Improving Light-Curing Instruction in Dental School


Abstract: Delivering an inadequate amount of light to a light-cured resin will result in a resin that is inadequately cured. This study measured the radiant exposure that students delivered to a simulated restoration to determine if instruction with immediate feedback increased the amount of light they delivered. The amount of light (radiant exposure in J/cm²) delivered to a simulated restoration by sixty-three dental students using the same curing light for twenty seconds was recorded. The experiment was repeated after the students had been given detailed light-curing instructions together with immediate feedback using the MARC-PS system. Initially, the students delivered between 1.4 and 17.5 J/cm² (mean±SD: 9.8±3.5 J/cm²). After receiving instructions and feedback on their light-curing technique, they delivered between 6.7 J/cm² and 17.8 J/cm² (mean±SD: 13.2±3.3 J/cm²). ANOVA and Fisher’s post hoc multiple comparison tests showed that providing immediate feedback on the students’ light-curing technique made a significant improvement in the radiant exposure they delivered (p<0.05). It was concluded that many dental students in this study were not using the curing light properly. After the students had received one session of additional instruction and immediate feedback using the MARC-PS, they delivered 35 percent more light energy to the same simulated restoration. Students who were closer to graduation showed a greater improvement in their light-curing technique (p=0.0091).

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Keywords: dental education, educational methodology, dental curing light, light curing, resin restoration, restorative dentistry, quality assurance

Submitted for publication 6/21/12; accepted 8/12/12

The teaching and use of posterior composite restorations in dental schools have increased dramatically over the last ten years.1,2 According to the American Dental Association’s 2005-06 survey of dental services rendered, during their yearlong survey, an estimated 146 million resin restorations and sealants were placed in the United States alone.3 Since almost all of these restorations used light-cured resins, it follows that the light-curing unit (LCU) has become an indispensable piece of equipment in dental offices. While the focus of most dental school education has been on choosing the appropriate resin-based composite (RBC), preparing the ideal cavity, and handling the restorative materials, little time is spent on teaching the light-curing technique itself.

Perhaps because light-curing is perceived to be an uncomplicated procedure, the critical role of the LCU and the importance of using the proper light-curing technique with appropriate eye protection1,5 are often not emphasized when teaching how to deliver successful RBC restorations. Most LCUs have an audible timer; however, the beep does not indicate that the resin is fully cured but only that a certain time interval has elapsed. After even a short exposure to the curing light, the resin will almost always appear to be fully cured at the surface. However, a hard surface at the top of the restoration does not indicate that the entire resin restoration has been adequately cured. There may be undercured resin at the bottom of the restoration, the so-called “soggy bottom” phenomenon.4 This is of concern because it has been reported that inadequate resin polymerization adversely affects the resin’s physical properties.7,12 This reduces the bond strength to the tooth,14,15 increases marginal wear and breakdown,11,12 decreases the biocompatibility of the resin restoration,16-20 and increases bacterial colonization of the resin restoration.18 Equally undesirable is using the LCU for longer than is necessary, thereby delivering too much energy, because this may cause thermal damage to the pulp or other oral tissues that are exposed to the light.21-24

Many challenges face a student or clinician when light-curing a resin. When the restoration is hard to reach, it is often difficult to position the tip of the LCU perpendicular to the resin surface. If the resin surface is not at 90º to the light tip or in direct line of sight, it will receive less light and may be inadequately polymerized.4 In addition, many LCUs in dental offices do not deliver as much light to the
resin as the clinician may think. This may be due to age-related deterioration of the light source, the internal reflectors and filters, or debris adhering to the end of the light tip. Even when the LCU is functioning correctly, a recent study demonstrated that the clinician’s light-curing technique can make a significant difference to how much light energy is delivered to the restoration. That study reported that when twenty dental professionals were asked to light-cure simulated restorations in a dental mannequin, there was up to a fourfold difference in the amount of radiant energy they delivered, even when they used the same LCU, on the same tooth, and for the same exposure time.

