The most commonly used direct restorative material today is composite resin. Light-curing, tooth-colored composite resins for direct use allow better control by the operator in terms of shaping and color matching, resulting in immediate satisfactory form and function.

The method and the light source chosen for the composite resin curing procedure may influence the longevity of esthetic restorations in terms of color stability, restoration integrity, and even bond strength to the tooth. Several studies on the efficacy of light curing of composite resins have demonstrated the importance of obtaining the best mechanical, chemical, and physical properties for the success and longevity of these restorations.1-6

Regarding the light intensity factor, scientific research demonstrates that the higher the light intensity, the higher the microhardness values.7-9 However, the question must be asked whether there is a relationship between high microhardness values and abrasion resistance when masticatory forces put the restorations under stress.

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The Use of Laser-ablation Rate to Evaluate the Quality of Cure in Light-polymerized Composite Resins

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\textbf{Purpose:} To compare two blue LED (light emitting diode) sources in terms of curing efficacy as determined by the ablation resistance of light-cured composite resins when irradiated with an Er:YAG laser.

\textbf{Materials and Methods:} A hybrid composite resin was photocured with two blue LED light sources at 105 mW/cm\textsuperscript{2} and 1000 mW/cm\textsuperscript{2}. Composite tablets were photocured for two different irradiation times: 5 s and 40 s. A focused Er:YAG laser at five energy levels per pulse (100 to 500 mJ), a fixed frequency of 10 Hz, and water flow of 0.46 ml/s, was used for 10 s to ablate the cured composite resin.

\textbf{Results:} The obtained values were plotted to allow a comparative observation of the removed material volume as a function of fluence. The higher the energy per pulse, the higher the ablation rate; however, above 300 mJ, the photocuring time and LED intensity were important factors influencing curing efficacy.

\textbf{Conclusions:} The lowest intensity parameter allowed the largest ablation rate on material photocured for 5 s, while the highest intensity produced the same result on material photocured for 40 s.

\textbf{Keywords:} photocuring, composite resins, LED, laser, Er:YAG, ablation rate.

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MATERIALS AND METHODS

Six cylinder-shaped tablets of the hybrid composite resin Z100 (3M; St Paul, MN, USA), A2 color shade (batch OWN 2003-05) were formed in a stainless steel matrix measuring 2.0 mm (depth) by 8.0 mm (diameter). The composite resin was inserted in the stainless steel matrix and packed preventing void formation in the samples. Following this, the composite resin tablets were photoactivated for 2 different times, 5 s and 40 s.

Two blue-based LED (light emitting diode) sources (470 nm) with different power intensity settings were used: one with peak power of 105 mW and intensity of 105 mW/cm² (LEC II, MMOptics, Brazil) and the other with 600 mW and intensity of 1000 mW/cm² (LEC 1000, MMOptics, Brazil). Thus, four different fluencies for the photocuring process were applied: 0.5 J/cm², 3.8 J/cm², 3.0 J/cm² and 24.0 J/cm².

The Er:YAG laser system (Twin Light, Fotona Medical Lasers; Ljubljana, Slovenia) operating for microseconds with pulse duration between 200 and 450 μs, emitting at a 2940 nm wavelength, maximum energy per pulse of 500 mJ, repetition rate or pulse frequency varying from 2 to 15 Hz, was used. Its delivery system is composed of an articulated arm, with a sapphire win dow handpiece operating through a noncontact beam with a focused transversal section area of about 0.0038 cm² with air/water spray cooling system.

The experimental setup was constructed in order to apply the laser beam perpendicularly to the sample surface and positioned at a focal distance between 12.0 and 15.0 mm (Fig 1b).

Each tablet was ablated with the Er:YAG laser for 10 s immediately after photoactivation, at the set focal distance, varying the energy per pulse (100, 200, 300, 400 and 500 mJ), with a fixed repetition rate of 10 Hz, water flow of 0.46 ml/s. The respective fluencies were: 26.3 x 10² J/cm²; 52.6 x 10² J/cm²; 78.9 x 10² J/cm²; 105.2 x 10² J/cm² and 131.6 x 10² J/cm² in a total of 9 microcavities per same photocuring process and ablation parameters.

