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Effect of infection control barriers on the light output from a multi-peak light curing unit

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ABSTRACT

Objectives: Curing lights cannot be sterilized and should be covered with an infection control barrier. This study evaluated the effect of barriers when applied correctly and incorrectly on the radiant power (mW), irradiance (mW/cm^2), emission spectrum (mW/nm), and beam profile from a multi-peak light-curing unit (LCU).
Methods: Five plastic barriers (VALO Grand, Ultradent; TIDIShield, TIDI Products; Disposa-Shield, Dentsply Sirona; Cure Sleeve, Kerr; Stretch and Seal, Betty Crocker) and one latex-based barrier (Curelastic, Steri-Shield) were tested. The radiant power (mW) and emission spectrum (mW/nm) from one multi-peak LCU (VALO Grand, Ultradent) was measured using an integrating sphere. LCU tip internal diameter (mm) was measured, then the tip area and irradiance (mW/cm^2) were calculated. The beam profiles were measured using a laser beam profiler.
Results: When applied correctly, the plastic barriers reduced the radiant power output by 5–8%, and the latex-based barrier by 16%. When the plastic seam or barrier opaque face was positioned over the LCU tip, the power output was reduced by 8–11%. When the plastic barriers were wrinkled, the power output was significantly reduced by 14–26%. The wrinkled latex-based barrier reduced by 28%, and further reduced the violet light. The beam profiles illustrated the importance of correctly barrier use without wrinkles over the tip.
Conclusions: Plastic barriers applied correctly reduced the light output (mW) by 5–8%. The barriers applied incorrectly significantly reduced the light output by 14–26%. The latex-based barrier wrinkled also reduced the amount of violet light.
Clinical relevance: Infection control curing light barriers should be used to prevent cross-infection between patients. However, they must be applied correctly to reduce their negative effects on the light output.

1. Introduction

The median longevity of resin composite restorations is approximately 6 years [1,2], with the main reason for replacement being secondary caries and restoration fracture [3,4]. The dental light-curing unit (LCU) is an essential part of the process of photocuring a resin composite [5,6], but light-curing units (LCUs) cannot be dry or steam heat sterilized. Instead, they are covered in a disposable infection control barrier and wiped down with a disinfectant between patients. These disposable infection control barriers will reduce the light output from the curing light [7]. In areas of low irradiation, this may cause inadequate or heterogeneous resin polymerization, that may then result in premature failure of the restoration [8,9]. The type of disposable barriers and how they were applied may contribute to these failures [8].

The presence of blood, saliva, respiratory particles and viruses in the oral cavity means that contamination and cross-infection between patients is a major concern in every dental office. According to the Centers for Diseases Control and Prevention guidelines, the LCU falls into the category of semi-critical instruments because it is in direct contact with the mucous membranes or non-intact skin and carries the risk of transmitting infection [10]. The use of protective infection control barriers on such devices has become essential to avoid transmitting diseases such as Hepatitis B, Acquired Immune Deficiency Syndrome, and, more recently, COVID-19 [10–13] because contamination can occur from the

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body, light guide, or the control buttons on the LCU that can all become contaminated when used on a patient [14]. Disposable infection control barriers are convenient, non-invasive, and prevent contact between the oral tissues and the LCU [15], the entire LCU must be covered, not just the tip of the LCU. This will prevent contamination from the operator's glove, oral fluids, or the patient's breath. The barrier will also prevent contaminating the light tip with uncured resin. This is relevant because it has been reported that 35–68% of the LCUs in dental offices have bonding agent or resin adhered to their light tip, which means that the LCUs were used without a barrier [16]. This debris will reduce the light output and potentially have a negative effect on the resin polymerization [17,18]. However, incorrect positioning of the barrier can cover the light tip with a fold or a seam in the barrier. Intuitively, this should reduce the light output from the LCU, but this has not been investigated. While it is known that the operator position when using different shapes and designs of LCU can affect the amount of light received by the restoration [19,20], the design and fit of the barrier over the LCU may also affect the amount of light received by the restoration.

