Effect of light-curing distance and curing time on composite microflexural strength

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This study investigated the influence of curing distance on µ-flexural strength (µ-FS) of a nano-hybrid composite, cured using the manufacturer-recommended curing time (MCT), compared to a consistent radiant exposure (CRE) using three different light-curing units (LCUs). Beams (6×2×1 mm) were cured using the MCT or CRE with a quartz-tungsten-halogen (QTH); a single-emission-peak light-emitting-diode (SLED), or a multiple-emission-peak light-emitting-diode (MLED) LCU. Specimens were cured at 0-, 2- or 8-mm distances (n=10) and the bottom irradiance and CRE were measured using a Managing Accurate Resin Curing-Resin Calibrator spectrometer. µ-FS testing was performed, and data analyzed using two-way ANOVA and Tukey multiple comparison tests (α=0.05).

Mean bottom irradiance was (25.4–99.7 mW/cm²) and CRE (0.31–1.11 J/cm²). Comparing CRE to MCT showed that µ-FS significantly decreased using the CRE at 2-mm (QTH) or the MCT at 2- and 8-mm (SLED). µ-FS may be significantly impacted by the curing protocol.

Keywords: Microflexural strength, Light-curing unit, Resin composite, Curing distance, Curing time

INTRODUCTION

Fracture is a common clinical cause of composite failure¹-³. The ability of a light activated resin-based composite (RBC) to withstand complex clinical stresses is a critical factor in fracture resistance⁴. RBCs perform as the manufacturer intended when they receive sufficient energy for the necessary amount of time to activate polymerization effectively⁵,⁶.

The manufacturer typically provides a curing time based on laboratory testing performed at 0-mm distance between the material surface and the light-curing unit (LCU), which is not clinically attainable⁵. Increasing the curing distance results in decreasing the experienced irradiance and radiant exposure (RE) values⁷-¹⁰. As a result, using the manufacturer curing time (MCT) as the distance increases may decrease the irradiance and RE the restoration receives, negatively impacting the final restoration’s longevity and properties⁷,⁸,¹⁰. Unfortunately, different curing protocols for different composites at multiple distances are rarely provided by the manufacturer despite the literature’s recommendation to do so¹¹,¹². Therefore, clinicians either use the MCT or subjectively increase the curing time, when the distance is increased.

Composites demonstrate similar properties when a consistent RE (CRE) is received¹³. Recent work showed satisfactory degree of conversion, hardness and cross-link density when a CRE of 10–11 J/cm² was received on the top, resulting in 0.7–1.29 J/cm² on the bottom, of a 2-mm increment using different LCUs at two distances¹⁴,¹⁵,¹⁶. Other studies reported that delivering a CRE did not result in similar properties¹⁷,¹⁸. Nevertheless, clinicians need to have curing guidelines to effectively polymerize composites. There is lack in the literature regarding the irradiance and RE received on a restoration bottom at clinically relevant distances. Therefore, it was worth investigating the effect of curing using the MCT compared to the CRE on the irradiance, and the RE received on the bottom at different distances.

Microflexural strength (µ-FS) can predict the mechanical performance of a material and is more clinically relevant because specimen dimensions are smaller, which allows for one shot curing, compared to the flexural strength test performed according to the ISO 4049 standards¹⁸-²⁰. Most studies have examined the flexural strength and µ-FS of various composites using the MCT at 0-mm distance¹⁹,²¹. Recent work has shown that µ-FS of two composites was not significantly impacted when cured using the MCT at 2- and 8-mm distances²². Nevertheless, different LCUs perform differently due to their differences in technology and spectrum²³,²⁴.

A quartz-tungsten-halogen unit (QTH) has a broad spectrum that falls within the absorbance range of most photoinitiator systems. The single-emission peak light-emitting-diode (SLED) unit has a narrow spectrum and contains blue LED chips that emit the wavelengths (420–520 nm) needed to activate camphorquinone (CQ). The multiple-emission peak LED (MLED) unit contains an additional violet chip that emits wavelengths (380–425 nm) needed to activate alternative photoinitiators²⁴-²⁶. Therefore, investigating the effect of distance on µ-FS when cured using the MCT and CRE at clinically relevant distances and different LCUs was worth investigating and would provide important information relevant to clinical material performance.

