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Influence of Light-curing Distances on Microflexural Strength of Two Resin-based Composites

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Clinical Relevance

Clinicians may light cure thin layers of the resin-based composites explored at 2-mm and 8-mm distances without significantly affecting the microflexural strength.

SUMMARY

Objective: Our objective was to investigate the influence of different curing distances on microflexural strength and the microflexural modulus of two resin-based composites.

Methods: Two nanohybrid composites were used; Filtek Z250 (Z250) and Tetric EvoCeram (TEC). Rectangular specimens were prepared (2-mm wide × 1-mm deep × 6-mm long) light cured according to the manufacturer's instructions at 0-mm, 2-mm, and 8-mm distances (n=10) and were stored wet at 37°C for 24 hours. A microflexural strength test was performed using a universal testing machine at a crosshead speed of 1 mm/min. The microflexural strength and microflexural modulus data were analyzed using a two-way analysis of variance followed by a Tukey multiple comparison post hoc test (α=0.05).

Results: The TEC composite had a significantly higher microflexural strength at an 8-mm distance compared with the 0-mm distance. The Z250 composite expressed significantly higher microflexural strength, at 2-mm and 8-mm compared with the 0-mm distance. TEC showed a significantly higher microflexural modulus at an 8-mm distance compared with the 0-mm and 2-mm distances. Z250 also exhibited a significantly higher microflexural modulus at the 2-mm distance, compared with the 8-mm distance. In total, Z250 presented a significantly higher microflexural strength and modulus compared with TEC.

Conclusion: Curing the explored composites at 2-mm or 8-mm distances from the specimen surface did not have a significant influence on microflexural strength but did significantly affect the microflexural modulus.

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INTRODUCTION

Light activated resin-based composite (RBC) is considered to be the material of choice as a direct restorative material due to its high esthetic demand.[1] Various external and internal factors affect polymerization effectiveness, which may affect the longevity of the final restoration.[2] External factors are related to the operator's technique and light-curing unit (LCU) characteristics, including the distance between the light-guide tip and the restoration surface.[2-4] Internal factors that affect polymerization effectiveness are related to the composite properties and composition, including the monomer, photoinitiator system, and concentration levels, filler type and size, as well as the shade and pigments.[2] Investigating the influence of curing distances and different resin composites associated with single and dual photoinitiator systems on the restoration's strength may contribute to understanding the material's performance and longevity from a clinical perspective.

A light-activated composite restoration must receive the required energy at the correct wavelength to effectively activate the photoinitiators for sufficient polymerization and for the material to perform functionally as intended by the manufacturer.[4,5] The manufacturer's curing time is typically based on laboratory studies when curing was performed at a 0-mm distance from the restoration.[4] Testing at 0-mm is not usually attainable clinically, as the distance between the guide tip and the gingival floor of a deep proximal box in a Class II cavity may reach up to 8-mm in distance.[4] Therefore, testing at a 0-mm distance is not clinically relevant.[6] Increasing the curing distance may result in a restoration receiving less than required irradiance and radiant exposure.[2,3] This may result in an insufficient composite polymerization, which could cause leaching of the unreacted monomer into the oral environment, thus negatively affecting the integrity of the final restoration and its overall properties.[2,3]

Composites contain different resin monomers, fillers, and photoinitiator systems. Camphorquinone (CQ) is the most commonly used photoinitiator and has an absorbance wavelength that peaks near 470 nm.[7] CQ is yellowish in color, which may affect esthetics; therefore, alternative photoinitiators have been developed, such as diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide (TPO), which is typically found in bleaching shades and has an absorbance wavelength that peaks near 380 nm.[7]

Composite restorations are subjected clinically to different stresses, such as flexure, tension, compression, and shear.[8] A flexural strength test is typically used to evaluate material behavior because it simulates complex forces generated at stress concentration areas.[9,10] This test produces compressive and tension stresses at the area of loading in opposite directions.[10] Microflexural strength tests (microflexural strength, σ_μ) are performed on specimens using smaller dimensions than those described in the International Organization for Standardization (ISO) 4049 specifications, which better simulate the clinical setting. Specimen dimensions for the σ_μ test are smaller than the active diameter of the light-guide tip, which allows a single shot curing.[9,11]

Most studies have investigated flexural strength at a 0-mm distance and have used the manufacturer's recommended curing time.[9,12,13] A study reported that specimen dimension and curing distance significantly affected flexural strength values, however, the specimen dimensions in the mentioned study were larger than the guide tip and required multiple shots for curing.[14] It was reported that flexural strength values varied among composites that had different filler content.[8,13,15] On the other hand, a study found no significant differences in flexural strength and modulus for some composites.[12] Therefore, exploring the influence of multiple curing distances on a composite's microflexural strength and modulus was worth investigating.

