Marginal Adaptation and Hardness of Resin Composite Restorations Activated with Four Energies

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ABSTRACT

Purpose: The purpose of this study was to evaluate the influence of variations in light intensity versus exposure time, under the same energy density, on the marginal adaptation and hardness of resin composites restorations.

Materials and Methods: The occlusal surfaces of 20 third molars were flattened with 180-grit SiC paper and a Class I cavity was prepared (4 mm wide, 4 mm long, and 2 mm deep). The specimens were randomly divided into four groups (n = 5 teeth). The adhesive system was applied according to the manufacturer's directions followed by one increment of Filtek Z250. The resin composite was light activated with 18 J/cm^2 according to one of the following light intensities/exposure times: group 1—100 mW/cm^2/180 s; group 2—300 mW/cm^2/60 s; group 3—600 mW/cm^2/30 s; group 4—1,000 mW/cm^2/18 s. After 24 hours, the restorations were longitudinally sectioned into two halves. Enamel, bottom, and total mean gap widths (in micrometers) were measured with a stereomicroscope (×200). After that, one of the sections was embedded in acrylic resin and polished up to 4,000-grit SiC for Knoop hardness number (KHN) measurements (100 g/15 s) at the top and bottom surfaces. The data from mean gap widths were analyzed by one-way analysis of variance (ANOVA). The KHN values (kg/mm^2) were subjected to a two-way, repeated-measures ANOVA (α = .05). Tukey's test was used for pairwise comparisons.

Results: No significant difference was observed between total and bottom mean gap widths among groups (p > .05). Group 1 showed lower enamel mean gap widths than did groups 3 and 4 (p < .05) but similar to those for group 2 (p > .05). The KHN at the top surface was higher than the bottom hardness (p < .05). For the bottom surface, all groups had similar KHN values (p > .05).

Conclusions: The variations in light intensity and exposure times allowed the achievement of adequate mechanical properties. The use of a low light intensity reduces only the enamel mean gap width but has no effect on the overall gap formation along the composite-tooth interface.

CLINICAL SIGNIFICANCE

As long as an adequate energy density is used to produce adequate mechanical properties in the resin composite, the use of a low light intensity for an increased time does not markedly improve marginal integrity.

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The generally preferred mode of cure in resin composites is photopolymerization.[1] Ideally, the dental restorative resin has all of its monomer converted to polymer during the polymerization reaction. However, all of the dimethacrylate monomers exhibit considerable residual carbon double bonds in the final product, with a degree of conversion ranging from 55 to 75% under standard irradiation conditions.[2] The use of curing devices with high light intensities results in a higher degree of monomer conversion with associated improvements in the mechanical properties of the resin composite being polymerized.[3]

For the sake of convenience and for economic reasons, it is suitable for practicing dentists to minimize the clinical exposure time of resin-type restorations. However, the use of high light-curing devices (light intensity > 500–600 mW/cm^2) induces a more rapid conversion of monomer to polymer, increasing the polymerization shrinkage stresses.[4,5] This results in a loss of adhesion at the tooth-restorative interface. As a clinical consequence, marginal failures, microleakage, postoperative sensitivity, and recurrent caries may occur.[6,7] Shrinkage stresses may also induce tooth deformation and cohesive failures within the restorative material or dental structure.[6–8]

The use of low light intensities over longer exposure intervals is more favorable for long-term maintenance of the marginal tooth-restorative integrity.[9–13] Several studies have reported improved marginal adaptation when low levels of light intensity were used during the initial exposure.[9–13] This finding presumably results from a more extended period of viscous flow in the pregelation phase within the setting resin, similar to that observed in chemical-cure composites. However, most of these studies did not use the same parameter of energy density to compare the use of high and low light intensities.[9–15] The energy density (in millijoules per square centimeter) is defined as the power density (in milliwatts per square centimeter) times the exposure time (in seconds).[13,16] The energy density usually indicated for resin composite polymerization is within the range of 18 and 24 J/cm^2.[17–19]

One can compensate for low light intensities by increasing the exposure duration to maintain the same energy density. Keeping the energy density constant, one could expect a better marginal sealing when low light intensities are used over prolonged exposure times without any detrimental effects on the mechanical properties of the resin composites. Therefore, this study aimed to evaluate the influence of variations in light intensity versus exposure time, with the same energy density, on the marginal adaptation and hardness of the resin composite restorations.

MATERIALS AND METHODS

Tooth Selection and Preparation

This study had the approval of the Ethics Committee of the University of Oeste de Santa Catarina School of Dentistry. Twenty noncarious, human third molars were used. Teeth free from cracks or any other kinds of structural defects were selected. The teeth were disinfected in an autoclave (121 psi/12 min) and stored for less than 6 months in 0.9% saline solution.[20]

All occlusal surfaces were flattened using 180-grit SiC paper and water cooling. On each occlusal surface, one standardized rectangular Class I cavity was prepared (4 mm wide, 4 mm long, and 2 mm deep) with carbide burs (no. 330, Kg Sorensen Ind & Com. Ltda, Barueri, SP, Brazil). The cavity size was controlled by means of a digital caliper (Absolute Digimatic, Mitutoyo, Tokyo, Japan). The specimens were randomly divided into four groups, with five teeth for each condition (Table 1).

Restorative Procedures

All cavities were restored with Single Bond adhesive system (3M ESPE, St. Paul, MN, USA) and Filtek Z250 resin composite, shade A3 (3M ESPE). The adhesive system was applied according to the procedure shown in Table 2, and the resin composite was placed in bulk by means of a Centrix syringe (Centrix Incorporated, Shelton, CT, USA) to minimize voids inclusion.[21]

TABLE 1. LIGHT INTENSITY, EXPOSURE TIME, AND ENERGY DENSITY FOR EACH GROUP.