This study aimed to investigate: 1) The RE received
on the bottom of a RBC increment when using the MCT compared to CRE cured at clinically relevant distances with three different LCUs; 2) The influence of using the MCT on \( \mu \)-FS compared to using a CRE when cured at different distances with three different LCUs. The working hypotheses were: 1) The RE on a specimen's bottom will significantly decrease when using the MCT compared to the CRE at clinically relevant distances with three different LCUs. 2) The \( \mu \)-FS will significantly decrease when curing specimens using the MCT compared to using a CRE at different curing distances with different LCUs.

**MATERIALS AND METHODS**

**Light characterization**

Three LCUs were explored; one QTH (Optilux 401, Kerr, Orange, CA, USA); one SLED unit (Demi Ultra, Kerr) and one MLED unit (Valo Cordless, Ultradent, South Gordon, UT, USA). The active light guide tip diameter for the units explored were: 10.8-mm (QTH), 8-mm (SLED), and 9.7-mm (MLED). The irradiance and RE from each LCU were measured using a Managing Accurate Resin Curing-Resin Calibrator (MARC-RC) spectrometer system (BlueLight Analytics, Halifax, Canada). The measurements were detected by the MARC-RC top and bottom sensors representing the irradiance and RE values received on the top and bottom composite surfaces. Before specimen preparation, each LCU position was standardized by mounting the LCU on a mechanical arm and centering the light guide tip over the top sensor at 0-mm distance, in a similar manner to previous work12,14,15,21). The irradiance and RE were collected at 0-, 2- and 8-mm distances from the top sensor by activating each LCU using two curing protocols. A dual-photoinitiator nanohybrid RBC was selected that contained CQ and diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide (TPO) photoinitiators (Tetric EvoCeram, bleaching shade XL, Ivoclar Vivadent, Amherst, NY, USA, Lot# X14357). The first curing protocol was done by using the MCT for the at the three curing distances where 0-mm was considered the control. The second curing protocol was performed by adjusting the curing time to deliver a CRE (10 J/cm\(^2\)) as detected by the MARC-RC top sensor at the three curing distances. The 10 J/cm\(^2\) was selected based on the information provided by the RBC manufacturer. Figure 1 illustrates the study design.

**Sample preparation**

A total of 180 specimens were prepared (\( n=10/\text{LCU/distance/curing protocol} \)). A rectangular black custom Delrin mold was used (6-mm-length×2-mm-width×1-mm-depth\(^21\)). Uncured composite was packed in the mold and sandwiched between Mylar strips and glass slides to remove excess material. The mold with Mylar strips was placed in the bottom sensor well. The mold was designed to lock in the well to standardize the location of the specimen over the sensor\(^21\). The position of each light guide tip was centered over the bottom sensor, similar to the setup on the top sensor. Specimens were cured using the MCT or CRE at 0-, 2- and 8-mm distances from the top of each LCU. Specimens were finished on the top and bottom surfaces using 1200- to 4000-grit SiC abrasive papers and stored in deionized water for 24 h at 37°C.

**Mechanical testing**

Specimen dimensions were measured using a digital caliper. The \( \mu \)-FS test was performed using a mini three-point bending fixture and a 2-kN-load cell in a universal testing machine (MTS, Sintech ReNew 1123, MN, USA). Testing was performed at a crosshead speed of 1-mm/min and support span of 4-mm. \( \mu \)-FS in MPa was calculated according to the following equation:

\[
\sigma_{\mu} = \frac{3Fl}{2bh^2}
\]

where \( F \) was the maximum load exerted on the sample (newtons); \( l \) was the distance between the supports (mm); \( b \) was the width of the sample (mm); and \( h \) was the height of the sample (mm).

**Statistical analysis**

The effect of the curing protocol, curing distance, and LCU on the bottom irradiance, and radiant exposure, as well as on \( \mu \)-FS, were analyzed using a two-way analysis of variance (ANOVA) followed by a Tukey multiple comparison post hoc test. Significant interactions among the curing protocol, curing distance, and LCU type, were
explored using a three-way ANOVA followed by a Tukey multiple comparison post hoc test. Statistical analysis was performed using SigmaPlot (Version 12.0, San Jose, CA, USA) (α=0.05).

RESULTS

The curing time used for each curing protocol at all curing distances with the different LCUs was different (Table 1). The MCT was 20 s for LCUs with an irradiance value less than 1,000 mW/cm² and 10 s for those greater than 1,000 mW/cm². To deliver a CRE of 10 J/cm², the curing time ranged from 8–26 s for each of the different distances. The curing time needed to achieve CRE with the LED units was the same for the 0- and 2-mm-distances and relatively doubled or tripled for the 8-mm distance from the specimen top.