The aim of the study was to investigate the influence of curing distances on microflexural strength and microflexural modulus of two nanohybrid resin composites. The working hypothesis was that increasing the curing distance would significantly decrease the microflexural strength and microflexural modulus compared with a 0-mm distance.

METHODS AND MATERIALS

Two nanohybrid RBCs were investigated: Tetric EvoCeram (TEC) (Ivoclar Vivadent, Amherst, NY, USA) and Filtek Z250 (Z250) (3M ESPE Dental Products, St Paul, MN, USA). Both composites explored were shade A2, and their compositions are presented in Table 1.

Sample Preparation

A total of 60 rectangular specimens were prepared using a custom-made mold (6-mm long × 2-mm wide × 1-mm deep). Composite material was sandwiched between Mylar strips and glass slides to remove excess material. Samples were light cured, according to the manufacturer's instruction for each composite: Z250 (20 seconds) and TEC (10 seconds) by a multiple-emission peak light-emitting diode (LED)

Table 1: *Manufacturers' Composition of the Resin Composites*

Resin-based Composite	Organic Monomers	Photoinitiator System	Filler Type	Filler (%)	Manufacturer	Lot No.
Tetric EvoCeram (TEC)	UDMA Bis-GMA Bis-EMA	CQ and TPO	Barium glass Ytterbium trifluoride Mixed oxides Prepolymer Inorganic filler particle size (40-3,000 nm) Mean particle size (550 nm)	75-76 (wt), 53-55 (vol)	Ivoclar Vivadent, Amherst, NY, USA	W98455
Feltik Z250 (Z250)	UDMA Bis-GMA Bis-EMA	CQ	Zirconia/silica Particle size (0.01-3.5 μm)	82 (wt), 60 (vol)	3M ESPE Dental Products, St Paul, MN, USA	N915750

Abbreviations: Bis-EMA, ethoxylated bisphenol A dimethacrylate; Bis-GMA, bisphenol A dimethacrylate, CQ, camphorquinone; TPO, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide; UDMA, urethane dimethacrylate; vol, volume; wt, weight.

curing unit (Bluephase N, Ivoclar Vivadent) at three different curing distances (0-mm, 2-mm, and 8-mm) from the top surface of the sample (n=10). The light guide tip optical diameter was 9-mm, and the LCU included a violet and blue spectral range (360-540 nm). The LCU irradiance and radiant exposure were measured for both curing times at the three distances using a laboratory-based spectrometer (Managing Accurate Resin Calibrator-Light Corrector, BlueLight Analytics, Halifax, Canada). The LCU position was standardized and centered over the uncured sample using a mechanical arm. After sample preparation, all the samples were finished using 800-grit to 2500-grit SiC abrasive papers. Samples were then stored in deionized water for 24 hours at 37°C.

Mechanical Testing

Specimen dimensions were measured using a digital caliper. After 24 hours of specimen fabrication and storage, the σ_μ test was performed using a universal testing machine (Instron model 5944, Norwood, MA, USA). The load cell was 2.5 kilonewtons. A mini three-point bending fixture (Instron, RO.25 6543) at a crosshead speed of 1 mm/min, and a 4-mm support span (Instron, CAT no. S4843A) was used. The σ_μ in MPa was calculated according to the following equation:

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

F is the maximum load exerted on the sample in newtons; l is the distance between the supports in millimeters; b is the width of the sample in millimeters; and h is the height of the sample in millimeters.

The microflexural modulus (E_μ) in GPa was calculated according to the following equation:

$$E_\mu = \frac{Fl^3}{4bh^3d}$$

F was the maximum load exerted on the sample in newtons; l is the distance between the supports in millimeters; b is the width of the sample in millimeters; h is the height of the sample in millimeters; and d is the deflection in millimeters.

