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Irradiance and Radiant Exposures Delivered by LED Light-Curing Units Used by a Left and Right-Handed Operator

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The combination of the restoration location, the hand preference of the operator using the light-curing unit (LCU), and the design of the LCU all can have an impact on the amount of the light delivered to the restoration. To evaluate the effect of left-handed or right-handed users, the position of the operator (dentist or assistant), and the LCU design on the irradiance, radiant exposure and emission spectrum delivered to the same posterior tooth. Two light emitting diode (LED) LCUs were tested: an angulated monowave LCU Radii-Cal (SDI, Victoria, Australia) and a straight aligned multi-peak LCU Valo Cordless (Ultradent, South Jordan, UT, USA). The irradiance values (mW/cm^2), radiant exposure (J/cm^2) and emission spectrum were measured using a sensor in maxillary left second molar tooth. The irradiance and radiant exposure were analyzed using three-way ANOVA followed by Tukey test (α=0.05). The emission spectra (nm) were analyzed descriptively. The interaction between LCU design, operator position, and hand preference significantly influenced the irradiance and radiant exposure ($P<0.001$). In all cases, Valo delivered significantly higher irradiance than Radii-Cal. The handedness and the operator position affected the irradiance and radiant exposure delivered from Valo. Operator position and access affect the irradiance and radiant exposure delivered to the maxillary left second molar. The irradiance and radiant exposure can be greater when a right-hand operator is positioned on the right side of the chair and a left-hand operator is positioned on the left side of the chair. This may result in better resin composite polymerization.

Key Words: dental curing lights, posterior restoration, dental assistants.

Introduction

To optimize dental treatment, the health care system has developed the expanded operation concept that integrates and optimizes the use of dental assistants and dentists to deliver dental care (1). One strategy to improve productivity and the quality of dental care is the four-handed concept that includes individual integrated activities within an ergonomically designed process (2). This concept of delivering dental services, consists of four basic principles: 1. operating in a seated position; 2. employing the skills of trained dental auxiliaries; 3. organizing every component of the practice; and 4. simplifying all tasks to the maximum (2). To maximize office productivity, dentists should focus on performing tasks that they perform best and not waste time doing tasks that can be delegated to assistant (3). The working position of dentist and assistant depends on the hand preference (handedness) of the operator, the tooth surface, the arch region to be worked on, and the vision method used by the operator (4,5). The correct working position reduces stress, improves quality and productivity, and reduces the potential of work related injuries and liability (6). The choice of in professional practice position are related to the preference, skillfulness and hand strength to manipulate the instruments (4,7). Around 90% of the population show a preference to use the right hand (8). Consequently, the most dental equipment and most dental offices are designed for right-handed professionals.

Worldwide, the scope dental therapist includes several procedures that include placing a light cured fissure sealants, restorations using resin composites, and bonding orthodontic brackets (9). Based on the market volume and materials sold, it has been calculated that more than 250 million direct composite resin restorations are delivered annually in private offices and public health services around the world (10). Thus, the process of light curing by both dentists and dental assistants is often used in the dental office.

To achieve the manufacturer's intended properties for light cured resinous materials, sufficient energy must be delivered at the appropriate wavelengths from the light curing unit (11,12). The optical design and the ability of the operator to effectively position the light-curing unit (LCU) directly over the restoration are factors that affect the irradiance delivered to the restoration (13,14). The light curing position should be determined by the operator or

assistant who is using the LCU so that they can watch what they are doing with the LCU through protective eyewear (15). To describe the LCU some basic parameters should be reported such as the irradiance, radiant exposure delivered and the emission spectrum (11). Contemporary LCUs deliver greater radiant power and irradiance than previous LCUs (16,14). Other factors that may affect the light activation of resin composite materials are the design of the LCU or the geometry and diameter of the light tip (17,14).

The location restorations in the posterior region of the mouth together with the design of the LCUs, the operator handedness, and the position of the dentist or assistant are all a challenge when teaching how to light curing, and how this is achieved in the dental office. There is a lack in the dental literature concerning the effect of left-handed vs. right handed operators when light curing. Thus, the aim of this study was to evaluate the influence of the left or right handedness when the user was positioned as either a dentist on the right chair-side, or as the assistant on the left chair-side. This was evaluated using both an angulated and a straight aligned LCU on a simulated posterior restoration in a mannequin head. The null hypothesis was that the operator position and the handedness when using the different designs of LCU would not influence the irradiance and radiant exposure delivered to the same maxillary left second molar tooth.