Table 1  Curing times (seconds) needed to polymerize composite specimens using two curing protocols as detected by the MARC-RC top sensor at different distances with different LCUs

| Distance (mm) | QTH       | SLED     | MLED     |
|--------------|-----------|----------|----------|
|              | MCT CRE   | MCT CRE  | MCT CRE  |
| 0            | 20 14     | 10 8     | 10 8     |
| 2            | 20 14     | 10 8     | 10 8     |
| 8            | 20 22     | 10 26    | 10 20    |

MARC-RC: Managing Accurate Resin Curing-Resin Calibrator; QTH: Quartz-tungsten-halogen; SLED: single-emission-peak light-emitting diode; MLED: multiple-emission-peak light-emitting diode; MCT: manufacturer curing time; CRE: consistent radiant exposure (10 J/cm²).

On the top surfaces, the irradiance and RE decreased as the distance increased, using the MCT (Tables 2 and 3). On the bottom, the irradiance and RE decreased in comparison with the top (Tables 4 and 5). Comparisons between the MCT and CRE presented interesting findings with respect to the bottom irradiance, RE, and µ-FS values. When using the MCT, the bottom irradiance values showed no significant differences for the different LCUs at different distances except at the 2-mm distance, which was significantly higher when using the SLED, and significantly lower when using the MLED unit. When comparing the bottom RE values, the MCT showed significantly higher values received at the 0-mm with all of the LCUs, at the 2-mm-distances with both the QTH and the SLED, and significantly lower RE values at the 8-mm-distance with all LCUs. The µ-FS value comparisons showed significantly higher values at
Table 4  Mean irradiance (mW/cm²) values (SD) received on the bottom MARC-RC sensor when curing specimens using two protocols with different LCUs at different distances

| Distance (mm) | QTH MCT | CRE | SLED MCT | CRE | MLED MCT | CRE |
|--------------|---------|-----|----------|-----|----------|-----|
| 0            | 55.9 (3.6)\(^a\)\(^A\) | 53.9 (3.4)\(^a\)\(^A\) | 97.5 (5.1)\(^a\)\(^A\) | 96.5 (5.4)\(^a\)\(^A\) | 70.2 (3.2)\(^a\)\(^A\) | 70.9 (4.0)\(^a\)\(^A\) |
| 2            | 52.5 (3.0)\(^b\)\(^B\) | 50.3 (2.4)\(^b\)\(^B\) | 99.7 (6.0)\(^a\)\(^A\) | 88.6 (2.8)\(^b\)\(^B\) | 61.5 (4.0)\(^b\)\(^B\) | 72.5 (3.5)\(^a\)\(^A\) |
| 8            | 33.2 (1.9)\(^c\)\(^C\) | 32.3 (1.7)\(^b\)\(^B\) | 30.9 (1.3)\(^b\)\(^B\) | 25.4 (6.4)\(^c\)\(^C\) | 27.9 (2.1)\(^c\)\(^C\) | 27.9 (1.4)\(^b\)\(^B\) |

Superscript lowercase letters represent significant differences between curing protocols for each LCU at each distance. Superscript uppercase letters represent significant differences among distances for each curing protocol (columns). MARC-RC: Managing Accurate Resin Curing-Resin Calibrator; QTH: Quartz-tungsten-halogen; SLED: single-emission-peak light-emitting diode; MLED: multiple-emission-peak light-emitting diode; MCT: manufacturer curing time; CRE: consistent radiant exposure (10 J/cm²).

Table 5  Mean radiant exposure (J/cm²) values (SD) received by the MARC-RC bottom sensor when curing specimens using two protocols with different LCUs at different distances