Several types of barriers have been used with LCUs, including adhesive touch and splash surface barriers, gloves, steri-shields, and even finger cots [21]. These infection control barriers can be made of different materials, including latex-free polyurethane, low-density polyethylene, and polyvinyl chloride [22]. Several previous studies of the effect of barriers on light emission have been conducted using LCUs that emit a blue light source [7,17,22]. Now that several different photoinitiators have been introduced that that require violet light, further studies are required to determine the effect of these barriers on the violet portion of the output from broad-spectrum violet-blue LCU's.

Therefore, the aim of this study was to evaluate the effect of different disposable infection control barriers on the radiant power (mW), irradiance (mW/cm^2), emission spectrum (mW /nm), and beam profile from a broad spectrum violet-blue LCU. The null hypotheses were that: 1) The presence and composition of the barriers would have no influence on radiant power, emitted spectrum light, or the beam profile: 2) How the infection control barriers were applied over the tip would have no effect on the radiant power, emitted spectrum light, and beam profile from the LCU.

2. Material and methods

2.1. Disposable barriers and LCU used

Six commercially available types of disposable infection control barriers (Table 1 and Fig. 1) were tested: five were plastic barriers with a transparent face that should be positioned smoothly over the LCU tip, and one was a latex-based barrier. The barriers were first tested fitting smoothly over the front face of the LCU tip as recommended by manufacturers, and then again simulating several different incorrect placements (Fig. 2). One broad spectrum violet-blue light-emitting diode (LED) LCU (VALO Grand, Ultradent, South Jordan, UT, USA) was used.

Table 1
Manufacturer's information about the disposable barriers.

Brand name	Type	Composition	Manufacturer
VALO Grand Disposable Barrier Sleeves	Full body barrier	Polyethylene	Ultradent, South Jordan, UT, USA Made by TIDI Products, Neenah, WI, USA
TIDIShield Curing Light Sleeves	Full body barrier	Polyethylene	TIDI Products, Neenah, WI, USA
Curelastic	Tip only	Polyurethane	Steri-Shield, Santa Barbara, CA, USA
Disposa-Shield	Full body barrier	Polyethylene	Dentsply Sirona, Konstanz, Germany
Cure Sleeve by Pinnacle	Tip only	Low-density polyethylene	Kerr, Metrex Research Corp, Romulus, MI, USA
Stretch and Seal Flexible Film	Food wrap	Polyvinyl chloride	Betty Crocker, General Mills, Inc., Minneapolis, MN, USA

Fig. 1. Materials used in this study: six different infection control barriers and one multi-peak LCU. A- Stretch and Seal Flexible Film (Betty Crocker); B- VALO Grand light curing unit (Ultradent); C- Cure Sleeve by Pinnacle (Kerr); D- Disposa-Shield (Dentsply Sirona); E- Curelastic (Steri-Shield); F- VALO Grand Disposable Barrier Sleeves (Ultradent); G- TIDIShield Curing Light Sleeves (TIDI Products).

This broad spectrum LCU emits both violet and blue light, it has the LED light source at the tip end, and the LCU cannot be heat sterilized. The internal and external light tip diameters were measured using a digital caliper (Mitutoyo, Tokyo, Japan). The active tip area was calculated from the inner diameter of the LCU tip.

2.2. Power and irradiance

A 6-inch integrating sphere (Labsphere, North Sutton, NH, USA) attached to a fiberoptic spectrometer (USB 4000, Ocean Insight, Largo, FL, USA) was used to measure the total radiant power from the LCU five times without, and then five times with barriers in all the various tested conditions. The LCU light tip was placed at the 12.5 mm diameter entrance to the integrating sphere, and all the light from the LCU tip was captured. The measurement system, comprising the spectrometer, optical fiber, and integrating sphere, was calibrated before use.

The mean irradiance across the light-emitting surface of the tip was calculated as the quotient of the average of the five radiant power values and the internal optical area of the LCU tip [23]. This result provided an averaged single irradiance value across the entire light tip.