The diameters and depths were analyzed through an optical microscope (40X magnification) followed by calculating the volume of removed material, assuming a conical shape of the resultant microcavity. The following formula was used for the ablated material volume calculation:

\[ V \left(10^{-9}m^3\right) = \frac{\pi}{3} \cdot D^2 \cdot \frac{P}{4} = \frac{\pi}{3} \cdot D^2 \cdot P \]

where “D” is the microcavity diameter and “P” its depth.
RESULTS AND DISCUSSION

A micromorphological study of the cavities resulting from the ablation procedure was done (Figs 2 and 3). A classification of three possible distinct zones in the microcavities, previously suggested through an SEM micromorphological analysis, was used: Z1 – zone in which the material was in fact removed and the depth and diameter were measured; Z2 – intermediate zone between the removed region and the margin around the original microcavity; Z3 – zone around the original microcavity which was not laser irradiated.

Below 300 mJ (or 78.9 J/cm²) per pulse, the Er:YAG laser system removed small amounts of material. When the four situations were compared for the energy of 100 mJ (26.3 x 10² J/cm²) per pulse, it was found that the microcavities were quite similar, except when the photoactivation source LEC 1000 was applied for 40 s. In this case, the ablation seemed to be hindered because – besides the poor definition of the cavity (irregular Z2) – in some spots, Z1 was irregular, demonstrating that the material is more resistant than under the other experimental conditions.

No major difference in the micromorphology was observed even at 300 mJ of energy per pulse (or fluence of 78.9 x 10² J/cm²). Based on this parameter, it was obvious that some characteristics resulting from ablation of a solid substrate were present. Some microcavities presented regular internal walls (Z1), demonstrating an ablation cleansing feature; also, marginal definition (absence in the Z2) was present when the LEC 1000 source (1000mW/cm²) was used for 5 s.

In other microcavities, a perforation of the bottom of the cavity was seen (Z1), presenting an ablation depth beyond 2.0 mm when the LEC II light source was used for 5 s. This may be explained by an insufficiently cured composite resin layer.

Redeposited material at the bottom of the cavity was also observed from internal portions of Z1 when both light sources were used for 40 s. Large light-curing exposition times led to a composite resin weakening regardless of the delivered energy.

It is possible that when the tablets were photocured at 105 mW/cm² for 5 s, a physical blocking of water and light may have occurred during the ablation process. This happened because it was expected that a less intense source led to poorly structured material, ie, a small number of polymeric chains had been formed. Thus, the laser could easily ablate a microcavity with a much greater depth vs diameter, matching the Gaussian profile of the emitted light beam. This would probably hinder water penetration together with the light beam.

However, the bottom of the microcavity did not present the original aspect when observed through SEM. Nevertheless, it was noted that the material accumulation resulted from the internal walls, deposited at the deepest portion of the microcavity, when the energy per pulse was 500 mJ. In addition, this material at the bottom was itself ablated, presenting a nanocavity in its center.

Redeposition may not necessarily have been a result of the laser action removing the composite material; weakened margins and microcavity walls may have released material.
When 500 mJ (fluence of 131.6 x 102 J/cm²) of energy per pulse was set on the LEC II lamp (105 mW/cm²) for 40 s, the material received enough energy to photopolymerize. The high impact of the laser did not remove all the target material (in an area corresponding to the laser beam’s transversal section); however, the laser irradiation may have generated shock waves which rearranged the material, thus weakening its internal walls. Portions of these internal walls were separated during the ablation process and were deposited at the bottom of the microcavity, and were again ablated by the Er:YAG laser. The resultant nanocavity presented fusion and resolidification. It is probable that the composite resin/laser interaction was different in this loose material, with its mechanically modified, weakened and dehydrated features. This phenomenon was also observed when the more intense source (1000 mW/cm²) was used for less than 5 s.

