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Effect of High Irradiance on Depth of Cure of a Conventional and a Bulk Fill Resin-based Composite

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Clinical Relevance

For both RBCs, rapid photocuring using a PAC light for five seconds resulted in a shallower depth of cure than when the same radiant exposure of (37 J/cm^2) was delivered by a QTH or LED curing light used for 40 seconds or 20 seconds, respectively.

SUMMARY

Objectives: This study evaluated the effect of using three commercial light curing units (LCUs) delivering a range of irradiance values, but delivering similar radiant exposures on the depth of cure of two different resin-based composites (RBCs).

Methods: A conventional hybrid RBC (Z100 shade A2, 3M ESPE) or a bulk fill RBC (Tetric EvoCeram Bulk Fill shade IVA, Ivoclar Vivadent) was packed into a 10-mm deep semicircular metal mold with a 2-mm internal radius. The RBC was exposed to light from a plasma-arc-curing (PAC) light (Sapphire Plus, Den-Mat) for five seconds, a quartz-tungsten-halogen (QTH) light (Optilux 501, Kerr) for 40 seconds, or a light-emitting-diode (LED) light (S10, 3M ESPE) for 20 seconds and 40 seconds (control). The Knoop microhardness was then measured as soon as possible at the top surface and at three points every 0.5 mm down from the surface. For each RBC, a repeated measures analysis of variance (ANOVA) model was used to predict the Knoop hardness in a manner analogous to a standard regression model. This predicted value was used to determine at what depth the RBC reached 80% of the mean hardness achieved at the top surface with any light.

Results: The PAC light delivered an irradiance and radiant exposure of 7328 mW/cm^2 and 36.6 J/cm^2, respectively, to the RBCs; the QTH light delivered 936 mW/cm^2 and 37.4 J/cm^2 and in 20 seconds the LED light delivered 1825 mW/cm^2

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and 36.5 J/cm^2. In 40 seconds, the control LED light delivered a radiant exposure of 73.0 J/cm^2. For Z100, using 80% of the maximum hardness at the top surface as the criteria for adequate curing, all light exposure conditions achieved the 2.0-mm depth of cure claimed by the manufacturer. The LED light used for 40 seconds achieved the greatest depth of cure (5.0 mm), and the PAC light used for five seconds, the least (2.5 mm). Tetric EvoCeram Bulk Fill achieved a 3.5-mm depth of cure when the broad-spectrum QTH light was used for 40 seconds delivering 37.4 J/cm^2. It required a 40-second exposure time with the narrow-spectrum LED, delivering approximately 73 J/cm^2 to reach a depth of cure of 4 mm.

Conclusions: When delivering a similar radiant exposure of 37 J/cm^2, the QTH (40 seconds) and LED (20 seconds) units achieved a greater depth of cure than the PAC (five seconds) light. For both resins, the greatest depth of cure was achieved when the LED light was used for 40 seconds delivering 73 J/cm^2 ($p<0.05$).

INTRODUCTION

In recent years, there has been a global reduction in the use of amalgam resulting in an increase in the use of resins to the extent that, in Scandinavia, almost no amalgam restorations are placed.[1,2] This trend will only accelerate with the signing of the Minamata Convention that contains provisions to phase-down the use of dental amalgam.[2,3] Although some photopolymerizable resin-based composites (RBCs) have been reported to have excellent long-term results in clinical trials,[1,4,5] the results achieved in dental offices worldwide have been less promising.[6-8] If the RBC is undercured, the result will be suboptimal properties for the restorative material that could increase the probability of fracture of the restoration, encourage more secondary caries, increase the wear rate, and result in premature failure.[9] Undercuring is especially of concern for Class II restorations that commonly fail due to bulk fracture or secondary caries at the cervicogingival margin.[10] This part of the restoration is the furthest away from the curing light (LCU) and is the most difficult to photopolymerize.[11] Additionally, when dental RBCs are not adequately polymerized (and thus do not reach a sufficient degree of monomer conversion), they are more likely to leach chemicals into the mouth.[12-14] Arbitrarily increasing light exposure times in an effort to prevent undercuring is not the answer because this may cause unacceptable thermal trauma to the pulp and surrounding tissues.[15-17] Thus, it is important for the clinician to know the optimal exposure times for the RBCs being used in the office.