2.3. Beam profile

The light beam profiles were evaluated with a laser beam profiler (Ophir-Spiricon, Logan, UT, USA). This device uses a charge-coupled device (CCD) digital camera with a 50-mm focal distance lens (SP928, Ophir-Spiricon). Two blue filters (HOYA UV–vis colored glass bandpass filter, Edmund Optics, Barrington, NJ, USA) were used to flatten the spectral response of the CCD camera. A reflective neutral density filter (Edmund Optics) was used to ensure the images were not saturated. The LCU was positioned at a fixed distance from a 60-degree holographic diffuser screen (Edmund Optics, Barrington, NJ, USA), facing the camera both with and without barriers simulating all the conditions used in this study. All the images were captured by the camera at the same distance, position, and exposure time, making the images comparable. The three-dimensional images were collected using the beam analyzer software (BeamGage Professional version 6.14, Ophir-Spiricon).

2.4. Statistical analysis

The power (mW) data were tested for normal distribution (Shapiro–Wilk test) and equality of variances (Levene's test), followed by

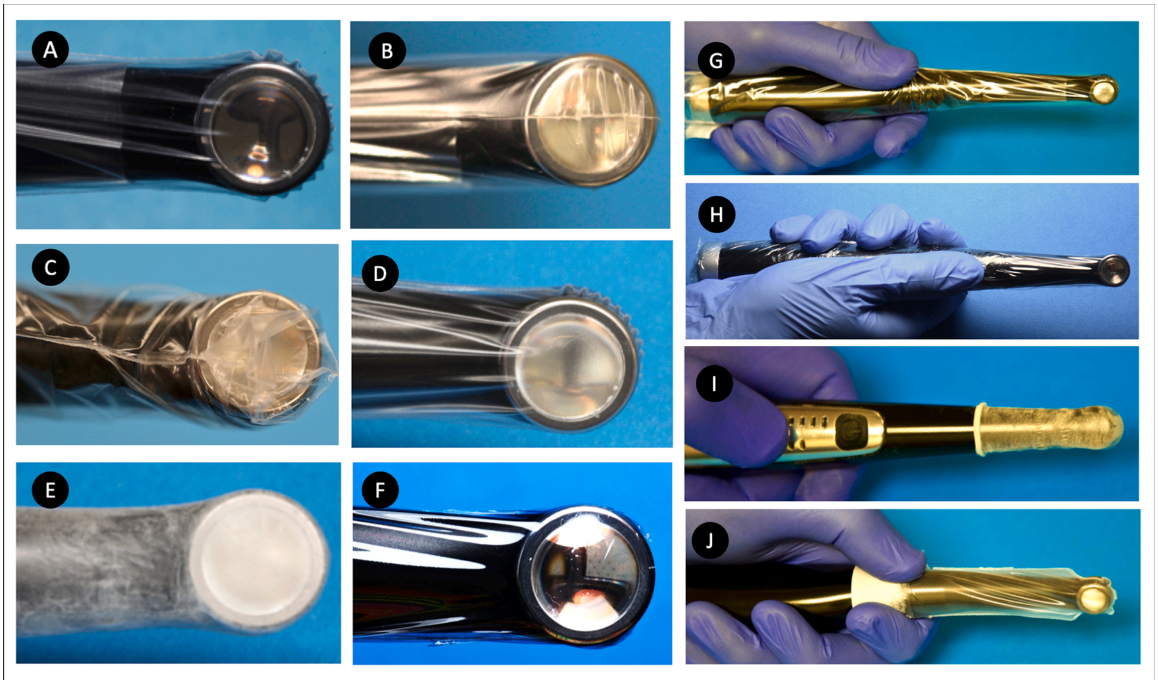

Fig. 2. The different types of disposable the infection control barriers over the LCU tip at illustrating the conditions used in the study to simulate correct and incorrect placement of the barrier. A- VALO Grand Disposable Barrier Sleeves positioned correctly; B- VALO Grand Disposable Barrier Sleeves with the seam over the light tip; C- Cure Sleeve by Pinnacle wrinkled over the tip; D- Cure Sleeve by Pinnacle correctly placed; E- Powder not removed from the Curelastic; F- Stretch and Seal Flexible Film correctly applied; G- VALO Grand Disposable Barrier Sleeves both correctly applied and covering the entire LCU; H- Stretch and Seal Flexible Film both correctly applied and covering the entire LCU; I- Powdered Curelastic only partially covering the LCU, and J- Cure Sleeve by Pinnacle correctly applied, but only partially covering the LCU.

parametric statistical tests. One-way analysis of variance (ANOVA) was performed, followed by a Tukey test for comparing different methods to use each barrier and Dunnet test for comparing with the control group without barrier. All tests used a significance level of $\alpha = 0.05$, and all analyses were carried out with the statistical package Sigma Plot version 13.1 (Systat Software, San Jose, CA, USA). The beam profiling images were analyzed qualitatively.

