ADA CE Program ARTICLE 2

The effectiveness of using a patient simulator to teach light-curing skills

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ABSTRACT

Background. The authors evaluated the effectiveness of using a patient simulator (MARC Patient Simulator [MARC PS], BlueLight analytics, Halifax, Nova Scotia, Canada), to instruct dental students (DS) on how to deliver energy optimally to a restoration from a curing light. Five months later, the authors evaluated the retention of the instruction provided to the DS.

Methods. Toward the end of the DS' first year of dental education, the authors evaluated the light-curing techniques of one-half of the class of first-year DS (Group 1) before and after receiving instruction by means of the patient simulator. Five months later, they retested DS in Group 1 and tested the remaining first-year DS who were then second-year DS and who had received no instruction by means of the patient simulator (Group 2). They gave DS in Group 1 and Group 2 MARC PS instruction and retested them. The authors also the tested fourth-year DS (Group 3) and dentists (Group 4) by using the MARC PS before giving any instruction by means of the MARC PS.

Results. The results of one-way analysis of variance (ANOVA) showed that there were no significant differences in the ability of dentists and DS to light cure a simulated restoration before they received instruction by means of the patient simulator ($P = .26$). The results of two-way ANOVA and Fisher protected least significant difference tests showed that after receiving instruction by means of the patient simulator, DS delivered significantly more energy to a simulated restoration, and this skill was retained. There were no significant differences between DS in Group 1 and Group 2 after they had received instruction by means of the patient simulator.

Conclusions. The abilities of dentists and DS to light cure a simulated restoration were not significantly different. Hands-on teaching using a patient simulator enhanced the ability of DS to use a curing light. This skill was retained for at least five months.

Practical Implications. The education provided to dentists and DS is insufficient to teach them how to deliver the optimum amount of energy from a curing light. Better teaching and understanding of the importance of light curing is required.

Key Words. Dental restoration; dental education; dental students; light curing; resin-based composites; irradiance.

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The teaching and placement of posterior resin-based composite (RBC) restorations have become increasingly popular in the last 10 years.[1] A survey published in 2011 reported that of 46 dental schools, 63 percent no longer taught that amalgam was the preferred posterior restorative material.[2] According to the American Dental Association Survey Center's 2005-06 Survey of Dental Services Rendered,[3] an estimated 146 million RBC restorations and sealants were placed in the United States during the yearlong survey. Heintze and Rousson[4] estimated that worldwide more than 261 million direct RBC restorations were placed in 2012. The authors of several reports indicated that the median longevity for posterior RBCs placed in dental offices was only about six years,[5-7] and the primary reasons for RBC replacement were secondary caries and bulk fracture of the resin.[4,5,7,8] Thus, there appears to be a need to improve the understanding of the factors that affect the longevity of RBC restorations. These factors include the patient, the operator, the technical difficulty of the procedure, the effectiveness of adequate moisture control, the size and location of the restoration, the effects of polymerization shrinkage and how much energy is delivered from the light-curing unit (LCU) to cure the RBC.[4,9] Some of these factors are difficult to measure, but the amount of energy required to cure the RBC and the amount of energy that the dentist delivers can be quantified.

Many terms have been used to describe the light output from a curing light (for example, "intensity," "power density," "energy density"). Table 1 provides the radiometric terms we use in this article.[10]

The amount of energy required to polymerize a resin depends on the volume of resin, shade, opacity, thickness, brand and type of RBC. The minimum amount of energy received by the RBC from a curing light to adequately cure a 2-millimeter–thick increment is between

6 and 24 joules per square centimeter, depending on the shade, opacity and type of RBC.[11-13] Although researchers have focused on the properties of the RBC or the LCU, until recently the ability of the dentist to deliver sufficient light energy from a curing light to the RBC in the tooth was not considered. In addition, in a recent review of 100 laboratory research–based articles published between 2010 and 2012 regarding the polymerization of dental resins,[14] the authors reported that in 40 percent of the articles, investigators delivered twice as much energy from a curing light to their resin specimens as the minimum recommended by the manufacturer. This research generated results that represented the best results that could be achieved rather than what would happen when clinically relevant amounts of energy are received by the resin.[15,16]

Clinicians face many unrecognized challenges when light curing an RBC restoration. If the preparation has limited access, it will be difficult to position the tip of the LCU perpendicular and close to the RBC surface.[17-20] When the RBC surface is not perpendicular to the LCU tip or in direct line of sight, it will receive less light and may be inadequately cured.[21] This is of concern because inadequate resin polymerization adversely affects the resin's physical properties,[11,12,15,22-24] reduces the bond strength to the tooth,[16,25,26] decreases the biocompatibility of the RBC restoration,[27-31] increases marginal wear and breakdown,[32] and increases bacterial colonization of the RBC restoration.[33] Conversely, using the LCU for longer than necessary, thereby delivering too much energy, may cause thermal damage to the pulp or other oral tissues that are exposed to the light.[15,34-37]

Providing appropriate education regarding the best light-curing technique should be an important element of dental education, as well as a consideration when purchasing a new LCU. This is supported by the results of surveys of general dentists' knowledge of polymerization of RBC and light-curing technology that revealed that there is a need for further education and guidance in this aspect of primary dental care.[38,39]