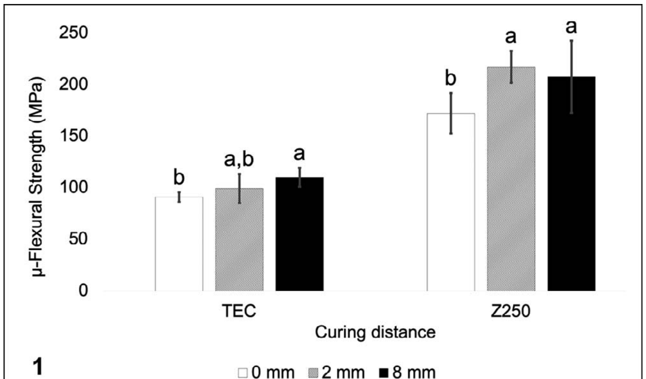
Statistical Analysis

The effect of the curing distance and composite on σ_μ and E_μ was determined using a two-way analysis of variance followed by a Tukey multiple comparison test (α=0.05). Log transformation was performed for the σ_μ data. Statistical analysis was performed using SigmaPlot (Version 12.0, San Jose, CA, USA).

RESULTS

The LCU irradiance values measured for the 9-mm optical diameter were 1342.7±3.21, 1324.0±4.36, and 1226.7±1.53 mW/cm^2 at 0-mm, 2-mm, and 8-mm distances, respectively. The radiant exposure values measured at 10 seconds were 13.6±0.12, 13.4±0.02, and 12.3±0.01 J/cm^2 for 0-mm, 2-mm, and 8-mm distances, respectively. Moreover, the radiant exposure values measured at 20 seconds were 27.0 ± 0.06, 26.7 ± 0.10, and 24.7 ± 0.04 J/cm^2 for 0-mm, 2-mm, and 8-mm distances, respectively.

The σ_μ and E_μ mean and standard deviation values of the two composite materials examined at three different curing distances are presented in Figures 1 through 4. The highest mean σ_μ value was demonstrated by Z250 at a 2-mm curing distance (217.1±15.5 MPa) followed by the same material at



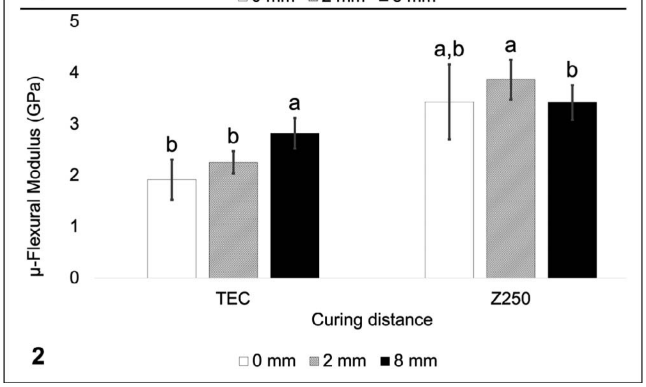
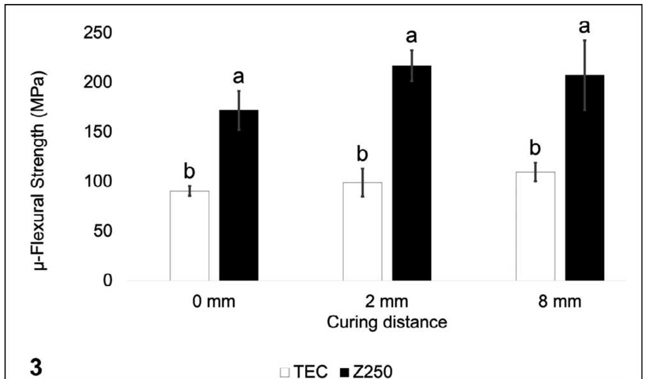


Figure 1. *Microflexural strength (MPa) means (SD) and significant differences among the curing distances for Z250 and TEC composites. Different letters represent significant differences among distances for each composite.*

Figure 2. *Microflexural modulus (GPa) means (SD) and significant differences among the curing distances for Z250 and TEC composites. Different letters represent significant differences among distances for each composite.*



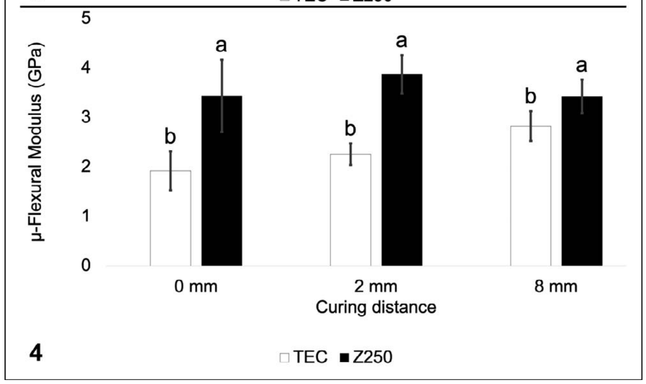


Figure 3. *Microflexural strength (MPa) means (SD) and significant differences between Z250 and TEC composites at each curing distance. Different letters represent significant differences between composites at each distance.*