3. Results

The barriers reduced the radiant power from the LCU by between 5 to 16% compared to the power output that was measured without a

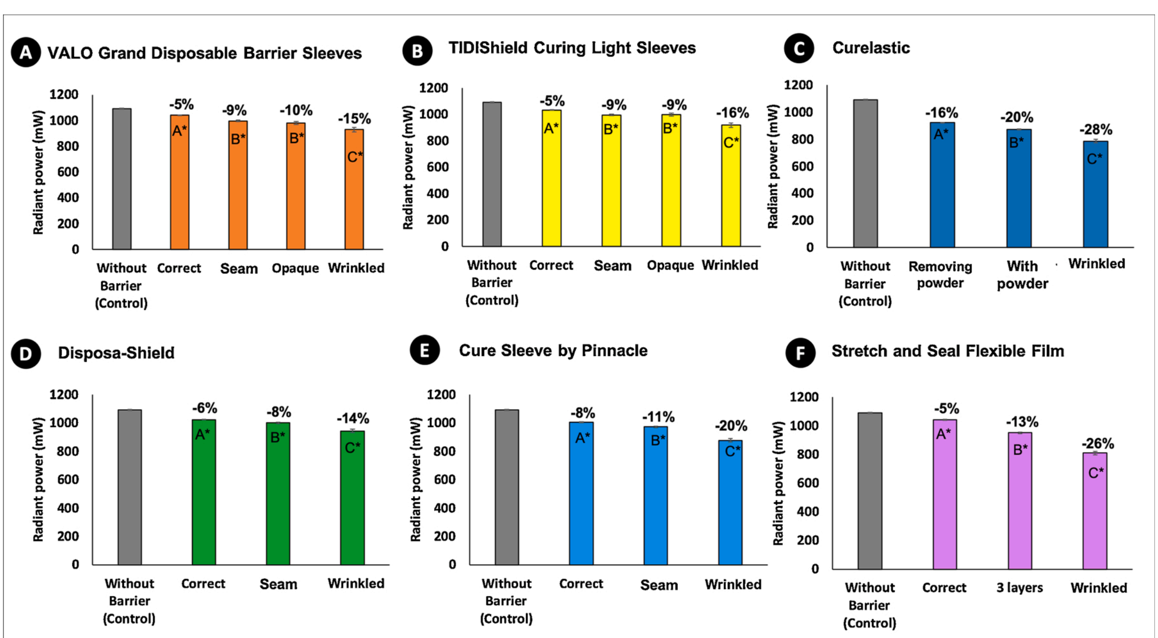

Fig. 3. Means and standard deviations of the radiant power (mW) from the VALO Grand used without the infection control barrier (control) and with six different infection control barriers. Different uppercase letters indicate a significant difference among the barriers tested (Tukey test $P < 0.05$); * indicates that all barriers delivered a lower power than the Valo used without a barrier (Dunnet test $P < 0.05$).

barrier. When using the correct technique, the VALO Grand Disposable Barrier Sleeves, the Stretch and Seal flexible film and the TIDIShield Curing Light Sleeves all delivered significantly higher radiant power than the Cure Sleeve by Pinnacle or Curelastic barriers (Fig. 3). The Curelastic barrier had the greatest adverse effect on the radiant power delivered through any of the barriers tested.