On the basis of advertising claims alone, most practitioners recognize that not all new LCUs are equivalent, and this observation is supported by the literature.[18,40-49] Investigators in several studies have evaluated the light intensity from LCUs used in dental offices.[50-55] The findings indicated that dentists in private practices worldwide often used inadequate LCUs and were unaware that these LCUs delivered either an inadequate amount of radiant exposure or the wrong wavelengths of light to completely cure their RBC restorations.[56] Consequently, it has been suggested that regulatory bodies consider the need for obligatory testing of LCUs in private dental offices.[54]

By following specific guidelines, clinicians can improve the odds that they will adequately polymerize the light-cured restorative materials they are using.[17]

TABLE 1

Radiometric terms and abbreviations.*

TERM	UNIT (ABBREVIATION)
Radiant Energy (Power × Time)	Joule (J)
Irradiance (Sometimes Incorrectly Called "Power Density")	Watts per square centimeter (W/cm^2)
Radiant Exposure (Irradiance × Time) (Sometimes Called "Energy Density")	Joules per square centimeter (J/cm^2)

* Source: Kirkpatrick.[10]

These guidelines have been compiled into a checklist known as CORE: Curing light characteristics; Operator technique; Restoration characteristics that include location, size and depth of the cavity relative to the position of the light tip; and the Energy requirement of the RBC being used, which is influenced by the shade of the RBC and spectrum of light needed to match the photoinitiators used in the RBC.[20,57]

There are seven steps dentists can follow to improve their light delivery technique[17,20]:

1. position the patient to provide the LCU the best access to the restoration;
2. wear blue-blocking orange protective glasses, which will allow dentists to watch what they are doing when light curing;
3. position themselves so that they can see what they are doing and so they can place the light tip in the best position;
4. adjust the light guide to provide the optimum straight-line access to the RBC;
5. stabilize the LCU during curing with the light tip at right angles to the surface of the RBC;
6. to prevent uncured resin from adhering to the LCU, start curing 1 mm from the preparation and after one second, move as close as possible to the preparation;
7. air-cool the tooth during the curing cycle to avoid any undesired consequences due to overheating the oral tissues.

Until recently, dentists could not measure the radiant exposure they were delivering from a curing light, which meant that the problem of inadequate energy delivery to the RBC restoration could not be managed.[18,21] Simulation technology has been recognized as an important part of health care education,[58] and simulators may help identify operators in need of instructional intervention.[59] A unique patient simulator (MARC Patient Simulator [MARC PS], BlueLight analytics, Halifax, Nova Scotia, Canada) was developed to measure by means of a laboratory grade spectroradiometer the irradiance, radiant exposure and

ABBREVIATION KEY. DS: Dental students. **LCU:** Light-curing unit. **MARC PS:** MARC Patient Simulator. **RBC:** Resin-based composite.

> When the patient simulator is used as an evaluation tool, the dentist or dental students light cure the simulated restoration, and the patient simulator measures the irradiance and radiant exposure that the restoration received.

spectral emission received by a simulated restoration in a dental mannequin head that can be attached to a dental chair.[18,21,60] The results—the irradiance, radiant exposure and spectral emission received by a simulated restoration in a dental mannequin head—are displayed on a computer monitor, and the user can see the effect of his or her light-curing technique in real time, which lets him or her receive immediate visual feedback regarding the effects that subtle changes in light-curing technique have on the irradiance and energy he or she is delivering. This patient simulator also can be used as an evaluation tool for dentists and dental students (DS) to verify that good clinical practices are being used when they are light curing dental resins.[60-62] When the patient simulator is used as an evaluation tool, the dentist or DS light cure the simulated restoration, and the patient simulator measures the irradiance and radiant exposure that the restoration received. The dentist or DS do not see the results displayed on the computer monitor.

The authors of several articles have questioned the adequacy of instruction in how to deliver a sufficient amount of energy from a curing light to a restoration to cure the RBC properly.[15,18,38,39] We have used the patient simulator in many continuing dental education courses to evaluate general dentists' light-curing techniques and to educate them regarding how to deliver an adequate amount of energy to cure their RBC restorations. During these courses and when conducting other studies, we found that there was a wide range in the abilities of dentists and DS to use their curing lights.[18,21,60] The results of one study demonstrated that a clinician's light-curing technique can have a significant effect on how much light energy from a curing light is delivered to the restoration.[21] There was up to a fourfold difference in the amount of radiant energy they delivered, depending on the technique, even when the same LCU was used on the same tooth for the same exposure time. The MARC PS is being used in some dental schools, and research results support its effectiveness. In a 2013 study, Federlin and Price[60] found that students who had not previously received individualized instruction that included instruction for using the MARC PS significantly increased the amount of radiant exposure they delivered after they had received additional light-curing instruction with feedback by means of the MARC PS. The authors, however, did not test whether the students retained the improvements made to their light-curing technique over time. The results of another study showed that students could retain their improved light-curing techniques learned by practicing with the MARC PS,[62] but this finding may have been due to the students' receiving more education as they progressed through dental school.

In our study, we investigated the use of the MARC PS to improve the ability of DS to deliver energy to a restoration from a curing light. We also determined whether this skill was retained for at least five months. Our first hypothesis was that before receiving individualized instruction with feedback by means of this patient simulator, dentists and fourth-year DS who were about to graduate would deliver equivalent amounts of radiant exposure. On the basis of the results of previous research,[62] our second hypothesis was that first-year DS who received additional individualized instruction with feedback by means of the MARC PS would deliver more radiant exposure than would DS who did not receive any additional instruction with feedback. Our third hypothesis was that DS who had received individualized instruction with feedback by means of the MARC PS would retain the information and deliver the same or higher radiant exposure five months later. Our fourth hypothesis was that five months later, DS who had received the additional individualized instruction with feedback in their first year would deliver more radiant exposure than would their classmates who had not received the additional instruction with feedback.

