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Evaluation of Curing Light Distance on Resin Composite Microhardness and Polymerization

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Clinical Relevance

Different light curing units, the thickness of the resin composite increments and the exposure distance to a curing light may change the physical properties of a restorative material and compromise its mechanical behavior under clinical loading conditions. Understanding how these factors can affect the quality of restorative products may help the dental professional in selecting the best activating source for a specific clinical application.

SUMMARY

This study evaluated the influence of the curing tip distance on cure depth of a resin composite by measuring Vickers microhardness and determining the degree of conversion by using FT-Raman spectroscopy. The light curing units used were halogen (500mW/cm²) and LED (900mW/cm²) at a conventional intensity and an Argon laser at 250mW. The exposure time was 40 seconds for the halogen light, 20 seconds for the LED and 20 and 30 seconds for the Argon laser. The curing tip distances of 0, 3, 6 and 9 mm were used and controlled via the use of metal rings. The composite was placed in a black matrix in one increment at a thickness of 1 mm to 4 mm. The values of microhardness and the degree of conversion were analyzed separately by ANOVA (Analysis of Variance) and Tukey test, with a significance level set at 5%. Correlations were analyzed using the Pearson test. The results obtained conclude that greater tip distances produced a decrease in microhardness and degree of conversion values, while increasing the resin thickness decreased the microhardness and degree of conversion values. A higher correlation between microhardness and the degree of conversion was shown. This study suggests that the current light curing units promote a similar degree of conversion and microhardness, provided that the resin is not thicker than 1 mm and the light source is at a maximum distance of 3 mm from the resin surface.

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INTRODUCTION

Since the introduction of light-cured resin-based composites, the quality of polymerization has now become one of the great concerns of researchers. Therefore, new technologies have been developed that enable production of the appropriate amount of light required for the efficient conversion of resin composites, resulting in the enhancement of their physical-mechanical properties.[1]

Although new light curing units are already being used clinically, there is still a need for these units to undergo laboratory testing, since insufficient polymerization of resin composites can result in restoration failures. The physical properties of resin composites polymerized by these curing units can be analyzed and studied by several means, such as microhardness tests and analysis of the degree of conversion.

With the advent of the pistol type of high intensity light curing units (400 mW/cm[2] or more), the microhardness of different thicknesses of resin composites cured with these new lights have been studied. Rueggeberg and others[2] detected that there were no differences in microhardness up to a depth of 2 mm. According to Unterbrink and Muessner,[3] the intensity of light is directly related to the resin composite flexural modulus and microhardness.

Another test that has been used to determine polymerization depth is the analysis of the degree of conversion using FTIR and Raman vibrational spectroscopy.[4-5] The spectroscopic techniques provide detailed information of the transitions among the levels of vibrational energy of samples. In the case of resin composites, the energy transitions of unreacted double links are detected.[5]

Raman spectroscopy studies the vibration of atoms in molecules. When laser radiation falls on a sample, the fraction of incident radiation that is scattered at a particular energy can be determined.[4]

According to some studies, Raman spectroscopy has also been shown to be an easy and precise technique for verifying the influence of various parameters on the degree of conversion of resin composites, mainly when compared with FTIR infrared spectroscopy.[5]

Knowing that adequate polymerization depends mainly on the intensity of the light source, the wavelength emitted and the irradiation time,[6] polymerization with Argon ion laser and LED (Light Emitting Diodes) has been suggested and must be studied. When studying these new light sources, the parameters for comparison are the data obtained with polymerization by halogen light.

The Argon ion laser emits light energy in the blue and green bands of visible light. The wavelength of blue light is 488 nm and is capable of polymerizing resin composites, a characteristic that no other laser has. The wavelength of green light is 514.5 nm and is used for procedures in soft tissue and blood coagulation.[7]

Use of the Argon ion laser as a light-curing source is controversial. While some authors affirm that this laser is efficient and capable of polymerizing resin composites more rapidly and with better physical and mechanical properties when compared with the halogen light curing unit,[8] other authors have shown the laser action to be less efficient[9-10] due to a difference in Argon ion laser wavelength of 488 nm from 470 nm, which is the absorption peak of camphorquinone.[1]