Until recently, dental educators could not accurately measure how much radiant energy was delivered to simulated restorations, so the problem of inadequate energy delivery could not be managed. Consequently, it is possible that many resin restorations are undercured—a fact that may explain why the median longevity of direct posterior resin restorations placed in dental offices has been reported to be as short as six years and why more failures occur in medium and deep restorations than shallow restorations. It may also explain why a recent study of 2,318 Class II composite restorations and 1,691 Class II amalgam restorations placed in the student clinic at a U.S. dental school reported the RBC restorations were ten times more likely to fail prematurely and require replacement than amalgam restorations. Most of the failures occurred due to bulk fracture of the RBC, and the authors thought it unlikely there was a problem with the bonding agent or restorative material.

Light-cured dental resins must receive sufficient radiant energy at the correct wavelengths; otherwise, they will not be adequately polymerized. The Phillip's textbook suggests that at least 16 J/cm² should be delivered to each 2 mm thick layer of composite resin, but others have reported that the minimum amount of energy required to adequately cure RBCs ranges between 6 and 24 J/cm² depending on shade and opacity. The radiant energy (E in J/cm²) received by the resin can be defined as the mathematical product of the irradiance (I in mW/cm²) from the curing light and the exposure time (t in seconds): E=I x t. Although resin manufacturers rarely specify how much radiant energy is required to adequately cure their resins, it is possible to calculate the minimum radiant energy required from the product of the manufacturer’s recommended minimum irradiance (mW/cm²) and curing time. Thus, if a resin manufacturer recommends using at least 400 mW/cm² for forty seconds, it means they are recommending that the resin should receive at least 16.0 J/cm². Unfortunately, LCU manufacturers only provide the irradiance measured at the exit tip of the LCU, which gives little indication of the irradiance delivered to the surface of the resin in a tooth. The top of a 2 mm thick layer of resin is often 4 to 5 mm away from the light tip. This relatively short distance can have a detrimental effect on the irradiance received by the resin. Using a dental radiometer, dentists can measure the irradiance from their LCU over clinically relevant distances, but these devices are known to be inaccurate. Thus dentists have no accurate way of knowing the irradiance or radiant energy they are delivering to their restorations.

The use of simulators has been recognized as an important part of health care training. In addition, simulators may help to identify students in need of early instructional intervention. Recently, a teaching aid—the Managing Accurate Resin Curing-Patient Simulator (MARC-PS, BlueLight Analytics Inc., Halifax, Canada)—has been introduced that uses a laboratory grade spectroradiometer (USB 4000, Ocean Optics, Dunedin, FL) to accurately measure the irradiance received by simulated cavity preparations in a mannequin head. The irradiance, spectral emission from the LCU, and radiant energy received by the simulated resin restoration are displayed on a computer monitor, and the user sees the results in real time. This allows the user to receive immediate visual feedback on the effects of changes in light-curing technique.

The purpose of this study was to determine if dental students were delivering a sufficient amount of light (radiant energy) to their restorations. The first hypothesis was that the radiant energy (J/cm²) delivered by all students would be greater than 6.0 J/cm², as this has been reported to be the minimum required to adequately cure some (but not all) dental resins. The second hypothesis was that the students would deliver more radiant energy after receiving immediate feedback to help them improve their light-curing technique.

Methods

Dental students who were at the end of their first term (n=23), second term (n=32), and fifth term (n=8) of their clinical studies at the University of
Regensburg, Germany, participated in this quality assurance investigation. These sixty-three students were given an individual code that only they knew, and they were tested and instructed anonymously by one of the authors (RBP) who was not associated with their dental education. The students used a mini-LED (Satelec, Merignac, France) curing light for twenty seconds (two ten-second exposures) in the fast mode to light-cure a simulated restoration in the MARC-PS. This exposure time exceeds the manufacturer’s recommended curing time of six to twelve seconds. To better simulate clinical reality, the MARC-PS mannequin head was attached to a dental chair in the student clinic, and the interincisal opening was limited to 35 mm. All of the students had used a dental mannequin similar to the MARC-PS in their preclinical teaching exercises and were experienced in light-curing simulated restorations. This study was part of a quality assurance program. Since the evaluation was done in class time and we were not doing anything out of the ordinary or that had any risk to the students, no ethics approval was considered necessary.