METHODS

Dalhousie University Health Sciences Research Ethics Board (Halifax, Nova Scotia, Canada) approved our study on the condition that all the participants remain anonymous (ethics approval nos. 2008-1706 and 2009-2006). The participants were 22 general dentists from the Halifax area and 66 DS from Dalhousie University who were in their first, second or fourth year of study. None of the dentists or DS had used the MARC PS previously, but all of the DS had used a mannequin head similar to that in the MARC PS as part of their preclinical exercises. All DS were experienced in light curing simulated restorations, had received equivalent lectures and instruction, and had previous experience using the LCU we included in our study. The fourth-year DS had three more years of clinical experience using the LCU than did the first-year DS.

The MARC PS unit has a laboratory grade spectrometer (USB4000, Ocean Optics, Dunedin, Fla.) inside a mannequin head and typodont.[18,60] A light detector is located at the base of a Class I preparation in the maxillary left second molar 2 mm from the cavosurface margin and 4 mm from the cusp tip. The detector's surface is parallel to the occlusal plane. When the end of the light guide is held in contact with the cusp tips, the light detector measures the irradiance that would be received by the top surface of the resin that is 4 mm from the LCU.

The dentists and DS groups used the same LCU (SmartLite iQ2 LED Curing Light, Dentsply-Caulk, Milford, Del.) on the same maxillary left second molar in the MARC PS. The LCU manufacturer suggests that most resins can be cured adequately in 10 seconds when this LCU is used.[63] Therefore, we set the light exposure time for 10 seconds. At the beginning of the study, one of the authors (R.B.P.) first measured the maximum radiant exposure (J/cm^2) that could be delivered to the detector in 10 seconds five times when the MARC PS was not attached to a dental chair but was instead fully accessible in an unrealistic clinical position on a laboratory bench. He repeated this step before each testing session to confirm that the LCU's output had remained stable. We reassembled the MARC PS and measured the irradiance and radiant exposure delivered by each of the DS in a simulated clinical setting. We did not determine the minimum amount of energy required to cure 2-millimeter–thick RBC, which has been reported to range from 6 to 24 J/cm^2 depending on the brand, type, thickness, opacity and shade of the RBC.[11-13] For our study, we chose 6 J/cm^2 as the lowest radiant exposure for adequate curing because that was the least amount of energy considered acceptable.

We randomly assigned the DS in the first-year dental school class into two groups: Group 1 and Group 2. We measured the radiant exposure delivered by the DS in Group 1 (n = 18) in May 2012 before they received any additional instruction regarding proper light-curing technique by means of the MARC PS. Before testing, we told all DS in lectures and during preclinical exercises to wear the blue-blocking orange protective glasses, to watch and pay close attention to what they were doing, and to stabilize the LCU with their fingers as close to the restoration as possible.

We noted that despite receiving these instructions in their lectures, not all of these DS wore blue-blocking orange protective glasses or paid close attention to what they were doing. After measuring the radiant exposures delivered by the DS in Group 1, we showed them their results, and one author (R.B.P.) provided individual coaching with immediate visual feedback by using the MARC PS to show these DS how they could optimize their own light-curing techniques. He demonstrated the practical relevance of wearing the blue-blocking orange protective glasses so that the DS could watch and pay close attention to what they were doing. The DS observed how making subtle changes in their techniques and stabilizing the LCU with their fingers could affect the amount of light they delivered. After DS received these instructions and practiced light curing twice on the patient simulator, we remeasured the radiant exposure delivered by the DS in Group 1 and recorded the results. We did not test the remaining first-year DS in Group 2 (n = 18), and they did not receive any additional instruction by means of the MARC PS.

Five months later, in October 2012, we tested all the DS in the second-year class. In the interceding time, Group 1 and Group 2 received the same light-curing instruction by means of didactic lectures and during their preclinical exercises. All DS then received individual instruction with visual feedback by means of the MARC PS, and we retested them. For the DS in Group 2, this was their first time receiving MARC PS instruction, whereas Group 1 had received one session of hands-on instruction by means of the MARC PS five months previously.

In addition, in April 2013 we measured the irradiance and radiant exposure delivered by the fourth-year DS (Group 3) (n = 30) and the general dentists (Group 4) by using the MARC PS system. No one in these groups had received prior instruction by means of the MARC PS. After testing, the participants in Groups 3 and 4 were all offered the opportunity to receive instruction for and feedback on their light-curing techniques. We did not retest them.

Although the same DS were tested more than once, owing to restrictions placed by the Health Sciences Research Ethics Board at Dalhousie University that participants remain anonymous, we could not compare individual results. Thus, we could not use repeated measures analysis. Instead, we compared the data from the group before instruction with the data from the group after instruction. We used one-way analysis of variance (ANOVA) to determine whether there was a difference in the amount of radiant exposure delivered to the simulated restoration by the four groups by means of the same curing light before they received any individualized instruction with feedback by means of the MARC PS. We used two-way ANOVA and a Fisher protected least significant difference test to determine whether receiving instruction by means of the MARC PS significantly improved the amount of radiant exposure delivered by the DS and to evaluate whether the DS in Group 1 retained this information ($\alpha = .05$).

