

Influence of light-curing units on the flexural strength and flexural modulus of different resin composites

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Abstract

Aim: This study aimed to evaluate the flexural strength and flexural modulus of different resin composites (MasterFill, Opallis, Z250, Supreme) after photoactivation with quartz-tungsten-halogen (QTH - XL2500) or light-emitting diode (LED - Radium and Ultrablue Is) light-curing units (LCUs). **Methods:** The irradiance and spectral emission of each unit were evaluated using a power meter and a spectrometer. Flexural strength (MPa) was determined in a three-point bending test in accordance with the ISO4049 standard specifications. Flexural modulus (GPa) was measured from the linear-elastic range on the stress-deformation profile. Data were submitted to two-way ANOVA and Tukey's test ($p < 0.05$). **Results:** Different values for irradiance (850, 780 and 590 mW/cm²) and peak of emission (484, 456, 467 nm) were detected for XL2500, Radium and Ultrablue Is, respectively. Flexural strength and modulus were dependent on both material and LCU. Among the resins, Z250 and Supreme showed significantly higher strength and modulus than MasterFill and Opallis. Comparing the LCUs, Ultrablue Is showed significantly lower flexural strength and modulus than the others. **Conclusion:** Flexural strength and modulus were dependent on the irradiance and the spectral emission of the curing units, as well on the resin composite tested.

Key words

Composite resin, light, physical properties, polymers, photoactivation.

Introduction

The ultimate goal of dental restorative materials is to replace the biological and functional properties of healthy tooth structures, with physical and esthetic properties matching those of natural teeth. Since their introduction about 40 years ago, restorative resin composites have proven to be successful¹, and it is expected that their use for restoring both anterior and posterior teeth will continue to increase. Although considerable improvements have been made in the properties of these materials over the last decade², Brazilian formulations are increasingly available, but little is known about their performance. For this reason, studies evaluating their properties are warranted.

Likewise composites, several light-curing units (LCUs) are available, each one having specific characteristics of light emission, such as irradiance level and spectral emission

range and peak. Although quartz-tungsten-halogen (QTH) LCUs are the most traditional ones, blue light-emitting diodes (LEDs) are increasingly popular among clinicians. These LCUs emit a narrow spectrum of wavelengths that is better correlated with the spectral absorbance of camphorquinone (CQ), the most commonly used photoinitiator in dental composites³.

In comparison to LEDs, QTH LCUs also present some drawbacks that may interfere with their long-term exposure efficiency, such as high heat generation within the quartz bulb, degradation of filters over the course of time, and relatively overall short efficient working life span⁴⁻⁵. However, although some studies describe similar curing efficiency for QTH and LED units, the actual efficiency of LEDs still needs further evaluation. Therefore, the aims of this study were to evaluate the light characteristics (irradiance level and spectral emission) of LED and QTH LCUs, and to investigate their influence on flexural strength and flexural modulus of different resin composites. The tested null-hypothesis was that no significant differences in strength and modulus would be observed regardless of the LCU or resin composite.

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Table 1 - Materials used in the study

Material	Manufacturer	Composition*
Filtek Z250	3M ESPE	BisGMA, BisEMA, UDMA, TEGDMA, zirconia/silica (75 wt%)
Filtek Supreme	3M ESPE	BisGMA, BisEMA, UDMA, TEGDMA, zirconia/silica (78.5 wt%)
Opallis	FGM	BisGMA, BisEMA, TEGDMA, Ba-Al-Si glass particles/silica (79 wt%)
MasterFill	Biodinâmica	BisGMA, UDMA, Ba-Al-Si glass particles (79 wt%)

*As informed by the manufacturers

Material and Methods

Four commercial hybrid resin composites, shade A3, were evaluated: MasterFill (Biodinâmica, Ibiporã, PR, Brazil), Opallis (FGM, Joinville, SC, Brazil), Filtek Z250 and Filtek Supreme (3M ESPE, St. Paul, MN, USA). Materials' compositions are shown in Table 1.

Light characteristics

Three LCUs were investigated: XL2500 QTH (XL - 3M ESPE), UltraBlue Is LED (UB - DMC, São Carlos, SP, Brazil) and Radian LED (RD - SDI, Victoria, Australia). The LCUs were connected to a voltage stabilizer and the output power (mW) of each unit was measured with a digital power meter (Ophir Optronics Inc., Danvers, MA, USA). The diameter of each light guide tip (cm) was measured with a digital caliper (Mitutoyo, Tokyo, Japan) accurate to 0.01 mm. Irradiance (mW/cm²) was computed as the ratio of the output power by the area of the light guide. Additionally, the spectral distribution of each LCU was obtained using a computer-controlled spectrometer (USB2000; Ocean Optics, Dunedin, FL, USA).