Material and Methods

Two different light emitting diode (LED) LCUs were used: 1) an angulated monowave LCU Radii-Cal (SDI, Victoria, Australia) with a 6.0 mm internal tip diameter, using standard mode (1200 mW/cm²); 2) a straight aligned multi peak LCU Valo Cordless (Ultradent, South Jordan, UT, USA) with a tip head inclination of 90º degrees to the body of the LCU and a 9.6 mm internal tip diameter, using standard mode (1000 mW/cm²). The characteristics of the LCUs are shown in Figure 1.

The study was designed to evaluate the 3 study factors:

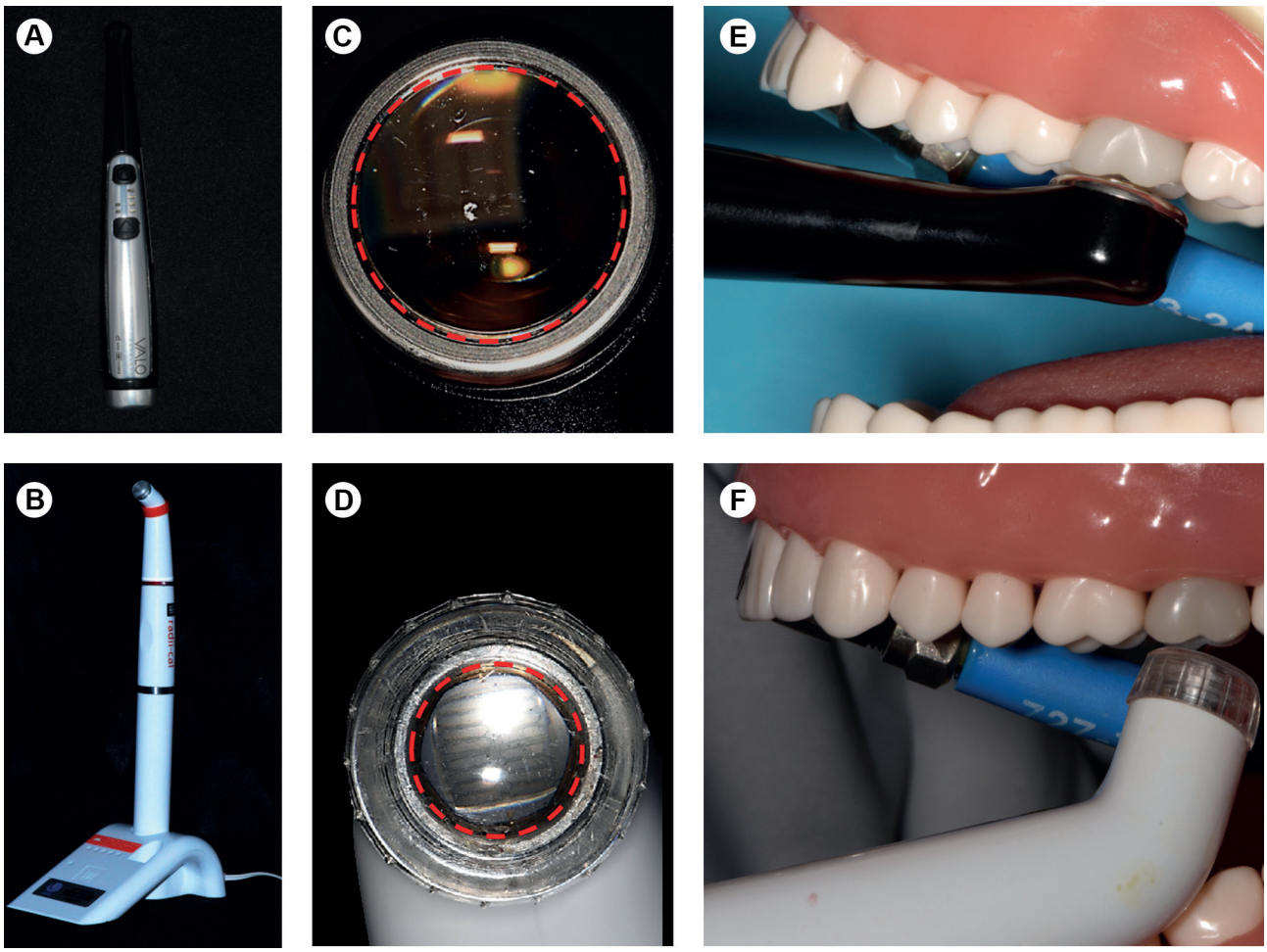

Figure 1. LCUs tested in this study. A: Valo Cordless; B: Radii-Cal - External and active internal tip diameter (red line). C: Greater tip diameter of Valo Cordless - 9.6 mm; D: Smaller tip diameter of Radii-Cal – 6.0 mm. Position of the LCU at posterior sensor: E: Demonstrating adequate alignment with occlusal surface of the posterior sensor when using Valo Cordless; F: Demonstrating angulation with occlusal surface of the posterior sensor when using Radii-Cal.