One method used to determine the potential clinical adequacy of photopolymerization is to measure the depth of cure (DOC) in a mold. The type and size of the mold, the RBC, and the light source used can all affect the measured DOC.[18-20] The test method described in the ISO 4049 standard can be used to evaluate the DOC.[21] This method uses a 4-mm diameter metal mold and evaluates the DOC at room temperature immediately after light exposure. The DOC is determined to be half the maximum length (depth) of hard RBC remaining after the soft RBC has been scraped away. The suitability of the ISO 4049 test to determine the DOC for bulk fill RBCs has been questioned because it has been reported to overestimate the true DOC.[22]

Depth of cure can also be assessed from microhardness measurements where a hardness value that is at least 80% of the maximum hardness is considered to be acceptable.[23-27] Two microhardness tests are commonly used, Vickers and Knoop. Both of these tests use loads less than 1000 g to make small indentations in the RBC, but the shape of the indentations is different for the two tests.[28] The Vickers test uses a square-based pyramid-shaped indenter to produce indentations that have approximately the same length on both axes. The lengths of the diagonals of the indentation are measured and averaged to calculate the hardness.[28] This test is most suitable for determining the hardness of brittle materials because, when this test is used to measure dental resins that exhibit some elastic recoil, elastic recovery occurs equally in both axes when the load is removed from the indenter, potentially resulting in an inaccurate measurement.[28] In contrast, the Knoop microhardness method uses a rhombic-shaped indenter to produce narrow indentations that have both a long and a short axis. Due to this unique shape, when the indenter is removed from the test material, elastic recovery (dimensional change) primarily occurs in the short axis leaving the length of the longer diagonal virtually unchanged. The Knoop hardness is calculated using only this longer axis and is virtually independent of the ductility of the tested material. This makes the Knoop test ideal for testing ductile materials such as RBCs.[28] Depth of cure values obtained by the Knoop test method may be more reliable[29] than the ISO 4049 test, and a strong positive correlation exists between the Knoop microhardness values and degree of monomer conversion within each brand of RBC.[19,24,30-32]

Light-cured RBCs contain at least one photoinitiator, such as camphorquinone (CQ), with additional initiators sometimes included.[28,32-38] CQ is a type II photoinitiator that undergoes a bimolecular reaction. It has a maximum absorbance of light at a wavelength of 470 nm, but it is activated by a broad range of light from wavelength of approximately 510 nm down to well into the ultraviolet range below 360 nm.[28,34] In contrast, alternative photoinitiators such as monoacylphosphine oxide (TPO) and derivatives of dibenzoyl germanium (e.g. Ivocerin) are not activated by light above 460 nm but are very sensitive to light below 420 nm.[38-40] These type I photoinitiators undergo a unimolecular reaction upon irradiation. Consequently, they are more reactive to light compared to CQ and may require a lower radiant exposure when placed in thin increments.[34,37,38,41,42] However, due to the reduced penetration of shorter wavelengths of light, this advantage is lost as the thickness of the RBC increases.

Due to postirradiation polymerization, the time between curing a resin specimen and measuring the hardness can have a considerable impact on the results.[43-45] Although all RBCs exhibit some postirradiation polymerization, the amount depends upon the RBC used and the extent to which it has been polymerized.[43,45] After 24 hours, the increase in hardness can range from 12% for a well-polymerized RBC to over 350% for the same RBC when it is less well polymerized.[43] Despite the known effects of postirradiation polymerization, RBC specimens are often measured 24 hours or more after light curing[19,23,24,27,32,46,47] as the physical properties will likely remain stable during the time taken to make the measurements.[43] However, in a clinical situation the patient will not wait 24 hours before chewing. Thus, the bottom and sides of the RBC restoration may well be stressed soon after placement, requiring the RBC to reach an 80% bottom/top hardness ratio within a clinically relevant time.