RESULTS

Under ideal laboratory conditions, the mean (standard deviation [SD]) maximum radiant exposure delivered by one of the authors (R.B.P.) using the same LCU for 10 seconds was 8.0 (0.4) J/cm^2. Table 2 shows the means and ranges of radiant exposures delivered to the simulated restoration from the curing light by the dentists and three groups of DS before receiving instruction by means of the MARC PS. The results of one-way ANOVA showed that there was no significant difference ($P = .26$)

TABLE 2

Mean radiant exposure delivered by the general dentists and three groups of dental students before receiving instructional feedback by means of the MARC Patient Simulator.*

VALUE	RADIANT EXPOSURE (JOULES PER SQUARE CENTIMETER) DELIVERED BEFORE MARC PATIENT SIMULATOR INSTRUCTION			
	Group 1 (First-Year Dental Students)	Group 2 (Second-Year Dental Students)	Group 3 (Fourth-Year Dental Students)	Group 4 (Dentists)
Mean	5.6†	6.3†	6.2†	5.5†
Standard Deviation	1.9	1.3	1.3	1.8
Range	0.2-7.5	3.4-8.0	2.9-8.1	1.0-8.0

* MARC Patient Simulator is manufactured by BlueLight analytics, Halifax, Nova Scotia, Canada.
† No significant difference between the four groups (one-way analysis of variance, $P = .26$).

TABLE 3

Mean radiant exposure received by the simulated restoration before and after participants received instruction and feedback by means of the MARC Patient Simulator.*

VALUE	RADIANT EXPOSURE (JOULES PER SQUARE CENTIMETER)†						
	Group 1 (Before Instruction, May 2012)	Group 1 (After Instruction, May 2012)	Group 1 (Before Instruction, October 2012)	Group 2 (Before Instruction, October 2012)	Group 3 (Before Instruction October 2012)	Group 1 (After Instruction, October 2012)	Group 2 (After Instruction, October 2012)
Mean	5.6	7.4^B	7.5^B	6.3^A	6.2^A	7.6^B	7.2^B
Standard Deviation	1.9	0.3	0.7	1.3	1.3	0.3	0.6
Range	0.2-7.5	6.6-7.9	5.3-8.1	3.4-8.0	2.9-8.1	6.9-8.1	6.1-8.1

* MARC Patient Simulator is manufactured by BlueLight analytics, Halifax, Nova Scotia, Canada.
† A superscript A or B indicates no significant difference between the groups (Fisher protected least significant difference, $P < .05$).

significantly less radiant exposure from the same curing light (Table 3) than did their classmates who previously had received instruction. Of the DS in Group 2, nine (50 percent) did not deliver the minimum amount of energy (6.0 J/cm^2) from a curing light, but two delivered the maximum radiant exposure. After receiving instruction in the amount of radiant exposure delivered by the DS and dentists in the four groups before they received instruction by means of the patient simulator.

Initially, the DS in Group 1 delivered a mean (SD) of 5.6 (1.9) J/cm^2 (Table 3). Before receiving additional instruction and feedback, nine (50 percent) of these 18 DS delivered less than 6.0 J/cm^2, which was the minimal acceptable amount of energy.[11] Before receiving instruction by means of the MARC PS, none of the DS in Group 1 were able to deliver the maximum radiant exposure of 8.0 J/cm^2.

After receiving the initial instruction by means of the MARC PS, the DS in Group 1 delivered significantly more mean (SD) radiant exposure (7.4 [0.3] J/cm^2) (Table 3 and Figure 1), and one DS delivered 7.9 J/cm^2 after receiving instruction.

Table 3 and Figure 2 (page 38) show how five months later, the DS in Group 1, who were then in their second year of dental school, delivered slightly more radiant exposure from the same curing light to the simulated restoration (7.5 [0.7] J/cm^2). However, this was not significantly more than five months previously, when they delivered 7.4 (0.3) J/cm^2. Before they received light-curing instruction and feedback by means of the MARC PS, the second-year DS in Group 2 delivered by means of the MARC PS, DS in Group 2 delivered significantly more energy (Table 3 and Figure 3 [page 39]). After receiving instruction, all of the DS delivered the minimum amount of exposure from a curing light to the simulated restoration, and five DS were able to deliver 7.9 J/cm^2 or more after instruction. There was no significant difference between the DS in Group 1 and the DS in Group 2 after they had received individual instruction with immediate feedback by means of the MARC PS ($P > .05$).

The DS in Group 3 delivered a mean (SD) radiant exposure of 6.2 (1.3) J/cm^2. This amount of radiant exposure was not significantly different from that delivered by the second-year DS in Group 2 before they received instruction by means of the MARC PS (Table 3 and Figure 4 [page 40]). Ten (33 percent) fourth-year DS failed to deliver the minimum radiant exposure, but three (10 percent) delivered more than 7.9 J/cm^2 by means of the same curing light.