A) Hand preference of the operator: left-handed or right-handedness; B) Position of light curing operator: dentist (right chair-side) and assistant (left chair-side); C) LCU type: angulated tip monowave LCU (Radii-Cal, SDI) or the straight aligned multi peak LCU (Valo Cordless, Ultradent).

Four dental professionals volunteered to be participants in this study. Two were right-handed and two were left-handed. For all tests, the dentist position was simulated on the right side, and the assistant on the left side of the mannequin head from MARC patient simulator (MARC- PS, BlueLight Analytics, Halifax, NS, Canada). All operators worked both as dentists and assistants, alternating chair position and the participants, totalizing twelve combinations per LCU, with three repetitions for each experimental condition with both LCUs, totaling 144 measurements, 72 per LCU (Fig. 2).

The irradiance (mW/cm^2), radiant exposure (J/cm^2) and emission spectrum (nm) delivered by the LCUs was measured using the MARC patient simulator for all twelve dentist/assistant combinations per LCUs. The restoration was simulated in the maxillary left second molar because the Marc patient simulator have only one posterior sensor with 4-mm diameter, which is located inside a Class I preparation in this tooth, and the sensor is connected to a fiberoptic spectrometer (USB4000, Ocean Optics, Dunedin, FL, USA) that is inside the mannequin head. The interincisal mouth opening was fixed at 35 mm and the same light exposure time of 10 seconds was used as an reference for both LCUs, light exposure time that is used also to light cure some adhesive system and composite resins like Filtek Bulk Fill Posterior (3M ESPE, Saint Paul, MN, USA), and Clearfil SE Bond (Kuraray Inc., Kurashiki, Osaka, Japan). The following protocol for light curing were used: 1. the LCU was positioned directly over and as perpendicular as possible to the sensor surface without touching, 2. the LCU tip was stabilized as close as possible to the cusp tip, 3. both the operator and the assistant wore blue-light-blocking glasses (13,15), so that they could see what they were doing when light curing, 4. The position of MARC patient simulator head was adjusted to provide maximum