There is a high demand from the dental profession to become more productive by shortening chairside procedures. Consequently, some manufacturers are suggesting that their high-output LCUs require much shorter exposure times than conventional lights.[48-51] It has even been calculated that, based on placing 2200 restorations in a year, a dentist could save enough time to produce US$26,399 more a year if five seconds of light exposure is used instead of 30 seconds under the same conditions.[52] Some contemporary LCUs claim to deliver irradiance levels up to 6 W/cm^2 and their manufacturers suggest that a very short (one to three seconds) exposure time will adequately cure the resin.[49] These recommendations have been challenged more than once, because for a given dose of energy, longer exposure times at a lower irradiance seem to be beneficial factors to ensure optimal RBC properties.[14,53-59] In addition, such high-output LCUs may cause more heating of the tooth and soft tissues, which raises the concerns of thermal damage.[15-17,36]

Another method to shorten chairside time is to bulk fill and cure RBCs in just one light exposure. According to the manufacturers, these bulk fill materials can be adequately cured in one 4- to 5-mm increment without having to extend the light exposure time.[38,60] Some reports have suggested that this is an acceptable technique,[25-27,46,47,61,62] but others have suggested that bulk filling and curing may produce undercured RBCs.[22,63,64] Bulk filling a cavity reduces some of the technical disadvantages associated with layering conventional RBCs, such as the incorporation of voids or contamination between the layers,[61,63] as well as improving chairside efficiency. However, as the thickness increases, exponentially fewer photons of light reach the bottom of the RBC, an effect which is more pronounced at the shorter wavelengths (410 nm) compared to longer wavelengths (460 nm).[33,65] To counteract this effect and increase the DOC, manufacturers have used different strategies, including using more reactive alternative photoinitiators and improving RBC translucency by reducing the amount of fillers or by matching the refractive indices of the fillers and resin matrix.[66] The advisability of rapid photocuring and bulk filling as an option for shortening chairside time needs to be examined, and the interaction of these two strategies requires further exploration.

The objective of this study was to evaluate the effect of using three commercial LCUs delivering a range of irradiance values, but similar radiant exposures, on the depth of cure of a popular version of a conventional hybrid and a bulk fill RBC. The tested null hypotheses were that: 1) when 37 J/cm^2 of radiant exposure was delivered from a plasma arc-curing unit (PAC), a quartz-tungsten-halogen unit (QTH), and a light-emitting diode unit (LED) light, both RBCs would achieve the manufacturer's claimed depth of cure; and 2) for each RBC, there will be no significant difference in depth of cure obtained using these different LCUs when the same radiant exposure was delivered.

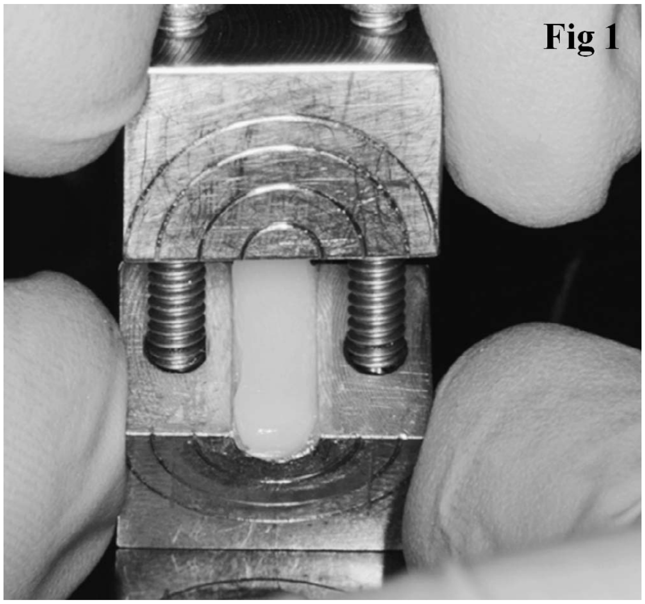

Figure 1. *The 10-mm deep half-cylindrical metal mold with a 2-mm internal radius filled with RBC.*

METHODS AND MATERIALS

A conventional hybrid composite (Filtek Z100 – shade A2, 3M ESPE, St Paul, MN, USA) and a bulk fill composite (Tetric EvoCeram Bulk Fill – shade IVA that is equivalent to shade A2 – A3, Ivoclar Vivadent, Amherst, NY, USA), which includes CQ and the alternative photoinitiator Ivocerin,[38] were used in this study. One example of three types of LCU was used to polymerize the samples: a PAC light; Sapphire Plus, DenMat, Lompoc, CA, USA), a QTH light; Optilux 501, Kerr, Orange, CA, USA), and a LED unit; Elipar S10, 3M ESPE). The PAC unit was used with its optional 4-mm "turbo" fiber-optic light guide, which is designed to deliver a high irradiance; the QTH unit was used with its 10-mm fiberoptic light guide; and the LED unit was used with its 10-mm fiberoptic light guide.