| Distance (mm) | QTH MCT | CRE | SLED MCT | CRE | MLED MCT | CRE |
|--------------|---------|-----|----------|-----|----------|-----|
| 0            | 1.11 (0.073)\(^a\)\(^A\) | 0.75 (0.051)\(^b\)\(^A\) | 0.99 (0.053)\(^a\)\(^A\) | 0.77 (0.042)\(^b\)\(^A\) | 0.71 (0.033)\(^a\)\(^A\) | 0.58 (0.034)\(^b\)\(^A\) |
| 2            | 1.04 (0.063)\(^b\)\(^B\) | 0.71 (0.034)\(^a\)\(^A\) | 1.02 (0.061)\(^b\)\(^B\) | 0.70 (0.027)\(^b\)\(^B\) | 0.62 (0.043)\(^b\)\(^B\) | 0.59 (0.035)\(^a\)\(^A\) |
| 8            | 0.65 (0.039)\(^c\)\(^C\) | 0.71 (0.037)\(^a\)\(^A\) | 0.31 (0.014)\(^b\)\(^B\) | 0.65 (0.163)\(^a\)\(^A\) | 0.28 (0.021)\(^c\)\(^C\) | 0.56 (0.028)\(^a\)\(^A\) |

Superscript lowercase letters represent significant differences between the curing protocols for each LCU at each distance. Superscript uppercase letters represent significant differences among distances for each curing protocol (columns). MARC-RC: Managing Accurate Resin Curing-Resin Calibrator; QTH: Quartz-tungsten-halogen; SLED: single-emission-peak light-emitting diode; MLED: multiple-emission-peak light-emitting diode; MCT: manufacturer curing time; CRE: consistent radiant exposure (10 J/cm²).

Table 6  Mean µ-flexural strength (MPa) values (SD) when curing specimens using two protocols with different LCUs at different distances

| Distance (mm) | QTH MCT | CRE | SLED MCT | CRE | MLED MCT | CRE |
|--------------|---------|-----|----------|-----|----------|-----|
| 0            | 516.6 (33.6)\(^a\)\(^A\) | 479.9 (42.7)\(^a\)\(^A\) | 442.3 (46.9)\(^a\)\(^A\) | 446.2 (50.5)\(^a\)\(^A\) | 512.3 (37.1)\(^a\)\(^A\) | 490.4 (56.3)\(^a\)\(^A\) |
| 2            | 505.8 (51.1)\(^a\)\(^A\) | 440.4 (53.5)\(^a\)\(^A\) | 433.3 (46.5)\(^a\)\(^A\) | 476.0 (33.3)\(^a\)\(^A\) | 496.3 (50.2)\(^b\)\(^B\) | 503.0 (32.1)\(^b\)\(^B\) |
| 8            | 447.5 (39.9)\(^a\)\(^A\) | 461.4 (32.6)\(^a\)\(^A\) | 422.1 (35.3)\(^a\)\(^A\) | 484.5 (54.9)\(^a\)\(^A\) | 453.8 (38.1)\(^b\)\(^B\) | 478.1 (38.3)\(^b\)\(^B\) |

Superscript lowercase letters represent significant differences between the curing protocols for each LCU at each distance. Superscript uppercase letters represent significant differences among distances for each curing protocol (columns). MARC-RC: Managing Accurate Resin Curing-Resin Calibrator; QTH: Quartz-tungsten-halogen; SLED: single-emission-peak light-emitting diode; MLED: multiple-emission-peak light-emitting diode; MCT: manufacturer curing time; CRE: consistent radiant exposure (10 J/cm²).

2-mm with the QTH, and significantly lower values at 2- and 8-mm with the SLED compared to using the CRE (Table 6). A significant interaction was found between the curing protocol and distance; where at 8-mm, the µ-FS values were significantly higher when using the CRE compared to the MCT protocol.

Comparisons among the different distances for each curing protocol with respect to the irradiance, RE and µ-FS values, showed notable results. In general, the bottom irradiance values significantly decreased with increased distance for each curing protocol and LCU. The bottom RE values significantly decreased when using the MCT. When using the MCT, the irradiance and RE values showed similar and significant differences in relation to the variant distances between the QTH and MLED. The irradiance and RE values with the SLED at 0- and 2-mm were significantly higher than 8-mm. When using the CRE, the irradiance values of the QTH and SLED were significantly different from each other at all distances. The irradiance values of the MLED
unit at 0- and 2-mm were significantly higher than from 8-mm. When using the CRE protocol, the RE values of the SLED at 0- and 8-mm were significantly higher than those at 2-mm. For the μ-FS test, our results showed that increasing the distance did not significantly impact the μ-FS regardless of the curing protocol, except when using the MCT with the MLED, which showed significantly higher values at 0- compared to 8-mm. A significant interaction was found between the curing protocol and the LCU; when using the MCT, the μ-FS values were significantly lower when using the SLED. When using the CRE, the μ-FS was significantly higher than when using the MLED unit.