The mean radiant power (mW) values and standard deviations from the LCU on the standard-setting without and with six barriers that had been used in different ways are reported in Fig. 4. ANOVA showed the barriers had significantly different adverse effects on the light output ($P < 0.05$). Dunnet test showed that all the barriers tested used in different ways significantly reduced the radiant power from the LCU (Fig. 4). Tukey's test showed that the following barriers: VALO Grand Disposable Barrier Sleeves, TIDIShield Curing Light Sleeves, Disposa-Shield, and Cure Sleeve by Pinnacle (Fig. 4A, 3B, 3D, and 3E) delivered significantly higher radiant power values when used correctly than when they were used incorrectly with their seam or their semi-opaque side over the front of the LCU tip. When any of the barriers were wrinkled or folded, the radiant power output was significantly lower compared to when the barrier was applied correctly (Fig. 3A-3 F). When the powder was removed from the Curelastic barrier before testing, this increased the radiant power measured through this barrier (Fig. 4C). The use of 3 layers of Stretch and Seal flexible film significantly reduced the radiant power output.

The spectral radiant powers delivered from all barriers tested are shown in Fig. 5. The amount of attenuation was similar for all wavelength peaks from the LCU, irrespective of the barrier type and how the barriers were applied. The Curelastic barrier, when used in the wrinkled condition, showed the greatest amount of attenuation and reduced the spectral radiant power in the violet range of wavelengths.

The three-dimensional representations of the beam profile recorded from the VALO Grand through each barrier used in different ways are shown in Fig. 6. The VALO Grand Disposable Barrier Sleeves, TIDIShield Curing Light Sleeves, and Disposa-Shield, when used correctly, showed a comparable homogeneity in the transmitted light to the VALO Grand used without a barrier. The Cure Sleeve by Pinnacle and Curelastic barriers, even when positioned correctly over the tip, significantly reduced the irradiance across the entire tip. When the seam of any barrier was placed over the light tip, this interrupted the light beam uniformity for all barriers. When any of the tested barriers were applied with folds over the tip, this caused a marked heterogeneity of the beam profile. This was most evident for Curelastic and the Stretch and Seal flexible film. The presence of any powder caused a further 5% reduction in the light transmitted through the Curelastic barrier.

4. Discussion

Since all the barriers significantly reduced the radiant power from the LCU by 5–16%, the first hypothesis was rejected (Fig. 3). Regarding the composition of the six types of barriers tested, the polyethylene and polyvinyl chloride-based barriers had the smallest adverse effect (5%), followed by the low-density polyethylene-based barrier (8%). The most drastic reduction (16%) was for the latex-based barrier. Any powder on the surface of the barrier further reduced the power from the light source. Therefore, this study confirmed that the type of infection control barrier affected the radiant power, the emitted spectrum, and beam profile of the multi-peak LCU.

Provided that the reduction in irradiance is kept below 150 mW/cm^2, about power this reduction may not compromise the curing of the composite resins provided that the LCU exposure time is long enough [7,15,22,24]. However, the latex-based barrier produced a greater reduction in the radiant power, which will likely affect the polymerization of the resin [22]. In the present study, even when used correctly, the Curelastic barrier, or a polyurethane barrier, drastically reduced the amount of light transmitted both with or without the presence of a powder. If this barrier is used on a less powerful LCU compared to the VALO Grand [25], the effect of such an infection control barrier on the polymerization process may be of concern.

An added benefit of using an infection control barrier is that the barrier also protects the tip against the deposition of materials on the surface of the light tip. This occurs often in many dental offices and one study reported that 35% of the LCUs had varying amounts of materials adhered to the light tip [16]. Another study showed that less than a third of the dental offices in Germany used disposable control barriers [6]. When barriers are used, damage to the light tip can be avoided, thus increasing the lifespan of the LCU and maintaining the output from the LCU.

The present study found that how the infection control barrier is applied over the light tip influenced the radiant power, emitted spectrum, and beam profile of the multi-peak LCU more than the type of barrier used. The incorrect use of all tested barriers caused the greatest adverse effect on the light output from the LCU. When the seam was placed over the light tip, this decreased the light output [26,27] which was further reduced when folds or wrinkles were present in the barrier [28], as showed on the beam profile images (Fig. 6). The presence of multiple layers will increase the thickness of the barrier and can trap air