The use of LEDs to polymerize resin composites was proposed by Mills in 1995. In place of the filaments used in halogen light bulbs, semiconductor junctions are used to generate light in LEDs. LEDs do not need a filter to produce blue light, are resistant to shocks and vibrations, generate little heat and consume little energy. They produce light with a wavelength of 400-500 nm, which is close to the absorption peak of camphorquinone.[11]

Although halogen light has a broad wavelength spectrum, filters are used to remove the wavelengths that are inactive to camphorquinone, making the band of light used by this apparatus very small, with only 1% of the energy produced being used. Furthermore, the high temperatures generated by halogen light units degrade the components over time, giving the lights a life of approximately 100 hours.[1,11]

Some studies of LEDs have shown that, when compared with halogen light, LEDs present either similar or inferior results, depending on the properties of the light cured resin composite.[12]

In addition to the type of light source used, several factors may interfere in the polymerization depth of resin composites, such as exposure time, resin shade, type of resin composite, quality of light emitted and location of the light.[5,13]

The distance between the halogen light source and resin composite directly affects light intensity on the resin surface. Light intensity diminishes when the distance of the tip to the resin composite is increased.[14] Thus, the most common clinical recommendation for the position of the light curing appliance tip is 1 mm from the resin.[13-14]

With regard to the Argon ion laser, the influence of the distance between the laser light source and the resin composite surface has been studied by means of bond strength to dentin.[15] That study found no difference in bond strengths for distances between 0.5 mm and 6 mm. However, those authors found higher bond strength values in groups with the resin composite placed in three increments compared with those of a single increment. Rode and others[16] compared the microhardness of resin composite *in vitro* using two dis-

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tances between the light source and the sample surface (0.5 mm and 6 mm). They found no statistically significant difference in microhardness between the two distances.

During some restorative procedures, it is not possible to locate the tip of the appliance close to the resin composite during polymerization due to factors such as cuspal tips, proximal restorations or the position of the tooth in the arch. In view of this difficulty, this study assessed to what extent the distance of the light curing tip interferes with polymerization depth of the resin composite polymerized with the Argon ion laser, LED and halogen light.

METHODS AND MATERIALS

Four hundred and eighty (480) samples were made from a hybrid resin (Z-250, 3M ESPE, St Paul, MN, USA) and divided into 60 groups with eight samples each. The variation factors were resin thickness (0, 1, 2, 3 and 4 mm) and the distance between the light source and the resin composite surface (0, 3, 6 and 9 mm).

The test specimens were made using circular black polypropylene matrixes with a 3 mm diameter cavity and heights of 1, 2, 3 and 4 mm. Each matrix was supported on a glass slide to obtain a smooth surface on the resin composite. A piece of black cardboard was placed under the glass slide in order to avoid light reflection from the bottom. The resin was inserted into the various sized cavities in a single increment, completely filling the matrix cavity (for each thickness, the corresponding matrix was used). To smooth the surface where the light was applied, a strip of polyester was used with a glass slide over it. The glass slide was removed prior to polymerization.

The resin composite was polymerized with various light curing units. The halogen unit used for polymerization for 40 seconds was the Degulux Soft-Star (Degussa, Dusseldorf, Germany) light-curing unit, whose intensity was measured with a radiometer (Litex, USA) and was found to be approximately 500 mW/cm^2. Polymerization with the Argon ion laser AccuCure 3000 (Lasermed, USA) was done at a power of 250 mW for 20 seconds and 30 seconds. An intensity of 892.85 mW/cm^2 was then used and calculated with the following formula: P/area (mW/cm^2), where the tip had a 12 mm diameter and a 6 mm spot size. The LED curing light Elipar Freelight II (3M ESPE, St Paul, MN, USA) was also used, the intensity of which (900mW/cm^2) was measured with a radiometer specifically designed for LED (LED Radiometer, SDI, Victoria, Australia) and was used for 20 seconds, in accordance with the manufacturer's recommendations.

For each type of unit, four different distances were used between the tip of the units and the resin composite surface during polymerization: 0 mm (with the tip touching the polyester strip), 3 mm, 6 mm and 9 mm. To standardize this distance, rings corresponding in height to the distances, with openings corresponding to the matrix sizes, were used. The spacer rings were fitted around each matrix, with the resin composite already inserted before polymerization and the tip of the light-curing unit placed over this ring.