DISCUSSION

Typically, the authors of clinical technique articles that involve light curing do not describe fully the LCU that was used, the position and diameter of the tip that was

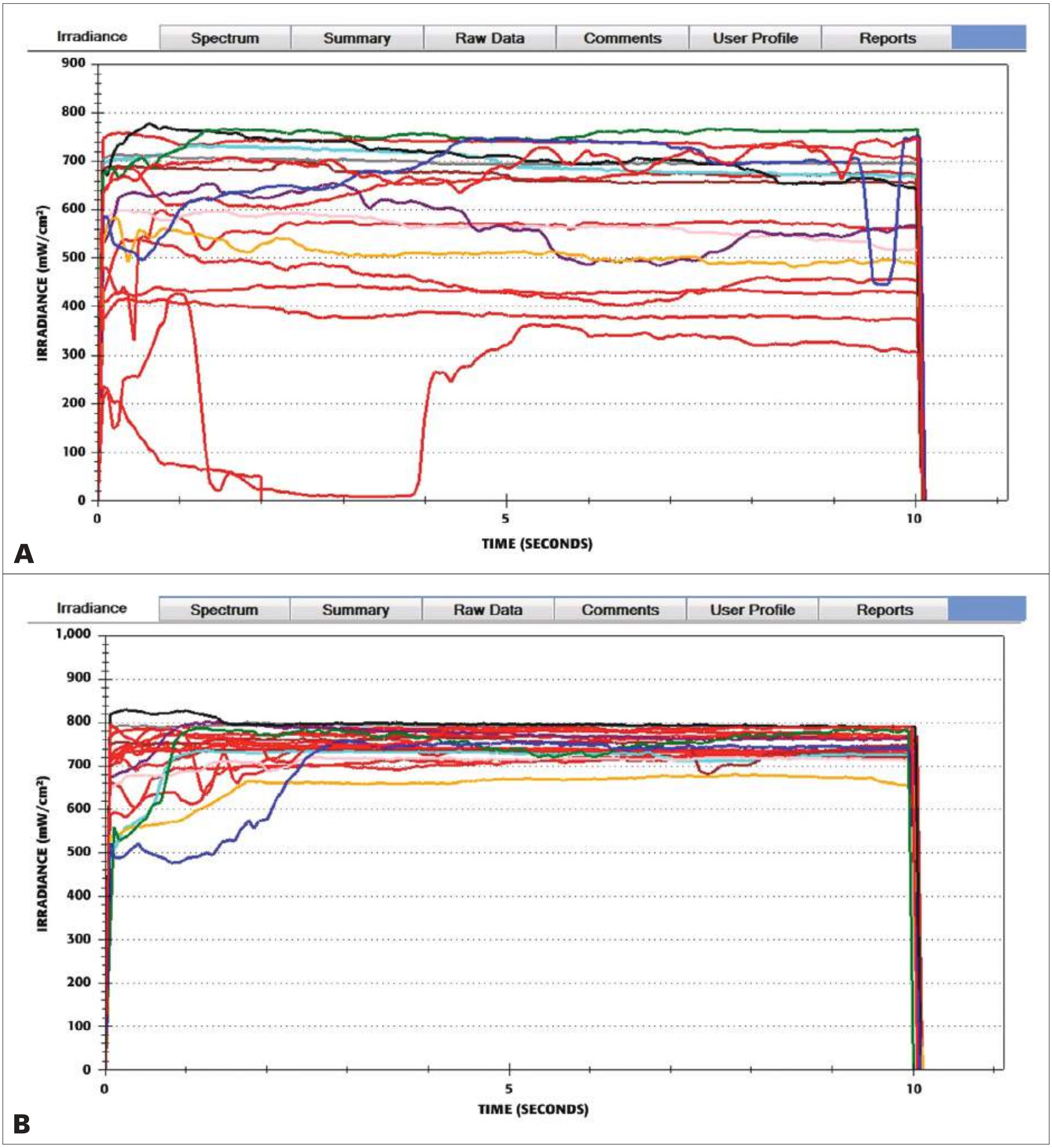

Figure 1. Irradiance (milliwatts per square centimeter) versus time (seconds) and radiant exposure (joules/cm^2) delivered by Group 1 dental students at the end of their first year of dental school (May 2012) before (**A**) and after (**B**) they received light-curing instruction by means of the MARC Patient Simulator (BlueLight analytics, Halifax, Nova Scotia, Canada). Each line on the graph represents the irradiance and radiant exposure delivered by a different dental student using the same curing light. Figure 1B shows the immediate improvement after instruction. The closer the lines are and the closer the irradiance is to 800 mW/cm^2, the better the result. Mean (standard deviation [SD]) radiant exposure before instruction was 5.6 (1.9) J/cm^2. Mean (SD) radiant exposure after instruction was 7.4 (0.3) J/cm^2. Image from the MARC Patient Simulator reproduced with permission of BlueLight analytics.

used or the type and amount of radiant exposure required to polymerize the RBC restoration adequately. Instead, the readers are told that they light cured for a certain number of seconds.[64-66] In our study, general dentists and DS used the MARC PS to measure how much radiant exposure they could deliver to a simulated