Figure 4. *Microflexural modulus (GPa) means (SD) and significant differences between Z250 and TEC composites at each curing distance. Different letters represent significant differences between composites at each distance.*

an 8-mm distance (207.4±34.9 MPa) and at a 0-mm distance (172±19.6 MPa). The lowest mean σ_μ value was presented by TEC at a 0-mm curing distance (90.8±4.8 MPa), followed by a 2-mm distance (99.2±14.1 MPa) and an 8-mm distance (109.9±9.3 MPa). A similar trend followed for the E_μ values. The highest modulus value was for Z250 at the 2-mm curing distance (3.9±0.4 GPa) followed by 0-mm and 8-mm distances (3.4±0.7 and 3.4±0.3 GPa, respectively). The lowest E_μ was for TEC at a 0-mm curing distance (1.9±0.4 GPa) followed by 2-mm (2.3±0.2 GPa) and 8-mm (2.8±0.3 GPa) distances.

Significant differences were found between the σ_μ values among the curing distances for both materials ($p<0.05$). In general, the curing distance had a significant influence on σ_μ, where 2-mm and 8-mm distances showed significantly higher σ_μ compared with a 0-mm distance. The significant difference trend among curing distances was not the same for each composite. For TEC, comparisons among the curing distances showed significantly higher σ_μ values at an 8-mm compared with a 0-mm distance. For Z250, significantly higher σ_μ values were shown at 2-mm and 8-mm distances compared with a 0-mm distance (Figure 1).

Significant differences between the E_μ values among the curing distances for both materials were examined ($p<0.05$). In general, curing distance had a significant influence on E_μ, where the 8-mm distance showed a significantly higher E_μ compared with the 0-mm distance. The significant difference trend among curing distances for each material was not the same. In addition, the significant trend was not the same as for the σ_μ values. TEC showed significantly higher E_μ at the 8-mm distance compared with the 2-mm and 0-mm distances. Z250 showed significantly higher E_μ at the 2-mm distance compared with the 8-mm distance (Figure 2).

The E_μ significant comparisons between the composites at each curing distance were performed ($p<0.05$). Z250 had significantly higher σ_μ (Figure 3)

Table 2: *Microflexural Strength (MPa) and Microflexural Modulus (GPa) Means (Standard Deviations) for the Resin Composites Cured at Different Distances*[a]

Curing Distance (mm)	Microflexural Strength (MPa)		Microflexural Modulus (GPa)	
	TEC	Z250	TEC	Z250
0	90.8 (4.8)^{z,Z}	172.0 (19.6)^{z,Y}	1.9 (0.4)^{z,Z}	3.4 (0.7)^{y,z,Y}
2	99.2 (14.1)^{y,z,Z}	217.1 (15.5)^{y,Y}	2.3 (0.2)^{z,Z}	3.9 (0.4)^{y,Y}
8	109.9 (9.3)^{y,Z}	207.4 (34.9)^{y,Y}	2.8 (0.3)^{y,Z}	3.4 (0.3)^{y,Z}

Abbreviations: TEC, Tetric EvoCeram; Z250, Feltik Z250.
[a] *Different superscript lowercase letters represent significant differences among the curing distances for each composite and property (each column). Different superscript uppercase letters represent significant differences between Z250 and TEC composites at each distance for each property (row of each property).*

and E_μ values (Figure 4) compared with TEC. The σ_μ, E_μ values and significant differences among the curing distances for each composite and property, as well as the significant differences between the composites at each distance for each property are presented in Table 2.

DISCUSSION

One of the factors that affects the longevity of a composite restoration is its ability to withstand complex clinical stresses.[16] Exploring the effect of different light curing distances (0-, 2-, and 8-mm) on σ_μ and E_μ would provide beneficial information regarding material clinical performance. The 2-mm and 8-mm curing distances were selected to represent the best and worst clinical case scenarios, respectively.[4] Investigating the effect of curing composites at different distances would aid in the understanding of material clinical performance.