Sample Preparation

The Z100 and Tetric EvoCeram Bulk Fill materials were packed in a 10-mm deep half-cylindrical metal mold with a 2-mm internal radius (Figure 1). The top and bottom surfaces of the RBC in the mold were covered with a polyester strip and pressed flat. The LCU light tip was fixed and centered as if the mold were a cylinder just out of contact with the top polyester strip, and the RBC was exposed to light in one of four curing conditions: PAC for five seconds, QTH for 40 seconds, LED for 20 seconds, and LED for 40 seconds (Figure 2). The first three exposure times represented clinically relevant light exposure

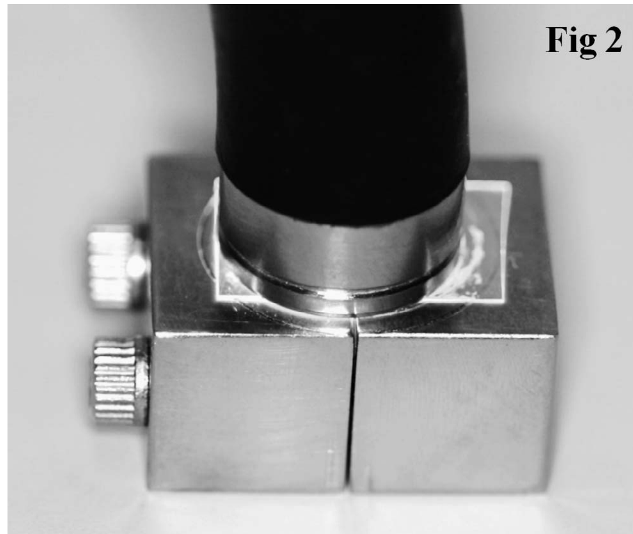

Figure 2. *The samples were polymerized with the tip of the light guide just out of contact with the Mylar strip.*

conditions and delivered similar radiant exposures to the specimens, all above 24 J/cm^2. The LED unit was used for an additional 40 seconds to provide an overexposure condition to act as a control. Five samples were prepared per RBC per irradiation condition for a total of 40 specimens (two RBCs * four LCU/time * five repetitions). All sample preparation and testing was conducted at ambient room temperature and humidity.

Depth of Cure Evaluation

The Knoop microhardness (KHN) was measured using an automated microhardness-testing device (HM 123, Mitutoyo Canada Inc, Mississauga, ON, Canada) applying a 50-gf load for eight seconds. The KHN was measured at nine points on the top surface and Figure 3 illustrates how, on each specimen, the hardness was also measured at three points on the lateral surface every 0.5 mm down from the top surface to the point where it was too soft to measure. The hardness measurements were started as soon as practically possible (termed near immediate measurement). All of the indentations were completed within 30 minutes of the end of light exposure.

Evaluation of Energy Delivered to the RBCs

The spectral radiant power output in milliwatts/nanometer (mW/nm) delivered to the specimens from each LCU was measured five times using a 6-inch integrating sphere (Labsphere, North Sutton, NH, USA) attached to a fiberoptic spectrometer (USB 4000, Ocean Optics, Dunedin, FL, USA), as previously described.[67] The integrating sphere had a 4.0-

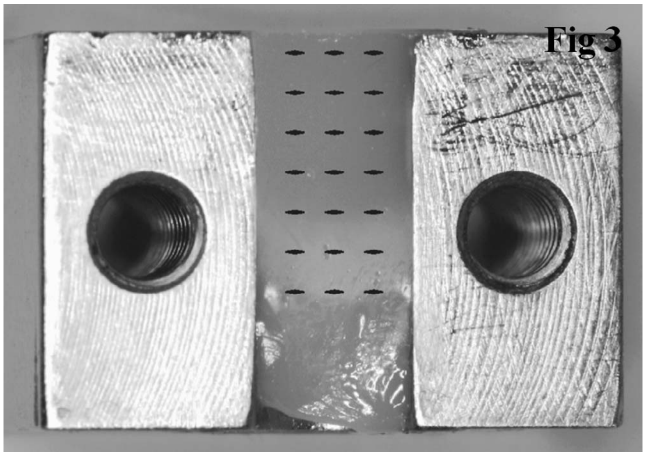

Figure 3. *Microhardness measured at three positions at each 0.5-mm increment down from the top surface of the RBCs.*