The irradiance received by the restoration in the MARC-PS unit was measured using a detector attached by a fiberoptic cable to a laboratory grade spectrometer (USB 4000, Ocean Optics) inside the MARC-PS head. The light detector was located at the base of a Class I preparation in the upper left maxillary second molar, 2 mm from the cavosurface margin and 4 mm from the cusp tip (Figure 1). When the end of the light guide was held in contact with the cusp tips, the light detector measured the irradiance that would be received by the top surface resin, 4 mm from the LCU. Prior to use, the MARC-PS system had been calibrated using a NIST-traceable (National Institute of Standards and Technology, Gaithersburg, MD) high power light source (HL-2000-HP, Ocean Optics), and the maximum amount of radiant energy that could be delivered to the detector in twenty seconds was measured five times by one of the authors (RBP) when the MARC-PS was fully accessible in the laboratory bench. The irradiance and radiant energy delivered by each of the sixty-three students were measured in real time, and the radiant energy (J/cm²) they delivered to the detector was calculated.

The students were observed (Figure 2) as they cured the simulated restoration before receiving the additional instruction on proper light-curing using the MARC-PS. It was noted that students who con-

Figure 1. The detector in the maxillary second molar in MARC-PS simulates the position of the top surface of a resin that is 4 mm away from the tip of the curing light

Note: Figure is reprinted with permission from Seth S, Lee CJ, Ayer CD. Effect of instruction on dental students’ ability to light-cure a simulated restoration. J Can Dent Assoc 2012;78:c123.
sistently delivered a low amount of energy did not 1) wear the orange protective eyeglasses that were readily available, 2) look at the preparation when using the LCU, 3) stabilize the LCU with their hand, or 4) pay close attention to what they were doing. Following these observations, the students were shown their results, and they received individual coaching with immediate visual feedback using the MARC-PS on how to optimize their light-curing technique. The students were instructed to 1) use blue-blocker eye protection, 2) look at the preparation, 3) stabilize the LCU with their hand as close to the restoration as possible, and 4) pay close attention to what they were doing.

After this, the light-curing experiment was repeated and the results recorded. The radiant energy delivered by the three different groups of students before and after instruction was subjected to a two-way analysis of variance (ANOVA) with group and before/after instruction results as factors, followed by Fisher’s PLSD post hoc multiple comparison tests (α=0.05). A multiple linear regression (SAS PROC REG) was used to predict how much radiant energy would be delivered by each group of students after they had received the individual instruction and feedback using the MARC-PS.

Results

When the tooth in the MARC-PS typodont was fully accessible, the maximum amount of radiant energy that could be delivered to the detector in twenty seconds was 18.0 J/cm². Before receiving the additional instruction, the amount of radiant energy delivered by the students ranged from 1.4 J/cm² to 17.5 J/cm² with an average of 9.8±3.5 J/cm² (Table 1). There was a 12.5-fold difference between the minimum and maximum amount of energy delivered.

Figure 2. The students were observed as they cured the simulated restoration using MARC-PS
Before MARC Instruction (LEFT): The student’s focus is directed away from the light source.
After MARC Instruction (RIGHT): The student is wearing blue-blocker eye protection, is stabilizing the LCU, and is focused on how she is light-curing the restoration.
Ten (16 percent) of the students did not deliver the minimum 6.0 J/cm² of radiant energy set for this study, and only three (5 percent) delivered 16.0 J/cm².

Figure 3 is an example of a typical MARC-PS software report showing the irradiance delivered by one student before and after receiving additional light-curing instruction. Figure 4 and Table 1 show that after receiving additional instruction, the amount of radiant energy delivered by the students ranged from 6.7 J/cm² to 17.8 J/cm² with an average of 13.2±3.3 J/cm². There was a much smaller range (maximum 2.7-fold difference) in the amount of energy delivered by the students compared to before instruction. After instruction, all students delivered the minimum 6.0 J/cm² of energy, and seventeen (27 percent) students delivered more than 16.0 J/cm². Overall, the mean amount of energy increased by 35 percent from 9.8±3.5 to 13.2±3.3 J/cm².