Characterizing polymerization effectiveness using the σ_μ test can better simulate the clinical setting compared with the ISO 4049 flexural strength test.[8,17,18] The flexural strength test according to ISO 4049 for polymer-based restorative materials uses a rectangular specimen with a dimensions of 2 × 2 × 25 mm.[19] These dimensions are not clinically relevant because they do not represent the tooth's dimensions.[8,18] Also, the active light guide tip of the different LCUs ranges from 7 to12 mm in diameter, which results in the flexural strength specimens being light cured in multiple irradiation cycles.[8,17] This results in certain areas on the specimens, receiving a higher radiant exposure, which can affect specimen polymerization uniformity.[8,17,20] Therefore, the reliability of the flexural strength test data may be affected.[14,20] The literature has reported that different sample dimensions have been used for the σ_μ test.[9,14,21] In our study, the specimen dimensions selected were smaller than the active diameter of the light guide tip in order to ensure a single-shot curing.[9,11,14] Smaller specimens result in higher flexural strength values and represent the combined effect of compressive, tension and shear deformation stresses.[8]

Generally, comparisons among the curing distances showed a significantly higher σ_μ at 2-mm and 8-mm compared with 0-mm and a significantly higher E_μ at 8-mm compared with 0-mm. The trend was similar between σ_μ and E_μ for each composite and differed to some extent in the significant differences among distances for each composite (Figures 1 and 2). TEC showed significantly higher σ_μ at the 8-mm distance compared with the 0-mm distance, and Z250 showed a significantly higher strength at 2-mm and 8-mm distances compared with 0-mm. The modulus for TEC significantly increased at the 8-mm distance compared with the 0-mm and 2-mm distances, which suggested that the TEC specimens were stronger and stiffer as the distance increased. On the other hand, the modulus for Z250 significantly decreased at the 8-mm distance compared with the 2-mm distance, which may denote that the Z250 specimens were strong but more flexible as the distance increased. Therefore, the working hypothesis was partially accepted. On the top surface of a restoration, light is reflected, scattered, and absorbed by the RBC components and structures surrounding the restoration, such as the Mylar strip, matrix band, and tooth structure.[22-24] The close proximity of the tip at the 0-mm distance to the Mylar strip may have affected the strength values because the light emitted from the curing unit could have reflected or scattered off the Mylar strip surface to a greater extent at a closer distance. As the distance between the guide tip and specimen increases, the light beam spreads over a larger surface area.[4,25] The increased distance may have allowed for less scattering and reflection off the Mylar strip surface permitting better light penetration through the specimens. Our results agreed to some extent with other work where no significant differences were observed when a clear Mylar strip was placed over a 2-mm specimen and cured at 0-mm or 2-mm distances.[26]

In our study, the differences between 2-mm and 8-mm distances were not significant regardless of the composite used. This might indicate that the 1-mm-thick specimens may have allowed light to reach the bottom of the specimen resulting in sufficient strength, which could also indirectly indicate satisfactory polymerization. This is supported with other work where 1-mm-thick microflexural strength specimens exhibited a satisfactory degree of conversion values on the top and bottom surfaces.[9] Other studies reported that hardness decreased on the bottom surfaces of increments more than 1-mm thick.[27,28] In our study, specimens were 1-mm thick, so we would expect specimens to exhibit sufficient hardness and degree of conversion. The nonsignificant differences between 2-mm and 8-mm distances, regardless of the composite, may also suggest that the amount of photoinitiator activated was sufficient to effectively generate enough free radicals that resulted in satisfactory composite strength. Our results were supported with a study that light cured 2-mm-thick specimens at 0-mm, 2-mm, 4-mm, and 8-mm distances and reported no significant change between 2-mm and 8-mm distances. However, there were some differences between 0-mm and 8-mm distances with which we agree.[14] The differences in the specimen dimensions in our study and the aforementioned study may have contributed to the differences in the results.