mm diameter entrance aperture (radius 2.0-mm), and the light tip was fixed and centered over this entrance. For each LCU, the mean radiant power (Watts) reaching the top surface of the semicircular mold was calculated as the average of the five radiant power values recorded by the integrating sphere divided by two. The irradiance (mW/cm^2) and radiant exposure (in J/cm^2) delivered to the RBCs was then calculated.

Statistical Analyses

For each RBC, Z100 and Tetric EvoCeram Bulk Fill, separate repeated measures analysis of variance (ANOVA) models were developed using the actual KHN measurements to predict the KHN over distance (depth) in a manner analogous to a standard regression model. The KHN measurements analyzed for each RBC constituted the five replicates that were measured under four different light/time conditions. A three by three grid on the top surface and three measurements at each of 18 depths (from 0.5 to 9.0 mm by 0.5 mm increments) constituted the 63 measurements that were modeled. Depth, light, and their interaction were the fixed effects in the statistical model that provided a predicted hardness at each 0.5-mm depth increment for each combination. This data analysis was carried out using SAS software (SAS, Cary, NC, USA), and statistical significance was set at $p \leq 0.05$.

RESULTS

The mean irradiance and radiant exposures delivered to the semicircular RBC specimens were respectively: PAC unit 7328 mW/cm^2 and 36.6 J/cm^2, QTH unit 936 mW/cm^2 and 37.4 J/cm^2, and LED unit (20 seconds) 1825 mW/cm^2 and 36.5 J/cm^2. In 40 seconds, the control LED delivered 73.0 J/cm^2 (Table 1). The spectral emissions from the LCUs through the 4.0-mm aperture into the integrating sphere are shown in Figure 4.

The mean KHN ± standard deviation measured at different depths for Z100 and Tetric EvoCeram Bulk Fill are reported in Figures 5 and 6, respectively. The level where the KHN was 80% of maximum hardness achieved at the top surface (100% line), irrespective of the choice of LCU, is shown on the Figures. Comparing Figures 5 and 6, it can be seen that the maximum top hardness of Tetric EvoCeram Bulk Fill was approximately 50% of the hardness of Z100. For Tetric EvoCeram Bulk Fill only, the broad-spectrum PAC and QTH lights produced harder KHN values down to a depth of 2.0 mm compared to the narrow spectrum LED light. At greater depths, the narrow spectrum LED unit used for 40 seconds produced harder KHN values for both RBCs (Figures 5 and 6).

In the statistical analysis, when considering the likelihood of the RBC to be cured at any point, depth was the most important predictor (F [18,72]=2714.62, $p<0.0001$). The choice of LCU had a smaller, but still very significant effect; however, this effect was not the same at all depths (F [54,216]=59.95, $p<0.0001$). Thus, it was not possible to directly compare the overall effect of the LCUs on the hardness. Instead, separate repeated measures ANOVA models were developed to predict a single hardness value for each combination of depth and light. For each RBC, these predictions were compared to the mean hardness value at the top surface achieved with all LCUs. The depth where the predicted value fell below 80% of the greatest top hardness value was used as the criteria for adequate curing. The greatest depth of adequate cure (5.0 mm) was obtained with Z100, whereas it was 4.0 mm for Tetric EvoCeram Bulk Fill (Table 1). For Z100, the LED used for 40 seconds achieved the best results, and the PAC used for five seconds, the worst. Plus or minus ties, the same is also true for Tetric EvoCeram Bulk Fill.

DISCUSSION

This study evaluated the effect of delivering different irradiances, between 936 and 7328 mW/cm^2, but very similar radiant exposures (approximately 37 J/cm^2) from three types of LCU, on the depth of cure of a conventional hybrid and a bulk fill composite. Using an automated hardness tester made near immediate hardness testing feasible and the test more clinically relevant.