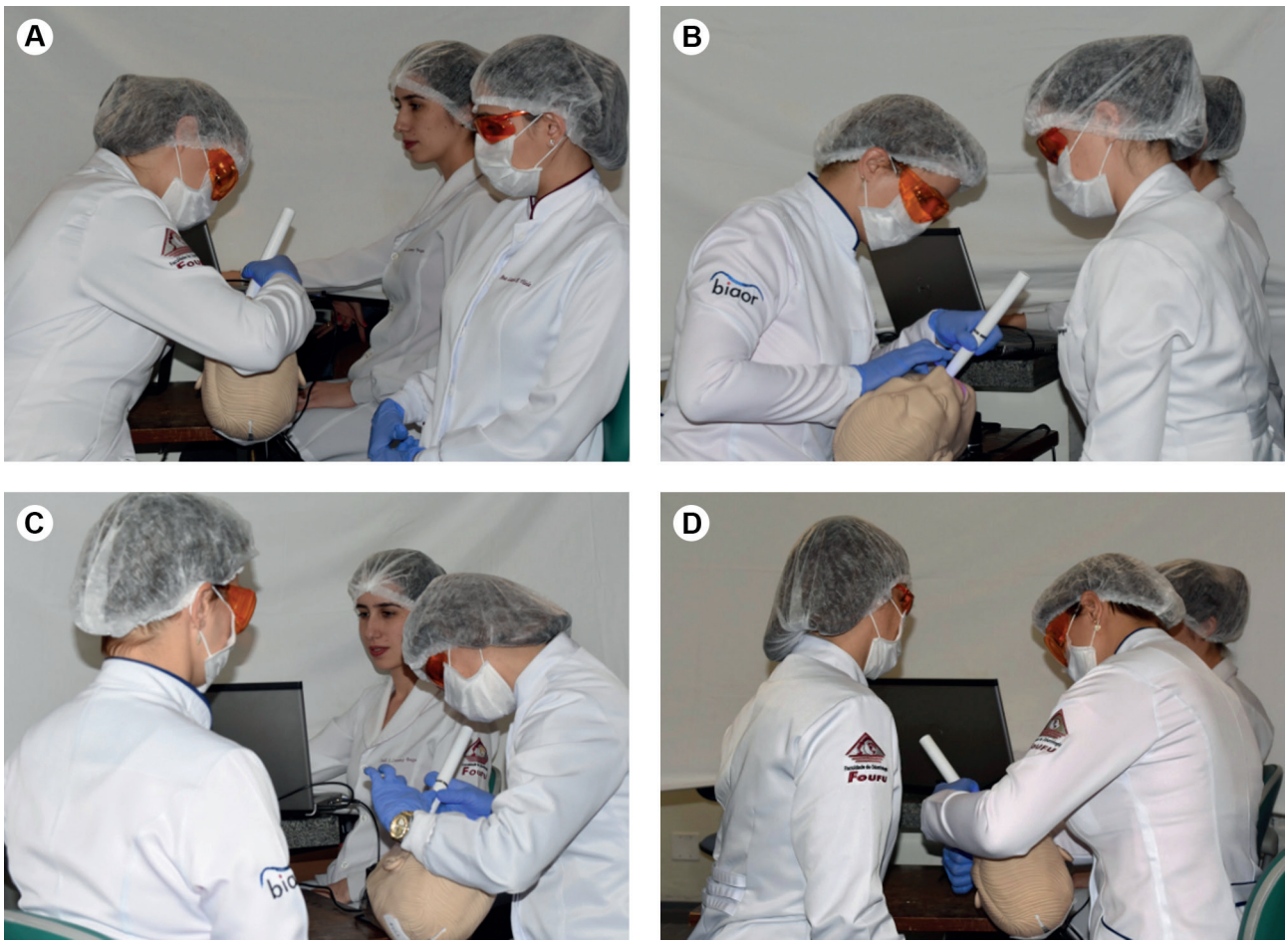

Figure 2. Position of the LCU simulating curing process on the upper left second molar: A: Right-hand when positioned as the assistant operator; B: Left-hand when positioned as assistant; C: Right-hand when positioned as the dentist operator; D: Left-hand positioned as the dentist operator.

visibility and access for the person using the curing light.

The both LCUs were fully charged and radiant power was measured using a handheld laser power meter (Nova, Ophir Spiricon, Logan, UT, USA) with a photodiode laser measurement sensor (PD300R, Ophir Spiricon, Logan, UT, USA) before starting each test. When radiant power decreases the LCUs were fully charged again after starting a new test an so on. Irradiance data were analyzed for normal distribution and homoscedasticity using the Shapiro-Wilk test and Levene's test, respectively. Three-way ANOVA (2X2X2) was used to compare the outputs from the 3 study factors. All tests were performed at a significance level of α=0.05, and all analyses were performed using the Sigma Plot version 13.1 statistical package (Systat Software Inc., San Jose, CA, USA). The emission spectra (nm) were analyzed descriptively.

Results

The irradiances delivered by both LCUs used by the right-handed and left-handed operators when positioned as the dentist or assistant are reported in Figure 3. Three-way ANOVA showed that the operator position ($p<0.001$), the LCU ($p<0.001$), and the interaction between LCU type, operator position and hand preference ($p<0.001$), all significantly influenced the irradiance delivered. Tukey test showed that Valo delivered a significantly higher irradiance than Radii-Cal for all conditions (dentist/right-handed: by 30%; dentist/left-handed: by 28%; assistant/right-handed: by 29%; and assistant/left-handed: by 54%). The right and left-handed positions had no influence on the effect of the assistant, or the dentist position when using Radii-Cal, but the irradiance and radiant exposure values were lower than from the Valo. When working as the dentist, using the Valo Cordless LCU with the right-hand delivered significantly greater irradiance than when they used the left-hand. Conversely, when working as an assistant, using the Valo Cordless LCU and their left-hand, they delivered significantly higher irradiance than when using their right-hand.

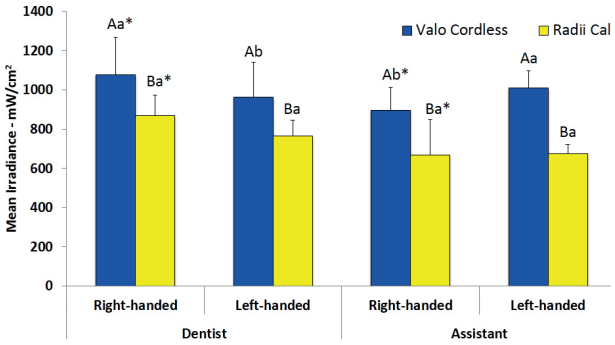

Figure 3. Mean Irradiance delivered by the Valo Cordless and Radii-Cal used by right and left-hand operators when positioned as the dentist or assistant operator. Different upper caser letter indicates a significant difference between LCUs for each experimental condition; different lower caser letter means significant difference between right and left-hand for each operator position. Similar letters indicate that there are no significant differences between the values, upper caser letters comparison between LCUs and lower caser letters comparison between operator position. * Used for comparison between dentist and assistant for each LCU and operator position, as determined by the Tukey test ($p<0.05$).