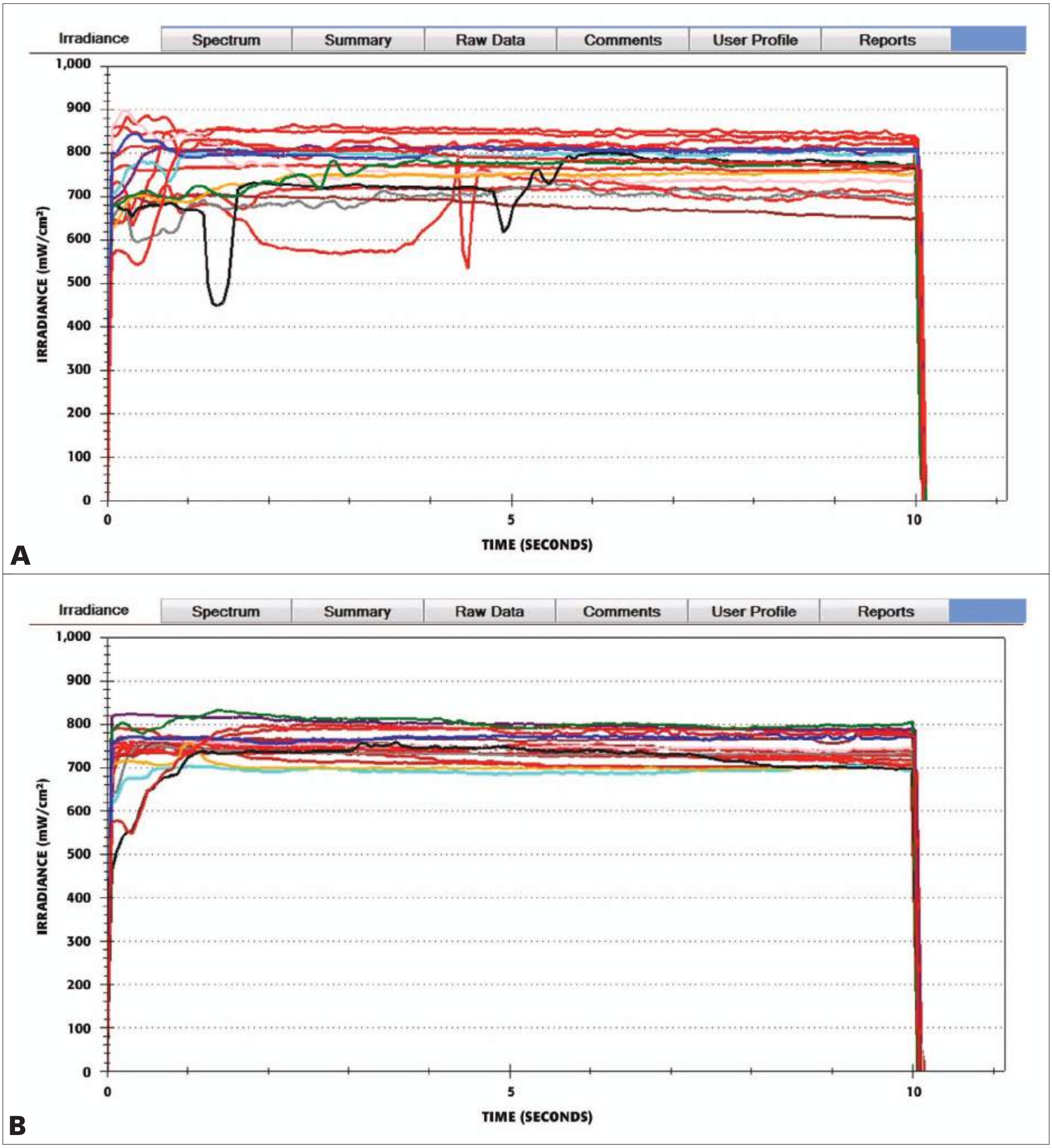

Figure 2. Irradiance (milliwatts per square centimeter) versus time (seconds) and radiant exposure (joules/cm^2) delivered by Group 1 dental students at the beginning of their second year of dental school (October 2012) before (**A**) and after (**B**) they received additional light-curing instruction by means of the MARC Patient Simulator (BlueLight analytics, Halifax, Nova Scotia, Canada). Each line on the graph represents the irradiance and radiant exposure delivered by a different dental student using the same curing light. Figure 2A shows that the improved technique was retained for five months, and Figure 2B shows minor improvement after additional instruction. Mean (standard deviation [SD]) radiant exposure before instruction (**A**) was 7.5 (0.7) J/cm^2. Mean (SD) radiant exposure after instruction (**B**) was 7.6 (0.3) J/cm^2. Image from the MARC Patient Simulator reproduced with permission of BlueLight analytics.

Class I resin restoration. Tables 2 and 3 and Figures 1 through 4 illustrate the large variability (range, 0.2-8.1 J/cm^2) in the radiant exposure received by a simulated maxillary left second molar restoration light cured by general dentists and DS. Thus, light curing may not be as easy to perform as it first appears. We accepted our first