Table 1: *Maximum Predicted Depth at Which the Knoop Hardness Number of the Resin-Based Composites (RBC) Achieved 80% of the Top Surface Value, Based on the Repeated Measures ANOVA Model ($p \leq 0.05$)*

RBC and Shade	Light and Exposure Time, s	Depth of Cure, mm	Irradiance Received by RBC, mW/cm^2	Radiant Exposure Received by RBC, (J/cm^2)
Z100 A2	PAC (Sapphire) for 5 s	2.5	7328	36.6
Z100 A2	LED (S10) for 20 s	3.5	1825	36.5
Z100 A2	QTH (501) for 40 s	4.0	936	37.4
Z100 A2	LED (S10) for 40 s	5.0	1825	73.0
Tetric EvoCeram Bulk Fill IVA	PAC (Sapphire) for 5 s	3.0	7328	36.6
Tetric EvoCeram Bulk Fill IVA	LED (S10) for 20 s	3.5	1825	36.5
Tetric EvoCeram Bulk Fill IVA	QTH (501) for 40 s	3.5	936	37.4
Tetric EvoCeram Bulk Fill IVA	LED (S10) for 40 s	4.0	1825	73.0

Tetric EvoCeram Bulk Fill did not cure to a greater depth than the conventional resin, irrespective of the LCU used (Table 1), and it did not reach the 4.47 mm DOC reported by Alrahlah and others[27] who used a similar split metal mold and the same S10 LED curing light for 20 seconds. These authors measured the Vickers microhardness of the RBCs after they had been stored for 24 hours at 37°C, and the test method and storage conditions would have affected the outcome.[30,43-45] The DOC results for Tetric EvoCeram Bulk Fill are much greater than previously reported (0.2 mm) in another study that also used a split metal mold and tested the hardness of the RBC immediately after irradiation.[22] However, the DOC is similar to the 3.32-mm DOC achieved for this RBC using the ISO 4049 scrape test in the same study.[22]

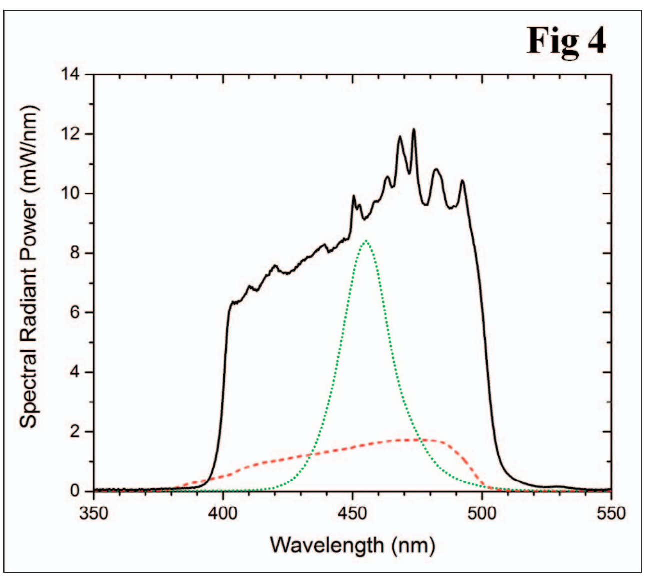

Figure 4. *Spectral radiant power from each LCU measured through a 4-mm diameter aperture placed at the entrance to an integrating sphere that was connected to a spectrometer.*

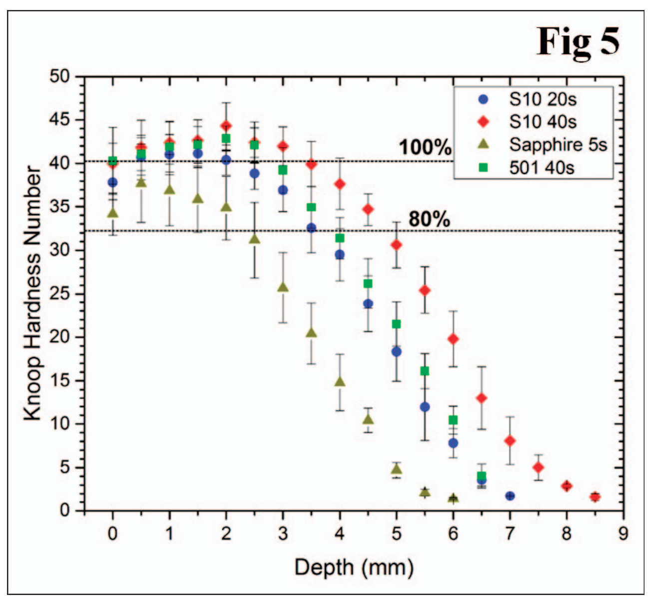

Figure 5. *Mean Knoop hardness number ± one standard deviation measured at each depth for Z100. Note the lines showing maximum top hardness (100%) and 80% value. Note also the different KHN scale compared to Figure 6.*