Flexural strength

Flexural strength test was conducted in accordance with the ISO4049 standard specifications⁶. Five rectangular bar-shaped specimens (25 x 2 x 2 mm) were prepared for each material-unit combination by placing the composites into a stainless steel mold held between two glass microscopic slides. After light-activation procedures, the specimens were removed from the mold and stored in distilled water at 37°C in the dark. After 24 h, the height and width of the specimens were measured with a digital caliper (Mitutoyo) and the samples were subjected to a three-point bending test in a mechanical testing machine (DL500; EMIC, São José dos Pinhais, PR, Brazil), at a crosshead speed of 0.5 mm/min until failure. Flexural strength (FS) was determined as follows:

$$FS = 3P_f L / 2WH$$

where P_f is the measured maximum load (N) at the time of specimen fracture, L is the distance between the supports on the tension surface (20 mm), W is the mean specimen width, and H is the mean height of the specimen between the tension and compression surfaces. Data were submitted to two-way ANOVA and Tukey's test ($p < 0.05$).

Flexural modulus

A chart plotter recorded the stress-deformation profile during the flexural test. Flexural modulus (FM) was calculated from the linear-elastic range, between bending force and specimen displacement before fracture, as follows:

$$FM = (DF / Dy) \times (L^3 / 4WH^3)$$

where DF / Dy is the change in force (DF) per unit change in deflection of the center of the specimen (Dy). Data were submitted to two-way ANOVA and Tukey's test ($p < 0.05$).

Results

Light characteristics

Table 2 presents the light characteristics for each LCU. Figure 1 shows a comparison for the spectrum of wavelengths. For XL, a spectrum concentrated in the 400-

Table 2 - Characteristics of the light-curing units

Unit	Manufacturer	Irradiance*	Peak of emission**
XL2500 QTH	3M ESPE	850 mW/cm ²	484 nm
Radian LED	SDI	780 mW/cm ²	467 nm
Ultrablue Is LED	DMC	590 mW/cm ²	456 nm

*Values confirmed with a digital power meter. **Data obtained with a computer-controlled spectrometer.

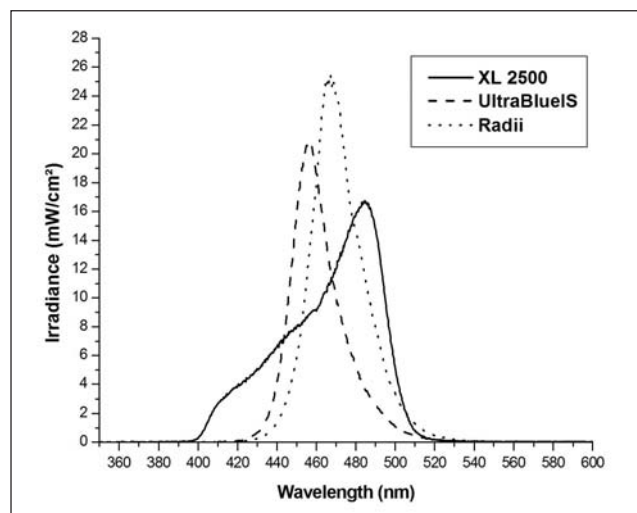


Fig. 1 - Spectral distribution of each light-curing unit

520 nm wavelength range was observed. For RD and UB, the spectrum was concentrated in the 430-530 and 420-520 nm range, respectively.

Flexural strength

Results for flexural strength are shown in Table 3. The factor 'LCU' was not significant ($p=0.179$), while the factor 'material' ($p<0.001$) and the interaction unit-material ($p=0.018$) were significant. For XL, Opallis showed significantly lower flexural strength than the other composites ($p<0.001$), which were similar to each other ($pe^{**}0.947$). Correspondingly, for RD, Z250 and Supreme were similar between them ($p=0.554$), while MasterFill was similar only to Supreme ($p=0.119$); Opallis showed significantly lower strength than Z250 and Supreme ($pd^{**}0.004$), but similar to MasterFill ($p=0.565$). On the other hand, for UB, all composites presented similar results ($pe^{**}0.349$). When comparing the different LCUs for each material, no significant differences were observed for MasterFill ($pe^{**}0.269$) and Opallis ($pe^{**}0.091$). For Z250 and Supreme, RD showed the highest flexural strength values, which were similar to XL ($pe^{**}0.31$), but significantly higher than UB ($pd^{**}0.041$); XL and UB presented similar results ($pe^{**}0.176$).

Table 3 - Means (standard deviations) for flexural strength (MPa)

	MasterFill	Opallis	Z250	Supreme
XL2500	124.2 (14.9) ^{A,a}	74.4 (14.1) ^{B,a}	130.4 (30.9) ^{A,ab}	124.4 (16.8) ^{A,ab}
Radii	106.4 (13.3) ^{BC,a}	91.6 (14.5) ^{C,a}	147.2 (3.7) ^{A,a}	132.2 (9.8) ^{AB,a}
UltraBlue IS	114.2 (7.4) ^{A,a}	98.8 (21.8) ^{A,a}	117.8 (29.0) ^{A,b}	103.8 (18.4) ^{A,b}

Means followed by different uppercase letters in the same row and lowercase letters in the same column, are significantly different at $p<0.05$.