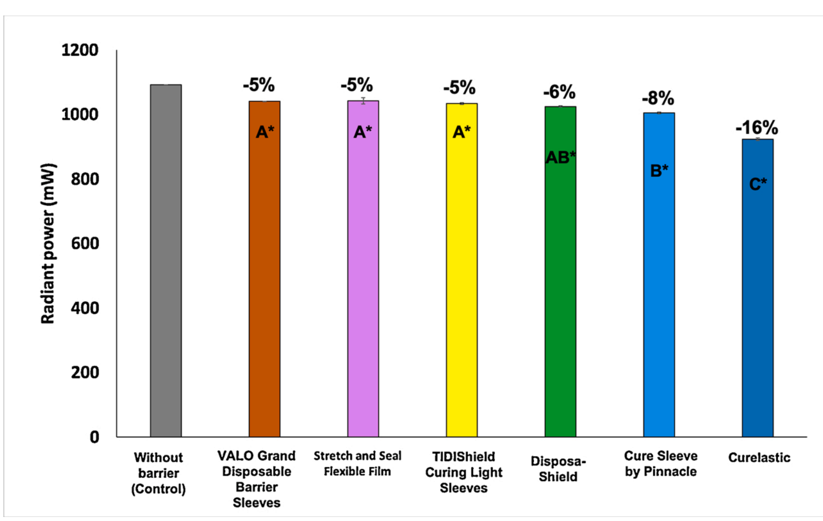

Fig. 4. Means and standard deviations of the radiant power (mW) from the VALO Grand used without the infection control barrier (control) and with six different barriers under each condition. Different uppercase letters indicate a significant difference among tested barriers (Tukey test $P < 0.05$); * indicates that all barriers delivered a lower power than the Valo without a barrier (Dunnet test $P < 0.05$).

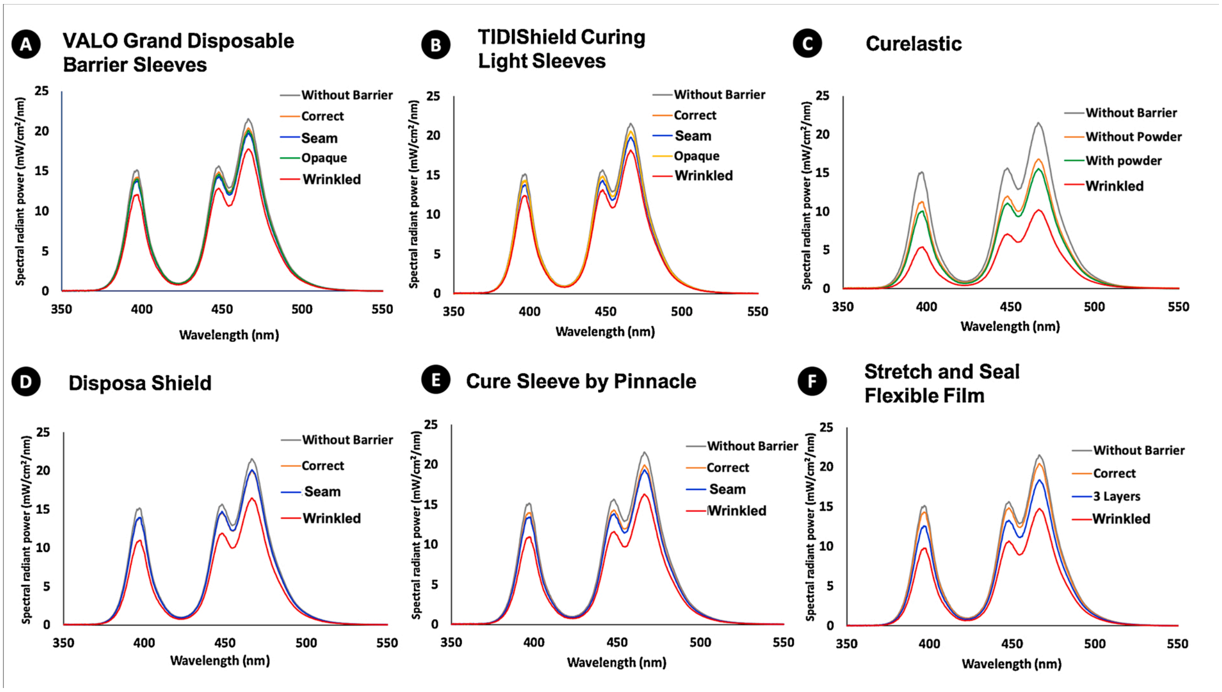

Fig. 5. The emission spectra of the VALO Grand tested with all the barriers used under the different conditions. Note all except the Curelastic had a minimal effect on the emission spectrum.