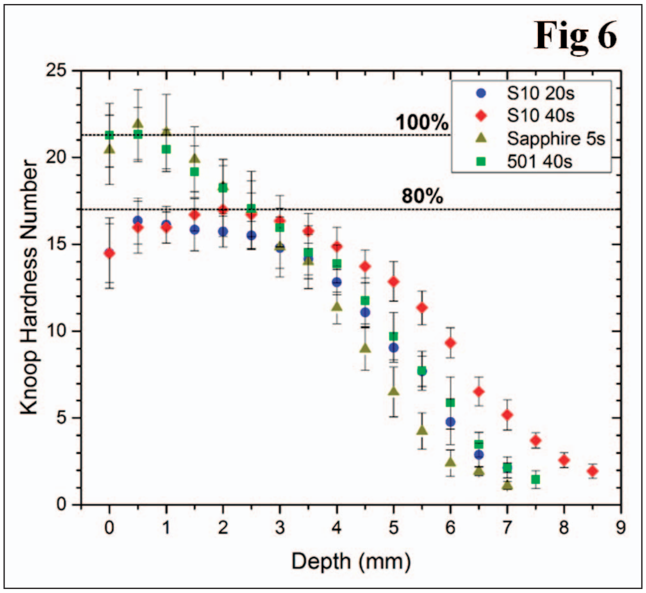

Figure 6. *Mean Knoop hardness number ± one standard deviation measured at each depth for Tetric EvoCeram Bulk Fill. Note the lines showing maximum top hardness (100%) and 80% value. Note also the different KHN scale compared to Figure 5.*

In view of the large differences in the microhardness values between the two RBCs, the analyses were carried out separately for each resin. The results show that, although the two RBCs were well cured at or near the surface when exposed to high irradiance levels for short times, as the depth increased, the microhardness values were negatively affected. When 37 J/cm^2 of radiant exposure was delivered from the QTH, LED, or PAC light, there were significant differences in depth of cure obtained using these different LCUs ($p<0.0001$). The conventional resin-based composite achieved the manufacturer's stated 2.0 mm depth of cure when any of the LCU units were used. The bulk filling RBC (Tetric EvoCeram Bulk Fill) only achieved a 4.0-mm depth of cure when the LED unit was used for 40 seconds, delivering twice as much radiant exposure, 73 J/cm^2, as the other test conditions. Photocuring using the PAC light for five seconds at 7328 mW/cm^2, resulted in the shallowest depth of cure for both RBCs. Thus, both the first and second hypotheses were rejected.

To minimize the effects of light beam inhomogeneity,[67] this study measured the wavelength and radiant exposure delivered from the LCU, centered over the 4-mm diameter aperture into an integrating sphere rather than the total energy delivered by the LCU. This minimized the effects of light beam inhomogeneity, and allowed for a close estimation of the radiant exposure received by the RBC specimens (~36.5 J/cm^2). This should have been more than enough for adequate photopolymerization.[28,38,68,69] Despite delivering a similar radiant exposure, Table 1 and Figures 5 and 6 show that the PAC light used for only five seconds produced the shallowest curing depth for both RBCs, although the PAC light produced the hardest resin to a depth of 1.5 mm for Tetric EvoCeram Bulk Fill (Figure 6). The irradiance from the turbo tip on the PAC light (7328 mW/cm^2) was much greater than that from both the QTH (936 mW/cm^2) and LED (1825 mW/cm^2) units (Table 1). These results corroborate previous findings that slower photopolymerization is more successful to rapid (five-second) photopolymerization of RBCs.[14,53-58,63]