Tables 2 and 3 show that receiving additional light-curing instruction made a significant improvement (p<0.05 Fisher’s PLSD) in how much radiant energy the students delivered. Fisher’s exact test showed that the number of students who failed to deliver 6.0 J/cm² before and after receiving additional instruction with immediate feedback was significantly different (p=0.0013). Multiple linear regression (PROC REG) was used to predict the energy delivered after instruction, including these predictors: the energy delivered before instruction, student term, and order of testing (both overall and within year). To make the intercept term more interpretable, the variables were rescaled by having the mean energies delivered before instruction subtracted (for both before and after scores) and having both the student group and order start at zero. Non-significant variables were dropped from the equation, leaving only the student group and the intercept—both highly significant (p<0.01). From the final linear regression model, the best indicator of the expected amount of improvement in light-curing performance was the level of training. Although all groups of students improved, the linear regression model predicted that the improvement in energy delivery after instruction would be 2.4 J/cm² for first-term students, 3.5 J/cm² for second-term students, and 5.8 J/cm² for fifth-clinical-term students (p=0.0091).

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Figure 3. Example of a typical MARC software report showing the irradiance delivered by one student before (red line, bottom line) and after (blue line, top line) receiving additional light-curing instruction using the MARC-PS

*Note:* Greater and more uniform irradiance is delivered after instruction using MARC-PS.
Table 1. Mean energy delivered by same students before and after receiving additional light-curing instruction using MARC-PS

<table>
<thead>
<tr>
<th>Term 1, Before Instruction</th>
<th>Amount of Energy (J/cm²)</th>
<th>Range</th>
<th>Term 1, After Instruction</th>
<th>Amount of Energy (J/cm²)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.8±3.5</td>
<td>1.4-17.5</td>
<td></td>
<td>13.2±3.3</td>
<td>6.7-17.8</td>
<td></td>
</tr>
</tbody>
</table>

Note: All students used the light for twenty seconds on the same tooth. The maximum amount of energy that could be delivered in twenty seconds was 18.0 J/cm².

Table 2. Two-way ANOVA showing effects of instruction on the groups of students

<table>
<thead>
<tr>
<th>Term 1, Before</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F-value</th>
<th>p-value</th>
<th>Lambda</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Term 1, After</td>
<td>1</td>
<td>366.85</td>
<td>366.85</td>
<td>33.22</td>
<td>&lt;0.0001</td>
<td>33.22</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 3. Fisher's PLSD showing the effect of instruction on students' ability to deliver energy to the tooth

<table>
<thead>
<tr>
<th>Fisher’s PLSD for Energy: Effect: Before/After Instruction</th>
<th>Mean Difference</th>
<th>Critical Difference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before/After Instruction</td>
<td>-3.34</td>
<td>1.17</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Significance level: 5%
Discussion

In this simulated clinical environment, sixty-three dental students used the MARC-PS to measure how much radiant energy they could deliver to a simulated Class I resin restoration that was 4 mm away from the light tip. Table 1 and Figure 4 show the large variability in the amount of light the students delivered to this maxillary molar tooth. Since ten (16 percent) students did not deliver the 6.0 J/cm² minimum amount of energy set for this study, the first hypothesis was rejected. After receiving individual instruction with immediate feedback using MARC-PS, all the students were able to deliver the 6.0 J/cm² minimum, and 27 percent delivered the 16.0 J/cm² minimum recommended in the Phillip’s textbook to adequately cure a 2 mm layer of resin. Several students came close to delivering 18.0 J/cm², which was the maximum possible radiant energy that could be delivered using this LCU for twenty seconds in this setting.

Table 1 and Figure 4 show that using a teaching aid to deliver customized light-curing instruction with immediate feedback resulted in a significant improvement to the amount of energy delivered by the students. The overall mean amount of radiant energy delivered by the sixty-three students increased by 35 percent from 9.8±3.5 J/cm² to 13.2±3.3 J/cm². Thus, the second hypothesis that the students would deliver more energy after receiving one session of additional light-curing instruction and feedback was accepted. As expected, the use of a simulator helped to identify students in need of additional instruction on how to use the curing light. Despite the fact that they knew what happened to the irradiance received by the detector as the LCU tip drifted away from the tooth towards the end of light-curing. Note the increased irradiance and radiant energy (area under the blue line) delivered by the student after receiving immediate feedback and additional instruction. The predicted improvements in energy delivery after instruction suggest that as the overall skills of the three groups of students improved, this also increased their ability to improve their light-curing technique (p=0.0091).