Figure 4 illustrates how the irradiance from the Valo Cordless and Radii-Cal are influenced by both the handedness and operator position. When using Valo Cordless, a right-hand operator positioned as the dentist and left-hand operator positioned as assistant were able to deliver more homogeneous and greater irradiance to the upper left second molar tooth (Fig. 4E and 4H). The Radii-Cal always delivered lower and more inhomogeneous irradiance curves than Valo Cordless (Fig. 4). The handedness of the operator when they were positioned as the dentist or the assistant chair had no significant influence on the emission spectrum from either LCU (Fig. 5).

Discussion

The operator position and the handedness when using different LCU types significantly affected the irradiance and radiant exposure delivered to a left maxillary second molar tooth (28 to 54%). Therefore, the null hypothesis was rejected.

One limitation of this study was the impossibility of performing the tests on a contralateral tooth because Marc patient simulator has only one posterior sensor which is fixed and located on the left second molar tooth. However, this limitation was compensated by the alternation of the operator positions. When used for the same exposure time, the Valo delivered a significantly higher irradiance than Radii-Cal for all conditions (dentist/right-handed: by 30%; dentist/left-handed: by 28%; assistant/ right-handed: by 29%; and assistant/left-handed: by 54%). Insufficient resin composite polymerization reduces the mechanical properties, reduces the bond strength, allows greater leakage at the margins, increases wear, increases the potential for more secondary caries and thus may lead to complete restoration failure (10,11). Therefore, delivering an adequate radiant exposure is directly related to success and longevity of the restoration.

Several factors should be considered to achieve proper photocuring of resin composite restorations in posterior teeth such as the characteristics of the restorative material, the selection of well-adapted instruments, the angulation of the LCU, the position of the patient, how the LCU is used, and the manual skills of the operators (13). The use of different brands and designs of LCU may also affect the ability to light cure the resin (7). This study used the Radii-

Cal that delivers a single peak of spectral coverage, and the Valo, which is a multi-peak source that delivers a wider emission spectrum (18). For resin composite restorations to be considered adequately polymerized, they should