In common with previous studies, this study used the 80% bottom/top threshold to define when the RBC is adequately cured.[22,24-27] It is interesting to note that using a metal mold under these test conditions, a conventional hybrid resin containing only CQ was able to achieve a 5.0-mm depth of cure when 73 J/cm^2 was delivered from the LED light in 40 seconds, whereas Tetric EvoCeram Bulk Fill only achieved a 4.0-mm depth of cure under the same conditions. Although the type I photoinitiators used in Tetric EvoCeram Bulk Fill undergo a unimolecular reaction upon irradiation and are therefore more reactive to light,[34,37,38,41,42] due to the effects of the Rayleigh scattering of light less light penetrates through the RBC as the wavelength decreases. Thus, little of the shorter wavelengths of light reach down into the depths of the RBC to initiate photopolymerization. This supports the observation that the depth of cure of CQ-based materials can be greater than that of TPO-based materials.[41]

As in a clinical situation at the bottom of the restoration, the RBC samples were not polished. The maximum microhardness was determined as the maximum hardness achieved by any LCU at the top surface. Figures 5 and 6 illustrate that both RBCs were harder just beneath the surface rather than at the surface. This observation has been reported previously[22] and may occur because in the subsurface region close to the irradiated surface, the RBC receives almost all the light from the LCU plus more of the beneficial effect of the exotherm from the RBC all around it. As the depth increases, the RBC receives fewer and fewer photons of light, and the amount of photopolymerization is less. Another possible explanation for this finding is that the polyester strip did not provide 100% protection from the air and thus the top surface of the resin contained an oxygen-inhibited layer. This effect requires further study.

To achieve a hardness value that was at least 80% of the maximum top value at 4 mm depth, the LED unit had to be used for 40 seconds for Tetric EvoCeram Bulk Fill. This is much longer than 10 seconds suggested by the manufacturer of this resin[38] for any LCU delivering >1000 mW/cm^2 (>10 J/cm^2), or the manufacturer of the LED unit.[48] This LED curing light has a relatively narrow spectral emission (Figure 4), and only the QTH and PAC lights delivered any spectral output below 420 nm. Thus, the TPO initiator used in the Tetric EvoCeram Bulk Fill may not have been efficiently activated by the LED light used in this study, and different results may have been achieved had a LED light delivering a broader spectral emission been used. However, since both the QTH and PAC lights are broad-spectrum lights and they delivered much more than the recommended amount of energy to the specimens, they should have been able to cure this RBC to a depth of 4 mm, but they failed to achieve this.

Similar to the ISO 4049 depth of cure scrape test guidelines,[21] the specimens were made in a metal mold at room temperature and they were tested almost immediately. The microhardness results obtained in the present study could have been influenced by the metal mold that completely blocked transmission of light outside the mold, unlike tooth material. However, the use of a metal mold has been recommended so as not to overestimate depth of cure.[20] The metal mold also created testing conditions closer to clinical conditions where a metallic matrix is placed around the proximal box in Class 2 preparations. In addition, had the specimens been examined at an intraoral temperature, or after 24 hours, a greater depth of cure would have been achieved.[30,43-45]

Despite these limitations, the results show that rapid photocuring using a broad-spectrum light source of a conventional RBC and a bulk fill RBC, which contains both Ivocerin and CQ, results in a shallower depth of cure. Future studies should evaluate the effect of using a broad-spectrum, polywave LED curing light on these RBCs and of using different combinations of exposure times and irradiance levels when photocuring other RBCs with similar amounts of energy.

CONCLUSIONS

Within the limitations of this study that used an 80% bottom/top hardness ratio to define adequate polymerization in a metal mold, it was concluded that:

1) When similar radiant exposures were delivered from the QTH, LED, or PAC light, there were significant differences in depth of cure depending on the LCU used.
2) The conventional resin-based composite (Z100) achieved greater than a 2-mm depth of cure when the PAC, QTH, or LED units were used delivering approximately 37 J/cm^2.
3) The bulk fill resin-based composite (Tetric EvoCeram Bulk Fill) achieved a 3.5-mm depth of cure when a broad-spectrum QTH light was used for 40 seconds. It required a 40-second exposure time with the narrow-spectrum LED delivering approximately 73 J/cm^2 to reach a depth of cure of 4 mm.
4) Rapid photocuring using the broad-spectrum PAC light for five seconds delivering 36.6 J/cm^2 at 7328 mW/cm^2 resulted in the shallowest depth of cure for both RBCs.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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