When polymerization was complete, each sample was stored dry in a black receptacle at 37°C for seven days. After storage, five samples of each group, while still in the matrix, were taken to a microdurometer (HMV, Shimadzu, Kyoto, Japan), where the surface opposite the one to which the light was applied was examined. In the 1 mm thick groups, the side that faced the curing unit, corresponding to the 0 mm group, was also examined. Five Vickers microhardness measurements were taken: one central (defined by the location of light application) and the other four at a distance of approximately 100 µm from the central location under a 50 gf load for 45 seconds.

Analysis of the degree of conversion was done in the Fundamental Chemistry Laboratory of the University of São Paulo Chemistry Institute. The remaining three samples from each group were taken to the FT-Raman RFS 100/S Spectrometer (Bruker) equipped with a liquid nitrogen cooled germanium detector. A Nd:YAG laser beam (1064 nm) was used to excite the molecules of the material to observe the scattering bands of the double bonds of the aliphatic and aromatic carbons. When excited, the active functional groups emitted specific frequencies (related to the vibration mode). Scanning was performed on the face where the light was applied, on the opposite face of the 1 mm group and on the opposite face of the other groups. The scattered spectrum was captured by a sensitive detector, and the data were stored in a computer, then analyzed by software to determine the spectral curves.

Measurements were also taken in unpolymerized resin composite to serve as a basis for calculating the degree of conversion, based on the following mathematical model:

$$\mathbf{DC\% = 1 - [(A/B)/(C/D)] \times 100}$$

Where:

DC = degree of conversion.

A= scattering band of aliphatic C=C bonds of the polymer.

B= scattering band of aromatic ring of the C=C bonds of the polymer.

C= scattering band of aliphatic C=C bonds of the monomer.

D= scattering band of aromatic ring of the C=C bonds of the monomer.

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RESULTS

The original results consisted of 2,240 values, 2,000 values from the resin composite microhardness and 240 values from the degree of conversion. For statistical analysis, the data of the two variables were assessed separately, then the correlation between the two was studied.

Microhardness

The analysis of variance showed that there was a statistically significant difference at the level of 5% between the distances (F=213.93), between the thicknesses (F=4711.65), between the sources (F=474.75) and in the interactions of distance versus thicknesses (F=24.88), source versus distances (F=33.33), sources versus thicknesses (F=45.67) and distance versus thicknesses versus sources (F=3.56). The Tukey (T=10.27) of the interaction distance versus thicknesses versus sources was calculated to compare the individual behavior of the groups.

When using the halogen light for 40 seconds at a distance of 0 mm, that is, with the curing tip touching the resin composite surface, there was no statistically significant difference in microhardness values up to a 2 mm thickness. At a 3 mm thickness, the values were lower than at 2 mm, and at 4 mm, the values were lower than at 3 mm. When evaluating the 3, 6 and 9 mm distances, there was no statistical difference for the 1 mm thickness. From 2 mm on, the microhardness values diminished as the thickness increased (Table 1).

With the Argon ion laser for 20 seconds at distances of 0 mm and 3 mm between the tip and the resin composite surface, there was no statistical difference up to a 1 mm thickness, but at thicknesses greater than 1 mm, the microhardness values diminished as the resin thickness increased. At the 6 mm and 9 mm distances, the microhardness values diminished as the resin thickness increased (Table 2).

When using the Argon ion laser for 30 seconds at distances of 0 mm and 3 mm, there was no statistical difference between the 0 mm and 1 mm thicknesses, but for thicknesses greater than 1 mm, the microhardness values diminished as the thickness increased. At the 6 mm and 9 mm distances, the microhardness values began to diminish at the 1 mm resin thickness (Table 3).

With LED used for 20 seconds at distances of 0 mm and 3 mm, there was no statistical difference up to a 2 mm thickness; for thicknesses greater than 2 mm, the microhardness values began to diminish. When using the 6 mm and 9 mm distances, there were no statistical differences in values up to a 1 mm thickness; for thicknesses greater than 1 mm, the hardness values diminished as the resin composite thicknesses increased (Table 4).