An association was suggested between material strength and other properties, such as hardness and degree of conversion.[29-31] Another study reported that the σ_μ and the degree of conversion was not compromised at a 0-mm distance.[9] It was also reported that the degree of conversion is not necessarily correlated to material strength.[32] A study stated that the increased distance resulted in a decreased degree of conversion.[33] In our study, specimens at increments of 1-mm thick were light cured using irradiance values that ranged from 1226.7-1342.7 mW/cm^2 at the different distances. These values were greater than 400 mW/cm^2, which is the minimum irradiance suggested to achieve sufficient polymerization according to the ISO 10650-2 specifications.[34] In addition, the mold used in our study was a light gray in color, which may have facilitated light transmission. It was previously reported that molds fabricated from lighter-colored material facilitated light transmission more than dark metal molds.[35] Our specimens were cured according to the manufacturer's instructions, which were different for unique to each composite. The radiant exposure values at 20 seconds ranged from 24.7 to 27.0 J/cm^2 and at 10 seconds ranged from 12.3 to 13.6 J/cm^2 at the different distances. Since the curing time affects the amount of radiant exposure received by the restoration, this may have contributed to the significantly higher σ_μ and E_μ values shown for Z250 compared with TEC. The literature has reported that a 2-mm-thick increment needs 12-24 J/cm^2 radiant exposure to achieve effective polymerization.[36,37] Recent work reported that 10-11 J/cm^2 resulted in a satisfactory degree of conversion for 2-mm-thick increments.[38] The aforementioned factors can indicate that the specimens received sufficient irradiance and radiant exposure to adequately polymerize the RBC. Nevertheless, further investigation about the influence of curing distance on other properties is needed.

Comparisons among composites showed that σ_μ and E_μ values were significantly higher for Z250 compared with TEC regardless of the curing distance. This may be explained by composite properties and how they are affected by various factors, including the polymer matrix, filler content, coupling agents, and light transmission through the composite.[2,32] It was reported that flexural strength and modulus values were influenced by monomer composition and the nature of the polymer matrix.[32] In this study, as shown in Table 1, Z250 and TEC had similar monomer combinations. In addition, both composites had similar filler particle size and some variations in the filler loading weight and volume percentage, filler type, and additives. Therefore, the differences observed in our results could be related to the photoinitiator system type and filler content. The higher filler loading, pigments, and additives can lead to scattering and attenuation of the light and decrease in light transmission.[2,39] In addition, filler particles can hinder light transmission by scattering, or refraction at the resin-filler interface, due to the refractive index mismatch.[2,40-42] Photoinitiators and pigments may absorb light, resulting in a lower depth of cure in darker shades.[43-45] In our study, one shade was investigated.

Photoinitiator concentration is a key factor that affects polymerization efficiency.[2,46] Composites in this study had different photoinitiator systems; therefore, specimens were light cured using a multiple emission peak LED unit that included the blue and violet LED chips needed to activate most photoinitiators. Interestingly, Z250, which contained only CQ, showed significantly higher strength and modulus values compared with TEC, which contained CQ and TPO photoinitiator systems. The differences in photoinitiator systems type and concentration may partially explain the significant differences between both composites. CQ is activated upon exposure to longer blue light wavelengths.[47-49] TPO is highly reactive with high molar absorptivity and is activated upon exposure to shorter violet light wavelengths.[47-49] When TPO is activated, free-radical growth centers are generated and form a polymer network at a faster rate compared with CQ.[47,50,51] However, due to the high reactivity of TPO, more entrapment of free radicals within the polymer network may occur, compared with CQ, thereby affecting the quality of polymerization.[2] This may partially explain the significant differences in strength and modulus values between composites. The results in our study suggest that polymerization kinetics has an important role in specimen strength. A strong correlation was shown between autoacceleration of the polymerization and entrapment of free radicals.[52] This suggested that a larger number of free radicals might have been entrapped in the TEC composite, resulting in a significantly lower strength and modulus value regardless of the distance.

Various fillers are incorporated in TEC (Table 1). Barium glass and ytterbium trifluoride are radiopaque agents.[53,54] It was reported that ytterbium trifluoride decreased flexural strength at higher concentrations.[53] Since the ytterbium trifluoride concentration was not disclosed by the manufacturer, this could have partially contributed to the lower strength and modulus for TEC in our study. The presence of prepolymer in TEC may have contributed to the significantly lower flexural strength and modulus compared with Z250. Our findings were supported by findings of other studies.[55,56] Additionally, the presence of zirconia and silica particles can improve the material mechanical properties.[57,58] This may partially explain the significantly increased flexural strength and modulus values for Z250 compared with TEC. The mentioned factors and the possible undisclosed components of the composites, including monomer ratios and weight percentages, may also contribute to the explanation of the significantly higher σ_{μ} and E_{μ} values for Z250 compared with TEC regardless of the distance. It is important to note that the results may differ to a certain extent using different composites and shades, thicker specimens, or curing with different LCU types. Further investigation is needed to explore the influence of curing distance on different composite properties using different LCUs.

CONCLUSION

Light curing of the RBCs explored, at 2-mm or 8-mm distances between the light guide tip and the composite surface, did not significantly affect microflexural strength values for the composites investigated but did significantly affect microflexural modulus values.

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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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