It was possible to plot volume graphs (mm³) in function of fluence (J/cm²) (Figs 4 and 5) for each curing situation and time with the resultant values from the depth and diameter readings. Comparing the curves for the ablated volume of the photocured samples with low intensity (105 mW/cm²) (Fig 4), it was noticed that at a fluence of 0.8 x 102 J/cm² (300 mJ per pulse), the curing time does not have a significant influence on the volume of removed material. The two curves present similar profiles where the volume increases linearly with the fluence increase.
With $0.8 \times 10^2$ J/cm$^2$, the ablated volume significantly increased when the curing time was only 5 s, becoming ca 4 times greater when the curing time was 40 s. This result demonstrates that there was no effective curing depth when the low intensity blue LEDs and very short curing times of 5 s were used.

SEM observations showed that the depth of the microcavity exceeded the tablets’ thickness, proving the material’s weakening. Therefore, when using low intensities, the photoactivation time should be at least 8 times higher (around 40 s).

On the other hand, comparing the ablated volume curves of high-intensity photocured composite resin (Fig 5), it was visible that up to $78.9 \times 10^2$/cm$^2$ offluence, the curing time was not a significant factor, and the two curves presented similar tendencies regarding the volume increase as a function of fluence. A significant increase in the ablated volume occurred with 40 s of curing time using a fluence of $1.05 \times 10^2$/cm$^2$; above this value ($1.32 \times 10^2$/cm$^2$), a fast decrease in ablated volume followed, which differed from the curve profile for the curing time of 5 s.

Thus, for low intensities, it is advisable to use higher photoactivation times (ca 40 s); for high intensities, curing time should be less than 40 s.

Independent of the photoactivation time, the volume proportionally increased with the Er:YAG laser fluence increase. Beyond 300 mJ per pulse (until 400 mJ), a rapid and exponential increase in the ablated volume was observed when the material was photocured for 40 s, but quickly decreased when the energy per pulse approached 500 mJ. It showed a different behavior when this high intensity LED was used for only 5 s.

This can be explained by a fast increase in the ablation amount caused by the heat generated from the LED light source, and also because the energy per pulse level of 400 mJ weakened the material, allowing a 4-fold increase in the volume of removed material. Under the energy per pulse of 500 mJ (fluence of $131.6 \times 10^2$/cm$^2$), a decrease to values similar to the energy per pulse of 300 mJ was observed, which can be explained by the shielding-plume effect. This phenomenon can be described as a plume of ablated material that is interposed between the target tissue (composite resin) and the incident laser beam. This plume shielding impairs both water (essential intermediary agent to produce ablation) penetration in the material and the laser beam; the lack of water decreases the ablation efficacy and thus the volume of material removed.

Figure 6 displays the volume-fluence relation when the same curing time is used for two different light sources. It was clear that when low intensity blue LEDs
(105 mW/cm²) were used for a very short period of time (5 s), the volume exponentially increased with fluence. The opposite situation occurred when the most intense light source (1000 mW/cm²) with a lower time was used, causing a less pronounced ablation volume and tending to a saturation point.

In this work, we examined the efficacy of photocuring by measuring the surface ablation caused by the laser’s photomechanical interaction with the cured composite resin.

Despite some relevant studies 16-18 which recommend that a 2-mm-thick composite resin specimen should receive light energy between 21.0 J/cm² and 24.0 J/cm² to be adequately photocured, here it was clear that the highest fluence or energy density resulted in a composite resin specimen with the lowest cohesion degree and weakened material, which, when under mechanical stress from laser ablation, revealed composite surface degradation due to high fluence of a blue LED during the photocuring procedure.

**CONCLUSIONS**

Our findings allow the following conclusions:

1. It was possible to observe that no major differences were found either micromorphologically or in terms of volume of ablated material with energy per pulse up to 300 mJ (78.9 x 10² J/cm² of fluence).
2. 500 mJ energy per pulse (fluence of 131.6 x 10² J/cm²) was not adequate under the present methodology to evaluate the composite resin curing efficacy because, besides weakening the material, it was inefficient for the removal of the irradiated portion, hindering the real measurement of the ablated volume.
3. The most effective parameters in the present study regarding curing efficacy of a composite resin lay between the energies per pulse of 300 mJ (78.9 x 10² J/cm²) and 400 mJ (105.2 x 10² J/cm²).
4. Z2 was hardly observed in most of the microcavities, which can be explained by the correct indication of this laser system in interaction with the composite resin material.

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REFERENCES


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