Degree of Conversion

For data obtained from the analysis of the degree of conversion, ANOVA was also calculated. It was shown that there were statistically significant differences at the level of 5% between the distances (F=43.09), thicknesses (F=205.73), sources (F=75.73) and for the interactions of the distance versus thicknesses (F=3.41), source versus distances (F=4.58), sources versus thicknesses (F=12.06) and distance versus thicknesses ver-

Table 1: *Microhardness averages and standard deviations of the interaction for distance versus thicknesses versus sources–halogen light for 40 seconds.*

	0 mm	3 mm	6 mm	9 mm
0 mm	84.28 ± 2.14	83.22 ± 2.74	85.16 ± 1.29	77.08 ± 2.04
1 mm	83.03 ± 3.24	77.94 ± 2.48	79.33 ± 2.89	72.92 ± 2.35
2 mm	82.39 ± 3.97	72.67 ± 2.08	67.22 ± 2.69	61.33 ± 1.25
3 mm	60.80 ± 3.52	53.07 ± 3.32	43.79 ± 2.40	33.18 ± 1.72
4 mm	35.33 ± 1.54	27.82 ± 2.96	16.92 ± 1.32	9.40 ± 5.90

Table 2: *Microhardness averages and standard deviations of the interaction for distance versus thicknesses versus sources—argon laser for 20 seconds.*

	0 mm	3 mm	6 mm	9 mm
0 mm	77.85 ± 4.80	79.69 ± 8.60	79.36 ± 2.60	79.29 ± 1.80
1 mm	70.55 ± 5.18	67.56 ± 3.02	66.05 ± 7.62	68.05 ± 5.31
2 mm	44.38 ± 4.45	43.94 ± 6.68	44.72 ± 8.45	42.88 ± 6.71
3 mm	18.27 ± 3.71	20.89 ± 4.71	6.44 ± 2.55	0 ± 0
4 mm	0 ± 0	0 ± 0	0 ±0	0 ± 0

Table 3: *Microhardness averages and standard deviations of the interaction for distance versus thicknesses versus sources—argon laser for 30 seconds.*

	0 mm	3 mm	6 mm	9 mm
0 mm	77.33 ± 6.45	78.83 ± 4.74	81.33 ± 3.17	83.87 ± 2.73
1 mm	72.21 ± 7.10	76.80 ± 2.89	66.94 ± 6.55	79.88 ± 3.92
2 mm	64.99 ± 1.72	62.40 ± 4.42	47.29 ± 8.73	56.68 ± 4.84
3 mm	37.48 ± 2.92	32.76 ± 5.74	28.16 ± 3.11	26.40 ± 4.29
4 mm	11.05 ± 3.44	13.26 ± 2.53	0 ± 0	0 ± 0

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sus sources (F=1.08). The Tukey (T=12.60) of the interaction for distance versus thicknesses versus sources was also calculated to assess the individual behavior of the groups.

When analyzing Table 5, the 0, 3, 6 and 9 mm distances showed no statistically significant differences between the degree of conversion values at the different resin composite thicknesses.

When using the Argon ion laser for 20 seconds (Table 6) at distances of 0 and 3 mm, there were no statistical differences up to the 3 mm thickness. However, the values for the degree of conversion were statistically lower at the 4 mm thickness. At distances of 6 mm and 9 mm, there were no differences up to a 2 mm thickness. At the same two distances but at a 3 mm thickness, the values were lower than those obtained at the 0 mm and 1 mm thicknesses but were similar to the values at a 2 mm thickness. With the Argon ion laser for 30 seconds, using the distances of 0, 3, 6 and 9 mm, there was no statistical difference in the degree of conversion values for thicknesses up to 3 mm, but at a 4 mm thickness, the values were lower (Table 7).

For the LED curing unit, there were no statistically significant differences between the values obtained using 0 mm and 3 mm distances at the different thicknesses. At the 6 mm and 9 mm distances, there were no differences in conversion up to 3 mm in thickness. The values for degree of conversion at the 4 mm thickness were lower (Table 8).

Table 4: *Microhardness averages and standard deviations of the interaction for distance versus thicknesses versus sources—LED for 20 seconds.*

	0 mm	**3 mm**	**6 mm**	**9 mm**
0 mm	80.64 ± 1.73	81.27 ± 1.61	81.06 ± 2.60	76.5 ± 2.32
1 mm	78.92 ± 2.33	80.32 ± 1.40	71.34 ± 2.72	66.42 ± 1.36
2 mm	75.85 ± 2.75	74.46 ± 2.20	60.48 ± 0.92	46.08 ± 5.31
3 mm	49.78 ± 3.61	47.60 ± 3.46	31.45 ± 2.91	17.20 ± 1.59
4 mm	28.08 ± 1.42	25.08 ± 2.99	6.37 ± 4.69	0 ± 0