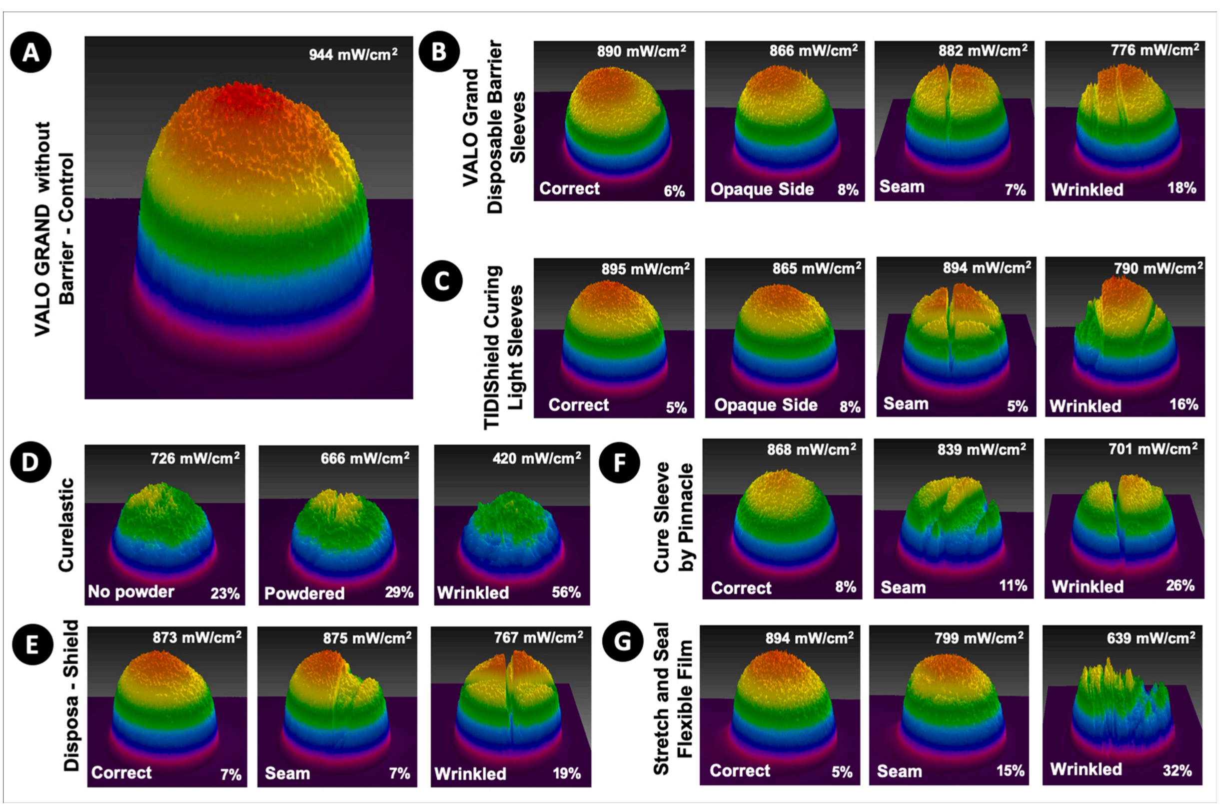

Fig. 6. The three-dimensional representations of the beam profile captured at the standard power mode of VALO Grand without any infection control barrier (control) and with the six types of barriers under the different conditions of the experiment. Note the effect of the seam in B, C, F, and E.

between each layer. This will further increase the amount of light refraction and decrease the light output. Most of the disposable barriers tested did not act as a wavelength-dependent light filter in the 380–500 nm range. Instead, there was a linear reduction in the reduction of the violet, mid-blue, and blue light wavelengths of light [15,22]. However, the latex-based Curelastic barrier had an adverse effect on the amount of violet light that was transmitted through the barrier. This effect was most noticeable when the barrier was wrinkled and thus thicker.