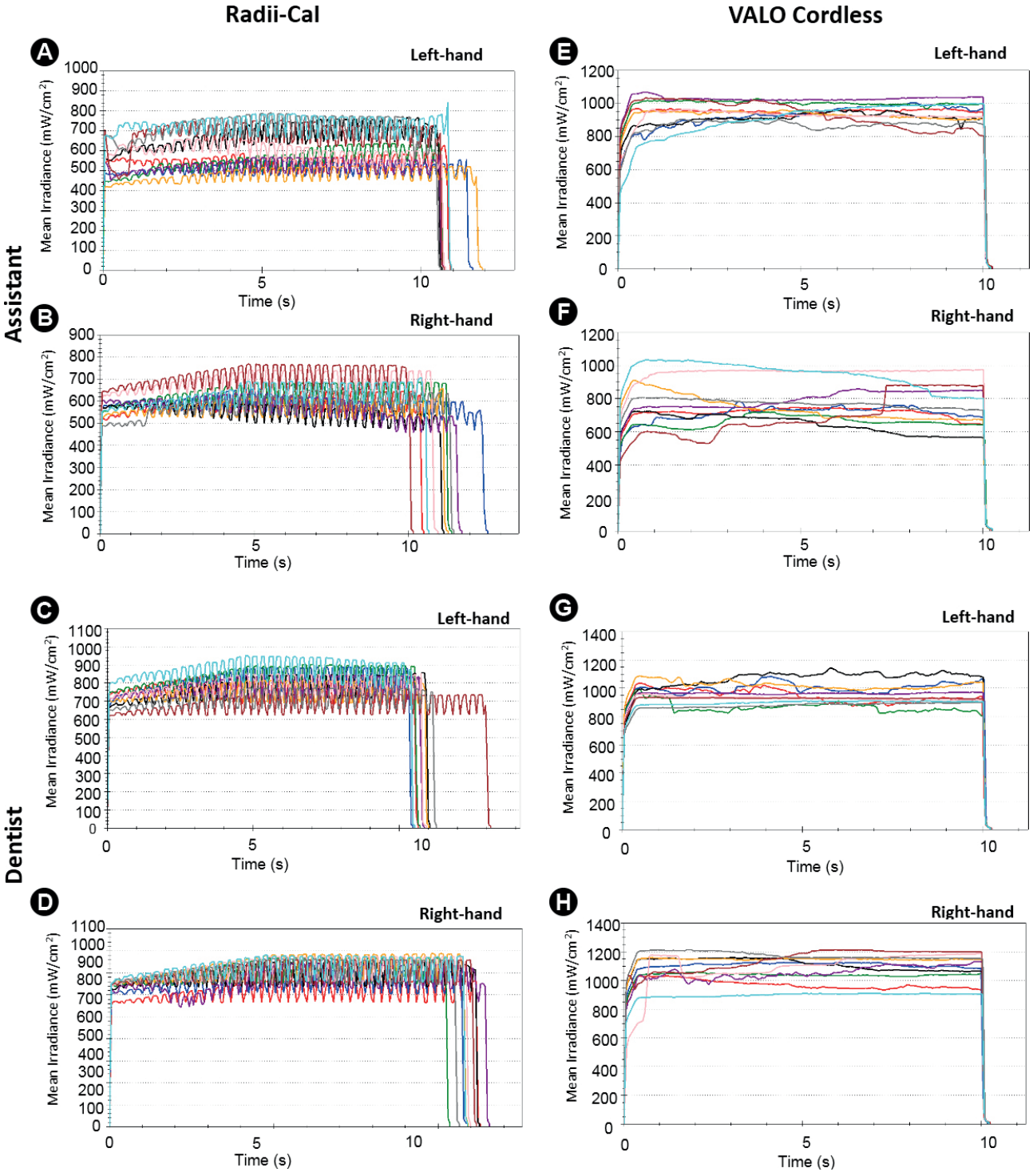

Figure 4. Mean irradiance curves delivered by: A: Radii-Cal/left-hand assistant operator; B: Radii-Cal/right-hand assistant operator; C: Radii-Cal /left-hand dentist operator; D: Radii-Cal/right-hand dentist operator; A: Valo Cordless/left-hand assistant operator; B: Valo Cordless/right-hand assistant operator; C: Valo Cordless/left-hand dentist operator; D: Valo Cordless/right-hand dentist operator. The irradiance scales are different in the images so as to better illustrate the differences. The output from the Radii-Cal pulses and has lower irradiance values than the Valo Cordless. Valo Cordless delivers a more uniform output design that makes it possible to see the effect of the operator position and handedness. The right-hand operator when positioned as a dentist and left hand when positioned as assistant delivered more homogeneous and higher irradiance curves (Figures 4E and 4H).

receive sufficient irradiance value in terms of efficient exposure curing time (radiant exposure), together with the appropriate range of wavelengths (from 385 to 515 nm, depending on the photoinitiator to be activated) (19). The energy delivered to the restoration also has a strong influence on the resin polymerization. Due to differences in the various products available on the market, the irradiance, emission spectrum and exposure time required for effective photoactivation are not the same for all brands. Therefore, it is necessary to know the requirements of the materials used