Table 5: *Degree of conversion averages and standard deviations of the interaction for distance versus thicknesses versus sources—halogen light for 40 seconds.*

	0 mm	**3 mm**	**6 mm**	**9 mm**
0 mm	68.07 ± 1.58	70.48 ± 3.16	67.27 ± 4.43	64.66 ± 1.73
1 mm	70.68 ± 2.78	70.68 ± 0.92	64.86 ± 4.59	65.06 ± 1.04
2 mm	67.85 ± 3.03	69.48 ± 1.25	70.08 ± 1.26	66.47 ± 1.51
3 mm	67.47 ± 4.34	64.66 ± 2.11	62.45 ± 1.93	58.84 ± 5.04
4 mm	61.65 ± 0.92	59.04 ± 1.59	59.64 ± 2.09	55.44 ± 0.57

Table 6: *Degree of conversion averages and standard deviations of the interaction for distance versus thicknesses versus sources—argon laser for 20 seconds.*

	0 mm	**3 mm**	**6 mm**	**9 mm**
0 mm	71.69 ± 4.70	64.03 ± 2.92	64.26 ± 2.50	65.26 ± 5.39
1 mm	66.87 ± 1.58	64.43 ± 1.15	63.66 ± 0.91	65.26 ± 3.08
2 mm	66.87 ± 1.20	59.24 ± 4.56	57.23 ± 4.78	59.04 ± 4.21
3 mm	60.85 ± 0.60	52.81 ± 5.05	48.21 ± 6.37	49.00 ± 0.69
4 mm	48.80 ± 4.22	36.94 ± 4.87	28.92 ± 4.54	33.33 ± 9.57

Table 7: *Degree of conversion averages and standard deviations of the interaction for distance versus thicknesses versus sources—argon laser for 30 seconds.*

	0 mm	**3 mm**	**6 mm**	**9 mm**
0 mm	69.47 ± 0.69	69.28 ± 4.70	68.27 ± 3.31	64.46 ± 3.35
1 mm	67.47 ± 2.08	66.06 ± 2.27	69.67 ± 0.92	65.07 ± 0.00
2 mm	64.24 ± 3.64	66.44 ± 2.26	64.06 ± 0.34	62.85 ± 2.85
3 mm	62.05 ± 2.08	57.83 ± 3.66	59.64 ± 3.35	56.63 ± 3.01
4 mm	52.41 ± 12.29	55.02 ± 4.01	45.99 ± 0.34	39.56 ± 3.47

Table 8: *Degree of conversion averages and standard deviations of the interaction for distance versus thicknesses versus sources—LED for 20 seconds.*

	0 mm	**3 mm**	**6 mm**	**9 mm**
0 mm	67.22 ± 0.30	68.08 ± 3.01	69.28 ± 3.75	65.04 ± 2.37
1 mm	72.68 ± 4.22	69.64 ± 4.64	68.27 ± 2.27	65.06 ± 3.18
2 mm	70.88 ± 3.42	68.85 ± 1.96	66.44 ± 2.82	63.05 ± 2.84
3 mm	67.87 ± 3.52	66.07 ± 2.11	62.45 ± 3.31	57.23 ± 4.75
4 mm	63.66 ± 4.56	60.04 ± 2.50	48.60 ± 4.01	47.19 ± 1.25

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Microhardness Versus Degree of Conversion Correlation

After analyzing the microhardness and degree of conversion separately, the level of correlation between these two variables was studied using the Pearson's correlation test with the help of BioEstat 3.0 software. For this calculation, the mean microhardness values from each group were used and correlated with the mean degree of conversion values from the corresponding group, thus a total of 80 pairs of data were used.

The results of the test showed that there was a high degree of positive correlation between microhardness and degree of conversion, with a value of r=0.8580 ($p \leq 0.01$).

DISCUSSION

The current curing units for light cured resin composites present several advantages over previously used units. However, although the polymerization rate has improved with the newer units, the rate achieved has still not attained ideal levels. With the aim of enhancing the properties of light cured resin composites, reducing the activation time and diminishing the working time, various types of light curing units have been suggested.[17] Currently, the dental professional has a variety of light curing units available on the market, such as conventional halogen, plasma arc, light emitting diodes (LEDs) and Argon ion laser light units.