It can be concluded that infection control barriers must be correctly and carefully applied over the light tip so that the barrier has the least effect on the light output. Ideally, the entire LCU and control buttons should be covered, not just the tip (Fig. 2 G–J). The VALO Grand Disposable Barrier Sleeves, TIDIShield Curing Light Sleeves, and the Stretch and Seal Flexible Film caused approximately 5–8% of light attenuation when they were used correctly. If there a dedicated barrier is not available for the LCU, plastic food wrap is a cost effective alternative that is readily available in dental offices for protecting parts of other dental equipment. Since they are flexible, thin, and clear, they adapt well over the light tip, the polyethylene and polyvinyl chloride barriers work well [22]. Moreover, these barriers can cover the entire body of the LCU, not just the tip, which is important to prevent cross-infection [29]. Covering the entire LCU will also mean that less disinfectants that can cause degradation to the LCU fiberoptic light tip, plastic body, electronics, and lenses over time are required [30]. If there is a more translucent side to the barrier, this must be the side that is well adapted over the tip without any wrinkles or seams. These wrinkles, seam lines, or folds increase the thickness of the barrier will cause a greater reduction in light output and may have a significant adverse effect on the light-curing process [22,26–28]. It is recommended that dental programs should include training on how to use the LCU and how to correctly apply the infection control barrier. To add clinical relevance, it is also recommended that researchers should use the LCU with an infection control barrier.

Clinicians are faced with a difficult situation. The use of barriers will decrease the light output [7,15,17,22,28], but barriers are necessary to reduce the chance of cross-infection in the dental office [29]. Since no LCU can be heat sterilized as this would destroy the electronics inside, a combination of barriers and surface disinfectants must be used. To minimize the reduction of the light received by the restoration, it would be helpful to:

1 regularly check the output from the LCU with the infection control barrier on the LCU. Any reduction in light output should be noted and addressed [6,31,32];
2 correctly apply the infection control barrier so that there are no seams or folds in the barrier over the light tip;
3 position the patient and yourself for a better view of what you are doing;
4 use orange glasses or a shield to protect your eyes from the blue and violet light;
5 actively monitor and adjust the position of the light tip so that it remains perpendicular to the surface of the restoration [19,33–35];
6 if using a high powered LCU, cool the tooth with air during the curing cycle to prevent overheating of the tissues [19,36,37].
7 increase the light-curing exposure time to compensate for the loss of light emitted by the LCU when a barrier is used [24]. A 10% in the exposure time should be sufficient if the barrier is applied correctly.

This study showed that infection control barriers should be applied correctly to minimize their adverse effect on the light output from the LCU. A limitation of the present study is that only one high-output LCU, that had a broad emission spectrum in the violet and blue light ranges, a homogeneous beam profile, an ergonomic design, and large active tip area [25] was evaluated. Further studies are necessary to evaluate the effect of the disposable barriers on other lesser powered LCUs, where the negative effect on radiant power, emission spectrum, and beam profile might be greater, and be of more concern. Also, future studies should evaluate the effect of the barriers on light transmission through deep direct and indirect restorative materials, and the effect on the properties of the resin.

5. Conclusions

Within the limitations of this study, the followed conclusion can be drawn:

- Disposable infection control barriers as VALO Grand Disposable Barrier Sleeves, TIDIShield Curing Light Sleeves, and the food wrap Stretch and Seal Flexible Film, when used correctly, reduced the power output from a multi-peak broad spectrum LCU by about 5–8%.
- When any of the infection control barriers were applied incorrectly, the adverse effects on the radiant power, and the beam profile images were greater.

CRediT authorship contribution statement

Carlos José Soares: Conceptualization, Methodology, Supervision, Project administration, Resources, Funding acquisition, Formal analysis, Writing - review & editing. **Stella Sueli Lourenço Braga:** Conceptualization, Methodology, Data curation, Formal analysis, Writing - original draft. **Maria Tereza Hordones Ribeiro:** Conceptualization, Methodology, Data curation, Formal analysis, Writing - original draft. **Richard Bengt Price:** Conceptualization, Methodology, Supervision, Project administration, Resources, Funding acquisition, Formal analysis, Writing - review & editing.

Declaration of Competing Interest

The authors have no conflicts of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jdent.2020.103503.

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