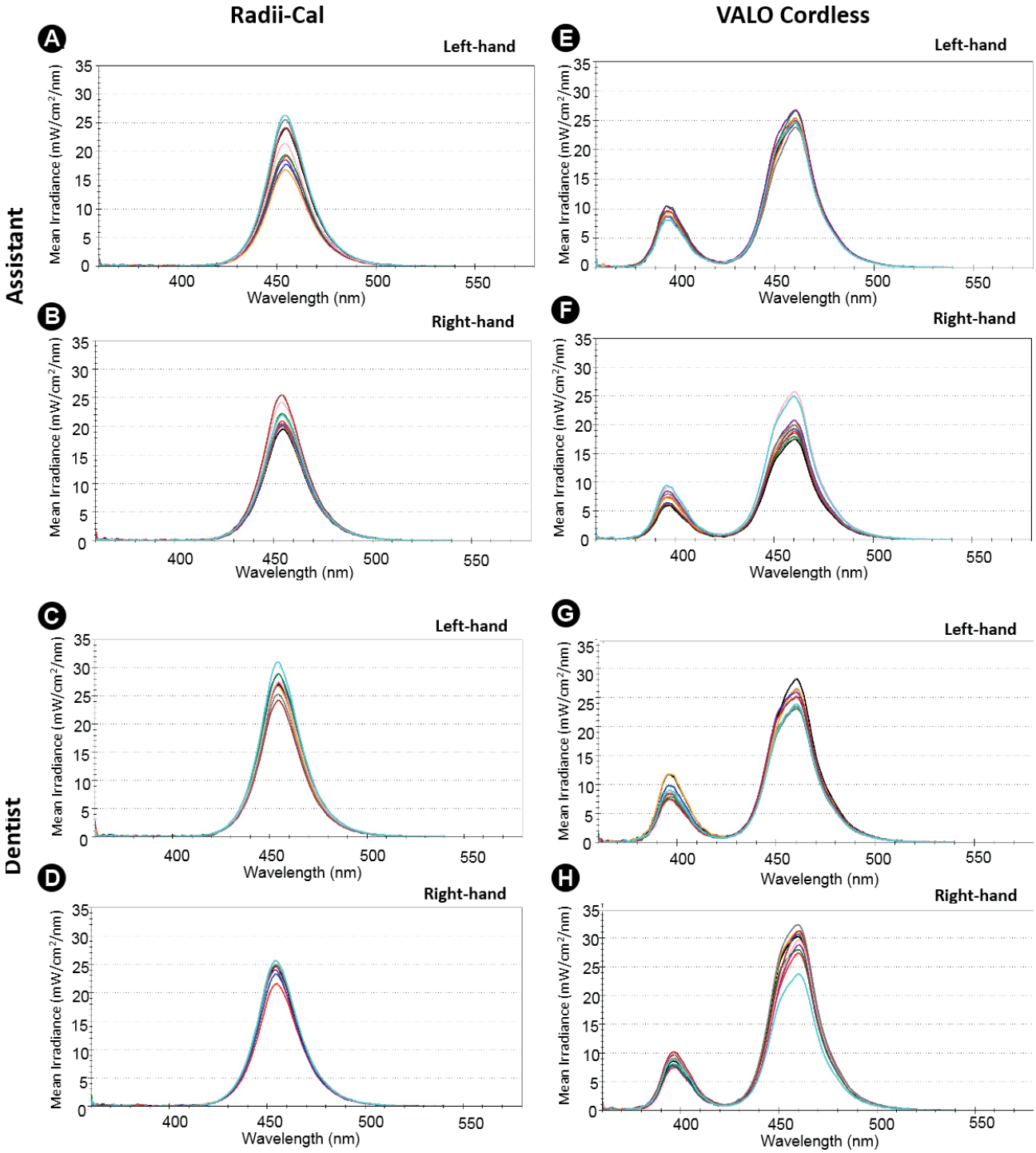

Figure 5. Emission spectrum curves from: A: Radii-Cal/left-hand assistant operators; B: Radii-Cal/right-hand assistant operators; C: Radii-Cal / left-hand dentist operators; D: Radii-Cal/right-hand dentist operators; A: Valo Cordless/left-hand assistant operators; B: Valo Cordless/right-hand assistant operators; C: Valo Cordless/left-hand dentist operators; D: Valo Cordless/right-hand dentist operators. Note that there is no difference related to the position. The Radii-Cal emits a single peak spectrum - blue light wavelengths; and Valo Cordless two major peaks – violet and blue light wavelengths.

to choose the LCU that best matches the resin to be light cured (19). Although, these differences are important, the main focus on this study was the effect of the LCU design.

The irradiance delivered by most curing units decreases over clinically relevant distances; therefore, as the distance to the resin increases, longer exposure times may be needed to deliver the required energy to the restoration (20). Several materials have recommended very short time for light activation, when the manufactures definy this time, they taking into account the sufficient energy delivered to the material. The same careful should be taken when light-curing adhesive systems, especially in deep proximal boxes where light be not adequately cured with a typical 10 seconds curing time because the increase of the distance, therefore dentin shear bond strengths increases when the curing time increase from 20, 40 or 60 seconds (21). In clinical practice, both dentist and assistant should be able to monitor that the light from the LCU tip has direct access to the RBC's surface. Ideally the LCU tip should positioned at a 90 ° angle to the RBC surface, and the distance between the tip and the restoration surface should as small as possible (22, 19). This correct positioning of the LCU can be facilitated by the design and size of LCU tip (15). As illustrated in Figure 1, the design of the Valo Cordless permitted the better access to teeth in the posterior region. In contrast, the angulation of the Radii-Cal tip makes it impossible to place its light tip perpendicular to the occlusal surface of molar teeth with an interincisal mouth opening of 35 mm. This fact explains the superior results for Valo, since the closer to the material is to the LCU tip, the greater the irradiance (23). The ability to freely change the position of the Valo Cordless made be possible to position this LCU optimally and the Valo Cordless delivered a higher irradiance and radiant exposure values than Radii-Cal, irrespective of the operator's position. Thus, the body and tip angulation of the Radii-Cal makes it more difficult to position this LCU in the mouth or to position the light tip directly over the restoration surface, irrespective if was performed by the right-handed or the left-handed operator. The larger size of the Valo's light tip may also explain the improved performance of this LCU (14). Despite the different tip diameters of the LCUs used on this study, the posterior sensor on cavity is only 4-mm diameter, therefore the both LCUs properly covered totally the sensor.