Flexural modulus

Results for flexural modulus are shown in Table 4. The factors 'material' and 'LCU' were significant ($p<0.001$), but not their interaction ($p=0.165$). For XL and UB, Z250 and Supreme showed significantly higher values than both MasterFill and Opallis ($pd^{**}0.012$), which performed similar ($pe^{**}0.147$). For RD, Z250 and Supreme presented similar results ($p=0.072$), and both presented significantly higher

Table 4 - Means (standard deviations) for flexural modulus (GPa).

	MasterFill	Opallis	Z250	Supreme
XL2500	9.0 (0.4) ^{C,a}	8.1 (0.3) ^{C,a}	12.2 (0.8) ^{A,a}	10.7 (0.7) ^{B,a}
Radii	8.2 (0.6) ^{B,ab}	8.7 (0.4) ^{B,a}	11.8 (0.7) ^{A,ab}	10.8 (0.3) ^{A,a}
UltraBlue IS	7.6 (1.1) ^{C,b}	7.9 (0.6) ^{C,a}	11.2 (0.9) ^{A,b}	9.3 (0.8) ^{B,b}

Means followed by different uppercase letters in the same row and lowercase letters in the same column, are significantly different at $p<0.05$.

modulus than MasterFill and Opallis ($p<0.001$), which were similar ($p=0.677$). When comparing the different LCUs for each material, no significant differences were detected for Opallis ($pe^{**}0.194$). For MasterFill and Z250, XL and RD were similar ($pe^{**}0.155$), and so were RD and UB ($pe^{**}0.295$), but XL yielded significantly higher modulus than UB ($pd^{**}0.04$). For Supreme, XL and RD were similar ($p=0.992$), generating significantly higher modulus than UB ($pd^{**}0.004$).

Discussion

Flexural strength is a measure of composite strength: the higher the value, the stronger the material. The ISO4049 standard⁶ classifies dental polymer-based restorative materials into 2 types: Type I materials are those claimed by the manufacturers to be suitable for restorations involving occlusal surfaces, while Type II are all other polymer-based restorative materials. The minimum flexural strength requirement for Type I materials is 80 MPa⁶⁻⁷. The results of this study showed that all composites presented flexural strength higher than 80 MPa, except for Opallis photoactivated with QTH. Indeed, Opallis showed the lowest strength values among all tested composites, regardless of the LCU. Therefore, the null-hypothesis is rejected. The probable explanation for this result may rely on the fact that the composites tested in this study present distinct compositions, and differences in filler load and type, organic matrix components, and even surface treatments of the particles, may affect the mechanical behavior of the materials.

On the other hand, flexural modulus describes stiffness, a measure of material's resistance to deformation under load. There are debates on how much modulus resin composites should possess⁸. Class V cervical cavities, for example, demand a low modulus restorative material to flex with the tooth. A relatively high modulus, on the other hand, is expected for posterior restorations to withstand the occlusal forces and preserve the adhesive interface. Theoretically, the ideal value would be similar to that of dental structures, so the restorative would have similar deformation to the surrounding tooth under loading. However, when compared to the modulus of human enamel (84 GPa)⁹, resin composites have much lower values; in comparison to human dentin (14 GPa)⁹⁻¹⁰, some composites may present similar values.

In the present study, Z250 and Supreme generally presented higher modulus than the other tested composites. This result might be related to differences in resin formulation or inorganic load among the materials, which strongly affect the properties of the dental composites. Opallis and MasterFill possess irregular glass particles, while the other composites possess spherical ceramic particles that present higher strength and improve the packing of the inorganic fillers, enhancing the properties of the composite. Composites made with irregular particles could have lower flexural strength and modulus than those made with

spherical fillers due to the fact that the stress concentration around the fillers would be expected to be greater for materials loaded with irregular-shaped particles¹¹.

The LCUs produced different results among the resin composites. In general, RD and XL generated higher values for strength and modulus. This is probably explained by the fact that these LCUs presented higher irradiance than UB. The amount of light energy delivered to the specimens might affect the conversion of double bonds which, in turn, might interfere with the development of mechanical properties. Moreover, a photo-polymerization initiated at low light level is generally associated with relatively few centers of polymer growth, possibly resulting in a more linear final polymer structure, with lower network strength. On the other hand, irradiance at high levels produces a multitude of growth centers and leads to the formation of densely cross-linked polymers¹²⁻¹³, which might also explain the results observed for RD and XL.

In addition to irradiance, the polymerization potential by photoactivation is also dependent on the correlation between the light spectrum emitted by the LCU and spectrum of absorption of the photoinitiator¹⁴⁻¹⁵. Therefore, one could expect better results for RD, since the peak of emission for this LCU was centered on the absorption peak of CQ, as shown in Figure 1. Nonetheless, similar results for flexural strength and modulus were detected for both RD and XL, irrespective of the resin composite. This result might be attributed to the fact that both LCUs presented high and similar irradiance values, which might have accounted for their similar results¹⁶.

The present results have clinical implications, since both flexural strength and flexural modulus were found to be dependent on the material and LCU tested. The Brazilian resin composites generally presented poorer properties as compared with the other composites tested, while high-intensity LCUs generated polymers with enhanced strength and modulus. Notwithstanding, the results of the present study should be restricted to the conditions tested here. Further studies evaluating different resin composites and curing devices are necessary.

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