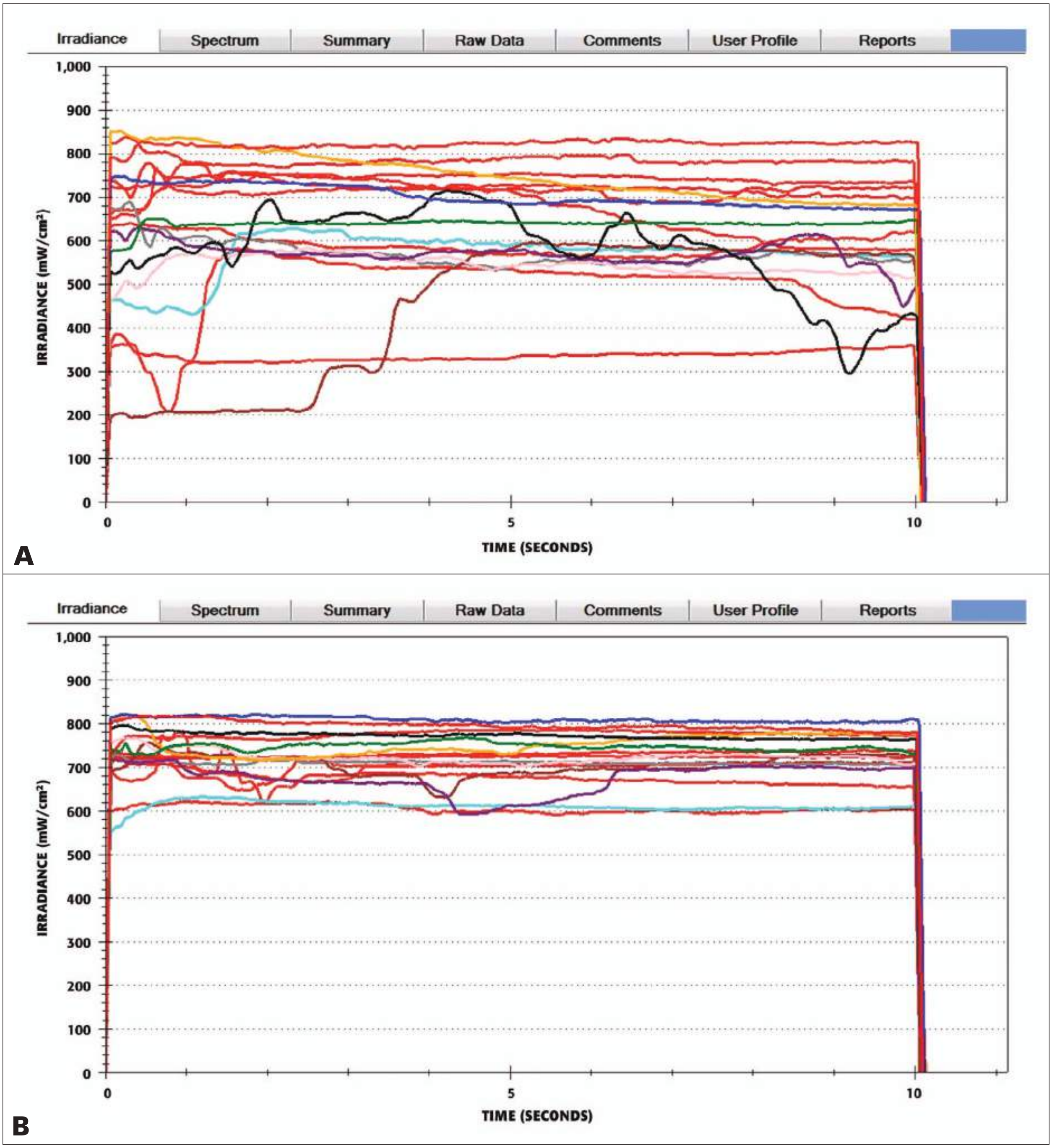

Figure 3. Irradiance (milliwatts per square centimeter) versus time (seconds) and radiant exposure (joules/cm^2) delivered by Group 2 dental students at the beginning of their second year of dental school (October 2012) before (**A**) and after (**B**) they received additional light-curing instruction by means of the MARC Patient Simulator (BlueLight analytics, Halifax, Nova Scotia, Canada). Each line on the graph represents the irradiance and radiant exposure delivered by a different dental student using the same curing light. Mean (standard deviation [SD]) radiant exposure before instruction (**A**) was 6.3 (1.3) J/cm^2. Mean (SD) radiant exposure after instruction (**B**) was 7.2 (0.6) J/cm^2. Image from the MARC Patient Simulator reproduced with permission of BlueLight analytics.

hypothesis that dentists and fourth-year DS who were about to graduate would deliver equivalent amounts of radiant exposure. In fact, the results of one-way ANOVA showed that there was no significant difference between all of the DS groups and Group 4 (general dentists) before they received instruction by means of the MARC PS

Figure 4. Irradiance (milliwatts per square centimeter) versus time (seconds) and radiant exposure (joules/cm²) delivered by Group 3 dental students in their fourth year of dental school (April 2013) before they received any light-curing instruction by means of the MARC Patient Simulator (BlueLight analytics, Halifax, Nova Scotia, Canada). Each line on the graph represents the irradiance and radiant exposure delivered by a different dental student using the same curing light. Using the same curing light, the dental students in Group 3 delivered a radiant exposure similar to that delivered by second-year dental students in Group 2 before receiving instruction by means of the MARC Patient Simulator. Mean (standard deviation) radiant exposure before instruction was 6.2 (1.3) J/cm². Image from the MARC Patient Simulator reproduced with permission of BlueLight analytics.

($P = .26$). Having demonstrated that dentists and DS delivered statistically similar amounts of radiant exposure before receiving instruction by means of the MARC PS, we proposed that dentists' light-curing abilities and retention of light-curing skills would be similar to those of the DS, suggesting that we would observe similar improvements for dentists. We considered it unethical to have conducted this study using dentists because one-half of the participants would not have received individual coaching with immediate feedback by means of the MARC PS until five months after the other one-half of the participants. During this time, they would be treating patients, and the researchers would have known that some dentists in this group were delivering low amounts of radiant exposure from a curing light to the restorations they were placing in their patients. This situation was not a concern with the first- and second-year DS, as they were not yet treating patients.