In the posterior teeth, the ability to access all regions of the restoration is more restricted, and patients may vary in their ability to open and maintain a wide-open mouth. This will affect access to the restoration site, which in turn has a significant effect on the clinician's ability to deliver sufficient energy from the LCU to the restoration (24). Thus, correctly positioning the patient's head will help to ensure a normal and stable alignment of the LCU to the restoration surface throughout the entire light exposure. The lack of ergonomic guidelines in planning the work environment and dentistry equipment for left-handed dentists means that they must make extra efforts to develop their skills while using equipment designed for right-handed users. This aspect is especially observed in the public dental service where almost all the equipment is designed for the right-handed user (25).

Dentistry is a profession that demands precision, skills and concentration (26). However, dental industries continue to develop equipment that works optimally for majority of the population that is right-handed and force left-handed operators to adapt. This may lead to a decrease in performance when used with the left hand compared to the right hand. This study showed that right-handed operators sitting in the position of the assistant on the side where the restoration was located (the maxillary left second molar) delivered a lower irradiance compared to left-handed operators working in the same position. When working on the right side of the patient, the performance of right-handed operators was significantly better compared to when they were positioned on the left side of the patient. The combination of all the factors discussed can facilitate access and provide greater success for clinicians. In this study, when the operator was not on the side of the chair that was compatible with their work hand preference and when they used a LCU with an angulated tip design, it was a challenge to deliver sufficient light to the posterior region, thereby potentially negatively influencing the final resin composite properties. In future, it is recommended that dental manufacturers should test their equipment using both right and left-hand operators and from both sides of the patient's head.

Within the limitations of this in vitro study, the conclusions were: the LCU design, the operator position and their hand preference can all significantly influence the irradiance and the radiant exposure delivered to posterior teeth; a right-handed operator using the Valo in the dentist position (right chair-side) or a left-handed operator when seated in the assistant position (left chair-side) improved the light delivery to a maxillary left second molar; the Valo that has a straight aligned LCU design and larger tip that resulted in better performance on posterior teeth than the Radii-Cal and the Valo delivered a significantly higher irradiance than Radii-Cal for all conditions (dentist/right-handed: by 30%; dentist/left-handed: by 28%; assistant/right-handed: by 29%; and assistant/left-handed: by 54%).

Resumo

A combinação da localização da restauração, a preferência de mão do operador ao utilizar aparelhos fotopolimerizadores (AFP) com luz emitida

por diodo (LED) e o formato do AFP podem afetar a quantidade de luz fornecida à restauração. O objetivo foi avaliar o efeito de operadores canhotos e destros, a posição do operador (dentista ou auxiliar), e o formato do AFP na irradiância, energia radiante e espectro de luz entregue ao mesmo dente posterior. Dois AFP foram testados: um com formato angulado, onda única Radii-Cal (SDI, Victoria, Australia) e um formato reto multi-pico Valo Cordless (Ultradent, South Jordan, UT, USA). Os valores de irradiância (mW/cm²), energia radiante (J/cm²) e espectro de luz foram medidos utilizando um sensor no segundo molar superior esquerdo. A irradiância e energia radiante foram analisados utilizando ANOVA 3 fatores seguido por teste de Tukey (α=0.05). O espectro de luz (nm) foi analisado de forma descritiva. A interação entre o formato do AFP, posição do operador e preferência de mão foram significativamente influentes na irradiância e energia radiante ($P<0.001$). Em todos os casos, Valo teve irradiância significativamente maior que Radii-Cal. A mão dominante e a posição do operador afetaram a irradiância e energia radiante com o Valo. Posição do operador e acesso afetou a irradiância e exposição radiante entregue ao segundo molar superior esquerdo. A irradiância e exposição radiante teve melhores resultados quando AFP foi utilizado com a mão direita pelo operador posicionado na cadeira do lado direito e mão esquerda do operador posicionado do lado esquerdo da cadeira. Estes resultados podem levar a uma melhor polimerização da resina composta.

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