One of the most frequently used indirect methods for verifying the degree of resin composite polymerization is the microhardness test.[9,13-14,18-19] However, the direct method of degree of conversion analysis by means of vibrational spectroscopy has also been used to verify the degree of resin composite polymerization.[4,18-22]

According to Rissi and Cabral,[23] there is an increased reduction in light intensity as a result of an increase in the distance from the light source. This effect of distance from the tip of light curing units is still a controversial issue in the literature.

In studies in which this effect was assessed by the indirect method (microhardness), some authors found that, for the Argon ion laser[15-16] and the halogen light,[24] the distance between the light source and the resin composite surface did not interfere with the hardness results. However, others showed that, with the halogen light[13-14] and LED,[25] the increase in distance from the curing tip diminishes the polymerization depth and light intensity.

The effect, both on the degree of conversion and microhardness of a resin composite, caused by the interference of polymerization resulting from clinical factors, is of great importance to the end result of a restoration. This becomes evident in Class II cavities, or even deep cavities in which it is not possible to place a curing tip very close to the first increments of resin.

In this study, with regards to the halogen light and resin thicknesses up to 1 mm, the increase in distance between the curing tip and the resin surface did not show any difference in microhardness. However, the distances of 6 mm and 9 mm influenced the hardness values at the same thicknesses. This is in agreement with the work of Pires and others[14] and Correr-Sobrinho and others,[13] who showed a decrease in microhardness values with an increase in distance from the curing tip to the resin composite.

According to some studies, as the distance from the curing tip of the LED increases, its power[26-27] and the values of resin composite microhardness diminish.[27] The results of this study showed that the distances of 0 mm and 3 mm showed no statistical differences up to 2 mm in thickness. However, the distances of 6 mm and 9 mm showed lower hardness values at similar thicknesses.

Some studies showed that there is no interference in microhardness results for the Argon ion laser with an increase in distances of up to 6 mm,[15-16] which is in agreement with the current study, where both for 20 seconds and 30 seconds, the laser showed no influence in distance from the curing tip in resin composite thicknesses up to 2 mm.

In this study, with regard to the degree of conversion analysis, there was no statistical difference between the distances studied when using a halogen light, which is in agreement with Leloup and others,[5] who did not find any differences below a distance of 10 mm.

When analyzing the results of the LED at distances of 6 mm and 9 mm, there was a decrease in the degree of conversion at the 3 mm and 4 mm thicknesses, which is in partial agreement with Lindberg, Emani and Dijken,[28] who found a small reduction in conversion values; however, they only studied distances of 0 mm and 7 mm.

The results of the group in which a laser was used for 20 seconds showed that there was a decrease in the degree of conversion at the 0 mm and 3 mm distances from thicknesses greater than 3 mm, and from 2 mm at distances of 6 mm and 9 mm. With laser curing for 30 seconds and at thicknesses greater then 3 mm, there was a drop in the degree of conversion at all the distances.

When assessing the degree of conversion values obtained, it can be noted that a small variation was found compared with microhardness results. This might be explained by the fact that an irradiation time double that of the one recommended by the material manufacturer was used both for the halogen light and LED, which might have led to saturation in conversion.

Although some studies found no correlation between hardness and the degree of conversion,[18,29] Ferracane[30] and Knobloch and others[19] showed that this correlation did exist. The difference in these results can be explained because, according to Ferracane,[30] this corre-

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lation exists when resin composite of the same composition is compared. In studies in which this correlation was not found, different resins were compared. In this study, the correlation between microhardness and the degree of conversion of one and the same resin composite was analyzed, showing that there was a high degree of direct correlation. Therefore, the microhardness test can be validated as an indirect method for assessing the degree of resin composite polymerization.

CONCLUSIONS

In view of the methodology used and the results obtained, it was concluded that:

- an increase in distance of the light source from the resin composite surface promoted a decrease in the microhardness values and in the degree of conversion for all types of light sources studied.
- for all light sources studied, an increase in resin composite thickness diminished the microhardness and degree of conversion values, irrespective of the distance from the light source.
- there was a high correlation between the microhardness test and the degree of conversion analysis.
- the current light curing units promote a similar degree of conversion and microhardness, provided that the resin is not thicker than 1 mm and the curing source is at a distance of no more than 3 mm from the resin composite surface.

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