This study transferred curing light research from the laboratory environment into a clinical setting and has real-life implications. The results showed that many students in this study were not using the dental LCU properly and may not be adequately light-curing their resin restorations. Additionally, it has been reported that improper light-curing technique can cause soft tissue burns. Since the students’ actual clinical performance is often worse than on the typodont, this result is a concern for dental educators and patients. The initial inability of the students to deliver at least 6.0 J/cm² of radiant energy to a restoration supports the findings of previous studies, and similar results have been obtained at courses in the United States, Canada, England, and Germany when the energies delivered by both students and dentists were measured using the MARC-PS.

This study was not designed to determine the minimum amount of energy required to cure dental resins since, depending on the thickness, brand, and shade, this has been previously reported to range from 6 to 24 J/cm². It is well documented that inadequate light-curing adversely affects the resin’s properties and no manufacturers recommend undercuring their resin. Consequently, the observation that before receiving additional light-curing instruction, only three (5 percent) students delivered above 16.0 J/cm², 16 percent of the students did not deliver 6.0 J/cm² of radiant energy, and none delivered 24 J/cm² 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 six years. The results also help to explain why different operators can achieve very different clinical success rates with the same dental resins or bonding systems.

The finding that 16 percent of the students did not deliver the minimum 6.0 J/cm² of radiant energy in twenty seconds is also of concern because the manufacturer of the LCU used in this study suggests that most resins can be adequately cured in six to twelve seconds. Our study showed that if the stu-
students had used this LCU for only six seconds, then none of the students would have delivered 16.0 J/cm², and most would have delivered much less than 6.0 J/cm². Unfortunately, even those resin restorations that received less than 6.0 J/cm² would still appear hard on the surface when tested with a dental explorer, but the resin beneath the surface would not be adequately polymerized. As this resin is usually inaccessible, the student or dentist has no way of measuring how well the resin is cured at the bottom. To be confident that the RBC has been adequately cured, practitioners need to know that they have delivered sufficient radiant energy at the correct wavelengths.

The MARC-PS mannequin head combined with the calibrated spectroradiometric measuring device used in this study provides a realistic simulation of light-curing a restoration for a patient. The immediate visual feedback showed how easily mistakes can occur when light-curing and allowed the students to practice their light-curing technique. Now that dental professionals can accurately measure how much radiant energy is delivered to simulated restorations, the profession can start to manage the problem of inappropriate energy delivery to resin restorations. This study showed that after one session of training with the MARC-PS, it was possible to improve the ability of dental students to use a LCU. Further improvements in energy delivery would be expected with additional sessions using MARC-PS. It would be prudent to monitor the students’ light-curing abilities as they progress through their dental training or whenever they use a different brand of LCU. This should result in an improved understanding by students of the important role of the LCU and the need to use the proper light-curing technique. Hopefully, all students will then deliver resin restorations that are correctly cured, meet the resin manufacturers’ specifications, last longer, and thus provide improved patient care.

Conclusion

We concluded from this study that students’ light-curing techniques could be improved when a patient simulator was used to provide immediate feedback on the amount of radiant energy delivered to a simulated restoration. The study had three major findings. First, before receiving the additional light-curing instruction, 16 percent of the students did not deliver 6.0 J/cm² of radiant energy in twenty seconds. There was a large range (between 1.4 and 17.5 J/cm²) in the amount of energy these dental students delivered. Second, using the same curing light, for the same time, on the same tooth, the students delivered on average 35 percent more light energy after receiving one session of individual light-curing instruction (p<0.05). Third, students who were closer to graduation showed a greater improvement in their light-curing technique after instruction using MARC-PS (p=0.0091).

Acknowledgments and Disclosure

This study was funded by Dalhousie University and the University of Regensburg. The authors wish to thank John Fahey for his statistical support. Dr. Price is the inventor of MARC. This device was assigned to Dalhousie University and subsequently licensed to BlueLight Analytics, a company in which he owns shares.

REFERENCES