**DISCUSSION**

Exploring the effect of curing with the MCT, compared to the CRE, regarding μ-FS when cured at different distances, and with different units, would aid in the understanding of composite clinical performance. Different sample dimensions have been reported when using the μ-FS test\(^{21,27,28}\). The specimen dimensions selected in our study were smaller than the active diameter of the light guide tip for the LCUs explored, to allow for one-shot curing\(^{21,27,29}\). The 2-mm and 8-mm curing distances selected in our study were to represent the best and worst clinical case scenarios, respectively, compared to the 0-mm typically performed in laboratory studies\(^{36}\).

Our results showed a 92–95% decrease in irradiance and RE from top to bottom regardless of the original values received at the top. This implied that the majority of the light was reflected, absorbed, or refracted, through the thin specimens. It is known that filler particles can hamper light transmission by scatter and refraction\(^{7,32,34,35}\). Our results were similar to previous work, that showed an 85–93% decrease in irradiance and RE from top to bottom for 2-mm thick specimens\(^{12,14}\). Price *et al.* reported 50% reduction in irradiance from 0- to 6-mm distances\(^{36}\).

Comparisons between using the MCT or the CRE showed interesting findings. The trend of the significant differences between the curing protocols on the bottom irradiance, RE and μ-FS values were not the same. Our findings showed significant and noteworthy differences in irradiance between using the MCT and the CRE. Therefore, the first working hypothesis was partially accepted. The non-significant differences in the bottom irradiance were expected because the irradiance is not dependent on the curing time [irradiance (mW/cm\(^2\))=power/surface area]. The significant differences observed in the bottom irradiance at 2-mm when using the SLED and MLED, suggest that light was not transmitted similarly through the specimens, although the percent of decrease in irradiance was similar among LCUs and the different distances. In addition, the significant differences in RE was not surprising due to the different curing times used for each curing protocol [RE (J/cm\(^2\))=irradiance (mW/cm\(^2\))×time (s)]. This was evident when using the CRE and resulted in significantly lower bottom RE values at 0- and 2-mm when less curing time was needed to achieve 10 J/cm\(^2\) compared to using the MCT. The opposite was true at 8-mm. Interestingly, the μ-FS values were in general, not significantly affected by the curing protocol regardless of the irradiance or RE values received with a few exceptions. Therefore, the second working hypothesis has also been partially accepted. The significantly higher μ-FS values presented when using the MCT with the QTH at 2-mm may be related to the curing time, although the same cannot be said at 0-mm. Our findings support that polymerization is a complex process where kinetics plays an important role.

An association was suggested between the material strength and other material properties, such as the degree of conversion and hardness\(^{37,38}\). Our study showed that the top irradiance at 8-mm for both curing protocols was greater than 400 mW/cm\(^2\). According to the ISO 10650-2 standard, this value is the minimum LCU irradiance suggested in order to obtain satisfactory polymerization\(^{39}\). On the bottom, irradiance values ranged from 25.4–99.7 mW/cm\(^2\) for both curing protocols, and the RE values ranged from 0.31–1.11 J/cm\(^2\). The 0.31 J/cm\(^2\) was received when using the MCT at 8-mm with the SLED and the MLED. This may explain the significantly lower μ-FS value when curing with the SLED unit. However, the same was not true when using the MLED. The significantly lower μ-FS values observed with the SLED, when using the MCT at 2- and 8-mm distances, compared to the CRE, may be due to the differences in the LCU wavelength spectral output. The SLED had no violet LED chip within the unit needed to produce the wavelengths required to effectively activate TPO. In addition, the non-uniform irradiance beam profiles of the LED units may have negatively impacted the number of free radicals generated. On the other hand, the non-significant differences in μ-FS when using the MLED unit suggested that enough free radicals were generated, although the MLED unit has a narrow wavelength spectral output and a non-uniform beam profile. This, because, MLED units include the violet chip that encompasses the wavelength needed to effectively activate TPO. Therefore, TPO activation generates free-radical growth centers, and forms a polymer network at a faster rate compared to CQ\(^{11,40}\). The SLED and MLED units explored in our study had LED chips in the LCU head, which maximizes irradiance values compared to the QTH. Our results were similar to previous work\(^{12}\).

