO Grand**
Center	**58.6 ± 4.0 Ba (88%)**	**50.4 ± 5.8 Ca (85%)**	**48.0 ± 5.0 Ca (79%)**	**65.8 ± 4.5 Aa (97%)**	**53.0 ± 4.2 Bb (84%)**	**51.1 ± 4.1 Ba (94%)**	**46.8 ± 3.1 Ca (84%)**	**65.2 ± 3.7 Aa (87%)**
Cervical	54%	44%	49%	69%	84%	80%	66%	90%
Incisal	67%	47%	49%	81%	89%	87%	65%	88%
Mesial	84%	74%	91%	86%	88%	74%	75%	88%
Distal	83%	79%	70%	85%	80%	72%	71%	86%

Different letters indicate significant difference – uppercase letters are used when comparing LCUs for each light exposure protocol, and lowercase letters are used for comparing the light exposure protocol for each LCU. (%) indicates the ratio between top and bottom KH values measured at the center location.

Table 5. Mean and standard deviation values of Knoop hardness (N/mm²) measured at the center of incisor central veneer Tetric N-Ceram specimens when 1 light exposure (40 s) and 2 light exposures (20 s) using different LCUs and the correspondent ratio value of different locations (cervical, incisal, mesial and distal).

TOP								
Location	**1 light exposure (40 s)**				**2 light exposures (20 s)**			
	Elipar Deep Cure	**Radii Xpert**	**Now Duo**	**VALO Grand**	**Elipar Deep Cure**	**Radii Xpert**	**Now Duo**	VALO Grand
Center	**58.9 ± 3.3 Aa**	**46.6 ± 4.4 Ca**	**55.4 ± 3.3 Ba**	**58.3 ± 4.1 Aa**	**54.5 ± 3.8 Ba**	**44.1 ± 3.8 Da**	**50.1 ± 4.5 Cb**	**57.4 ± 3.6 Aa**
Cervical	61%	53%	72%	83%	90%	96%	93%	95%
Incisal	85%	83%	87%	95%	88%	94%	91%	90%
Mesial	73%	65%	75%	93%	92%	96%	98%	91%
Distal	78%	81%	86%	94%	91%	92%	99%	92%

BOTTOM								
Location	**1 light exposure (40 s)**				**2 light exposures (20 s)**			
	Elipar Deep Cure	**Radii Xpert**	**Now Duo**	**VALO Grand**	**Elipar Deep Cure**	**Radii Xpert**	**Now Duo**	**VALO Grand**
Center	**56.0 ± 4.8 Aa (95%)**	**48.2 ± 3.4 Ca (103%)**	**50.3 ± 4.2 Ca (91%)**	**53.7 ± 4.9 Ba (92%)**	**47.2 ± 4.4 Bb (87%)**	**45.0 ± 3.3 Ba (102%)**	**47.8 ± 4.5 Bb (95%)**	**53.7 ± 4.2 Aa (94%)**
Cervical	63%	46%	58%	73%	83%	89%	72%	86%
Incisal	81%	78%	73%	82%	84%	82%	79%	87%
Mesial	71%	63%	64%	88%	87%	83%	78%	81%
Distal	78%	80%	84%	94%	88%	83%	90%	87%

Different letters indicate significant difference – uppercase letters are used when comparing LCUs for each light exposure protocol, and lowercase letters are used for comparing the light exposure protocol for each LCU. (%) indicates the ratio between top and bottom KH values measured at the center location.

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