Table 3 and Figures 1 through 3 show that using the MARC PS to deliver individualized light-curing instruction with immediate feedback resulted in a significant improvement in the amount of radiant exposure delivered by DS to a simulated restoration. The overall mean radiant exposure delivered by the first-year DS in Group 1 increased by 32 percent, from 5.6 to 7.2 J/cm². This finding is similar to that of a study conducted in Germany whose authors reported a 35 percent increase after instruction was given by means of the MARC PS,[60] and it was similar to findings of other previous studies.[18,62]

After second-year DS in Group 2 received instruction and feedback by means of the MARC PS, the radiant exposure they delivered to the simulated restoration increased by 14 percent, from 6.3 to 7.2 J/cm². After receiving instruction, all of the DS delivered the minimum required amount of radiant exposure to the simulated restoration, and five DS were able to deliver 7.9 J/cm² or more after instruction. Thus, we accepted our second hypothesis that the DS would deliver more radiant exposure to the simulated restoration after receiving one session of individualized instruction with immediate visual feedback by means of the MARC PS. We accepted our third hypothesis that there would be no significant difference between the mean radiant exposure delivered by the DS in Group 1 after they had received instruction by means of the MARC PS in their first year and five months later when they were in their second year. We also accepted our fourth hypothesis that five months later, DS who had received the additional individualized instruction with feedback in their first year would deliver more radiant exposure than would classmates who had not received the additional instruction with feedback.

Figures 1 through 3 show the irradiance delivered by the DS before and after they received additional light-curing instruction with immediate feedback by means of the MARC PS. We found that after just one session of instruction delivered by means of the MARC PS, it was possible to improve DS' ability to use an LCU. The results of our study support the use of a patient simulator to help identify DS in need of additional instruction regarding the proper use of a curing light.[18,60,62] Despite the fact that DS in Group 2 and Group 3 all used the blue-blocking orange protective glasses and thought they were using the optimal light-curing technique, Figures 3 and 4 show that DS in both groups still needed to improve their light-curing techniques.

Initially, in their first year not all of the DS in Group 1 wore eye protection before instruction, which may account for the lower mean radiant exposure of 5.6 J/cm^2 they delivered compared with the higher before-instruction mean of 6.3 J/cm^2 for the DS in Group 2. This finding supports the belief that when operators watch what they are doing, they will deliver more energy to the restoration from the curing light. However, the operators will not know by how much unless they have tested their techniques and curing light use by means of the MARC PS.

In a 2012 study, Overton and Sullivan[67] reported that RBC restorations placed in one U.S. dental school were 10 times more likely to fail prematurely and require replacement than were amalgam restorations. The authors' speculation that improper positioning of the curing light may have contributed to this result is supported by the results of our study, in which, before receiving instruction by means of MARC PS, only 41 percent of the dentists and 58 percent of the DS delivered more than the minimum of 6.0 J/cm^2 when using the LCU for 10 seconds. The low amounts of energy delivered by some dentists and DS is a concern for dental educators and patients because students' actual clinical performance often is worse with a live patient than on a typodont.[68] Assuming that the large range in radiant exposures delivered by the dentists and DS in the simulation is representative of the radiant exposure that is delivered clinically to posterior restorations, this finding provides a potential explanation as to why the median longevity of direct posterior resin restorations placed in dental offices has been reported to be only about six years.[5-7] In addition, because five DS and five dentists delivered close to 8.0 J/cm^2, which was the maximum possible radiant energy that could be delivered by using this LCU for 10 seconds in this setting, the results also help explain why different operators can achieve different clinical success rates with the same dental resins or bonding systems.

Even RBC restorations that received less than 6.0 J/cm^2 still would appear to be hard on the surface when tested with a dental explorer, but the resin beneath the surface would not be adequately polymerized. As the resin below the surface usually is inaccessible, dentists or DS have no way of measuring how well the resin is cured at the bottom of the restoration. This is especially of concern for Class II restorations, which fail mostly at the gingival portion of the proximal box.[69] It is this region that is the most difficult to reach with the curing light. Consequently, the resin here will receive the least amount of light and may be undercured.[26,70-72]

The results of our study provide guidance for future directions in dental education that can be taken to improve the ability of dentists to light cure RBC restorations. The MARC PS mannequin head combined with the laboratory grade spectroradiometer we used in this study provides a realistic simulation of light curing a restoration in a mouth. We believe that the immediate visual feedback provided by the MARC PS software (Figures 1-4) showed how easily mistakes could occur when light curing and allowed the DS to practice and improve their light-curing technique. With an evidence-based approach behind the use of this patient simulator, LCU manufacturers and dental schools can provide the appropriate education to dentists and DS regarding how to use curing LCUs optimally, and they can quantify the outcomes of their instruction. Thus, the profession can start to manage the problem of inappropriately delivering energy to resin restorations.

We plan to monitor the light-curing abilities of the DS in Groups 1 and 2 as they progress through their dental education by retesting them at the end of their third and fourth years of dental school. We believe that testing DS by means of this patient simulator will allow us to monitor the retention of proper light-curing techniques and determine their competency when light curing. We also plan to reevaluate the dentists we tested. We hope that these steps will result in an improved understanding by DS and dentists of the important role of the LCU and the need to use the proper light-curing technique so that more restorations placed by practitioners will be light cured optimally.

CONCLUSIONS

When we used the MARC PS to measure the irradiance and radiant exposure received by a simulated restoration in a dental mannequin head from the same curing light, we found that although dentists and DS believed that they were using the LCU optimally, there was a large range (0.2-8.1 J/cm^2) in the radiant exposure delivered to the simulated restorations. We also found that before they received additional light-curing instruction by means of the MARC PS, there was no significant difference ($P = .26$) in the amount of radiant exposure delivered by general dentists and by DS.

When we provided individual coaching with immediate visual feedback by means of the MARC PS, the DS were able to optimize their light-curing techniques and increase the radiant exposure received by the simulated restoration by 32 percent. The DS retained their improved light-curing skills for at least five months. ■

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