Though significant differences were observed between both curing protocols at certain distances, the μ-FS values were not compromised meaning the differences may not hold clinical significance. Studies reported that 12–24 J/cm\(^2\) was needed to achieve sufficient polymerization\(^{15,42}\). In recent work, it was reported that adequate degree of conversion, microhardness, and cross-link density was exhibited, when a CRE (10–11 J/cm\(^2\)) was delivered to 2-mm thick specimens at two different distances using the same
composite used in our study and different units.\cite{12,14,15}

Our µ-FS results were comparable to previous work that investigated the impact of beam profiles on the degree of conversion and µ-FS of 1-mm thick specimens, when using MCT at 0-mm distance and the same RBC and LCUs as in our study.\cite{25} The results of the work demonstrated satisfactory degree of conversion values (49.7–65.8%) on top surfaces, and sufficient µ-FS values (313–458 MPa)\cite{25}. Previous work exploring the relationship between beam profile of different LCUs on the degree of conversion and cross-link density (%microhardness reduction within a RBC) at two different distances showed that 0.7–1.5 J/cm² received on the bottom of 2-mm-thick specimens yielded localized discrepancies, yet, showed sufficient degree of conversion (52.7–76.8%), Knoop microhardness (39.0–66.7 kgf/mm²), and %microhardness reduction (26.7–57.9%) at 2-mm distance\cite{14,10}. Moreover, the results showed satisfactory localized degree of conversion (50.4–78.6%), Knoop microhardness (40.3–73.7 kgf/mm²), and %microhardness reduction (28.2–56.8%) at 8-mm curing distance\cite{18}. More recently, an investigation of the relationship between distance and RE on the degree of conversion of a 2-mm thick specimen of the same composite used in our study showed no significant differences in degree of conversion values (63.21–70.28%) between 2- and 8-mm curing distances for the same LCUs explored in our study.\cite{18} A study reported that 10 s curing time resulted in a degree of conversion 47% and greater\cite{18}. In addition, lighter shades of composite demonstrated higher microhardness values, according to another study.\cite{18} Therefore, we can indirectly expect that our specimens exhibited satisfactory polymerization when using the MCT or CRE.

It is important to note that the studies discussed here used the same nanohybrid composite used in our study and the results may differ when using other composites, shades, and increment thicknesses. This particular type and shade of RBC was selected because it is a dual-photoinitiator composite that contains CQ and TPO, with a higher TPO concentration compared to CQ than the remaining shades of the same composite. Therefore, the impact of the LCU type may accentuate the potential differences in material strength due to differences in beam profiles and differences in the wavelength spectral output.

Comparisons among the curing distances for each LCU used for each curing protocol, showed interesting findings. As expected, the irradiance values significantly decreased with increasing the distance for both curing protocols. These findings are consistent with the literature.\cite{12,14,25,18} In addition, the RE significantly decreased when using the MCT at increasing distances, regardless of the LCU, except with the SLED at 0- and 8-mm. Interestingly, the µ-FS values were not significantly impacted with increasing the distance for each LCU used for each curing protocol, except when curing with the MLED while using the MCT at 8-mm. Our findings showed that the distance did not negatively affect the µ-FS regardless of the irradiance and RE it received. As mentioned, this suggests that the thin specimens may have allowed enough light transmission, free radical generation, and RE to reach the bottom, resulting in sufficient strength. Our results were similar to other work that showed curing at 2- or 8-mm using the MCT did not affect the µ-FS.\cite{25} In addition, our results agreed to some extent with another study which reported a significant difference in µ-FS between 2- and 8-mm but not 0-mm of a 2-mm thick nanohybrid composite when cured with a SLED unit.\cite{27}

Specimen dimension differences may explain the variances in the results. Our findings are clinically relevant because, clinicians may use the MCT to light cure the dual-photoinitiator nanohybrid composite investigated, with the LCUs explored, at a 2- or 8-mm distance, without significantly impacting the µ-FS. Further studies are needed to investigate the impact of using the MCT, compared to applying CRE, on different properties at different distances using a variety of LCUs, composites, and shades.

CONCLUSIONS

The following can be concluded when using the nanohybrid composite and LCUs investigated: 1) the RE values on the bottom surfaces were significantly lower when using the MCT as the distance increased with the different LCUs. 2) When using the MCT instead of the CRE, the µ-FS was significantly reduced when curing at 2-mm with the QTH, but significantly increased at 2- and 8-mm with the SLED. However, the µ-FS was not impacted when using either the MCT or the CRE to light cure thin increments at 2- or 8-mm with the different LCUs.

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