Group	Light Intensity (mW/cm^2)	Exposure Time (s)	Energy Density (J/cm^2)
1	100	180	18
2	300	60	18
3	600	30	18
4	1,000	18	18

In all groups, the resin composite was light cured with an energy density of 18 J/cm^2; however, the light intensities and exposure times varied as shown in Table 1.[17]

The light-curing device employed was a quartz-tungsten-halogen light, Jetlite 4000 Plus (J. Morita, Osaka, Japan), with a light intensity of approximately 1,200 mW/cm^2. To achieve differences in the light intensities, an acrylic tube of different heights was employed. The acrylic tube (with a hole in its center) was fitted on the light tip of the curing unit. The passage of light through the acrylic resin was avoided by placing a black adhesive tape on the external side (Figure 1). There was no acrylic resin interposed between the composite to be cured and the light-curing unit. These hollowed spacers were used to better standardize the light intensity for each group. The light intensity after placing each acrylic tube was measured with the radiometer of the light-curing unit and confirmed with the Demetron Radiometer (Mod. 100, Demetron Research Corp., Danbury, CT, USA).

After a storage period of 24 hours at 37°C in distilled water, the restorations were finished and polished by means of Sof-Lex Pop-On (3M ESPE) to smooth the surface and facilitate sectioning of the restorations for the gap and hardness measurements.

Gap Measurement

The restorations were longitudinally sectioned (Labcut 1010 machine, Extec Corporation, Enfield, CT, USA) to obtain two slices. On each side of the slices, the total mean width of the gap at the resin-dentin interface was measured under a magnification of ×200 in a stereomicroscope (Shimadzu HMV-2, Shimadzu, Tokyo, Japan).[22,23]

Unlike other studies, this experimental design did not report the mean maximum gap or subjectively qualify the gap.[24–28] This study opted to measure the mean gap width along the entire restorative material–tooth substrate.[22,23] Therefore, to achieve this goal, the entire interface was divided into sections with a regular geometric shape. The height and length of each section were measured with a digital micrometer coupled in the stereomicroscope, as shown in Figure 2. The sum of all partial areas, divided by the total length of the interface, resulted in the total mean gap width. The enamel and bottom

TABLE 2. COMPOSITION, ADHESIVE PROCEDURE, AND BATCH NUMBER OF THE MATERIALS USED.

Adhesive	Composition	Adhesive Procedure	Batch No.
Single Bond	35% phosphoric acid gel Adhesive: BIS-GMA, HEMA, dimethacrylates, polyalkenoate acid copolymer, initiators, water, and ethanol	1. Acid-etch (15 s) 2. Rinse (15 s) 3. Air dry (30 s) 4. Re-wet dentin with water 5. Apply 2 coats of adhesive systems, brushed for 10 s each 6. Air dry for 10 s at 20 cm 7. Light activate (10 s at 600 mW/cm^2)	4C2 4KE

BIS-GMA = bisphenol A glycidyl methacrylate; HEMA = 2-hydroxyethyl methacrylate.

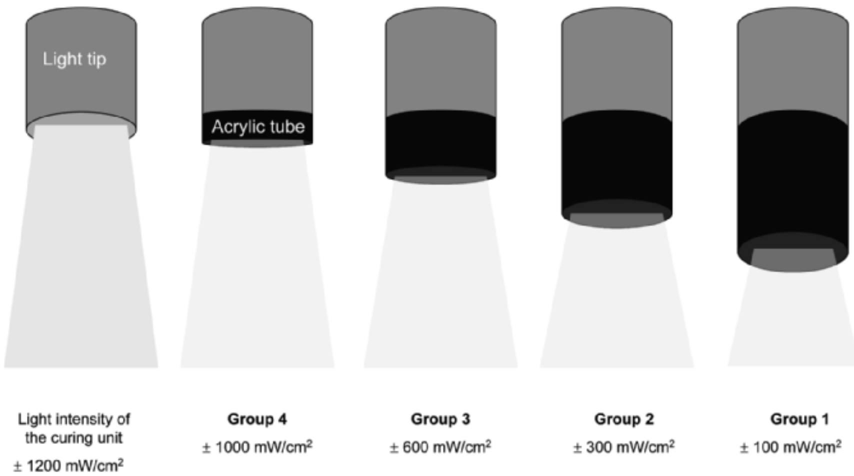

Figure 1. Placement of the acrylic tubes in the light-curing tip and the consequent decrease in the light intensity for all groups.

mean gap widths were also measured in a similar manner. These values were averaged for each tooth. During the gap measurement, specimens were kept stored in distilled water in a dark environment at 37°C.

Hardness Measurement

One of the sections was embedded in a polyvinyl chloride tube using acrylic resin, after the gap measurement. The surfaces of the embedded specimens were polished with 320-, 400-, 600-, 1,000-, 2,000-, and 4000-grit SiC paper under water cooling (Panlab, Pantec, Cotia, São Paulo, Brazil). Six indentations were performed in each slice with a load of 100 g for 15 seconds (Shimadzu HMV-2, Shimadzu, Tokyo, Japan) so that three indentations were made in the resin composite at the bottom of the cavity (50 µm away from the resin-dentin interface), and three indentations were performed at the occlusal surface of each restoration (50 µm from the surface). After the diamond penetrated the material for 15 seconds, the Knoop indenter was removed and the KHN (in kilograms per square millimeter) was registered. The measurement was performed with the software NewAge Version 5.0/w32 (NewAge Industries Inc., Southampton, PA, USA; software: CAMS_win testing system). A mean value from top and bottom surfaces was calculated from the three readings.

Statistical Analysis

The means were analyzed separately by one-way analysis of variance (ANOVA) and a post hoc test (Tukey's test at $\alpha = .05$) for pairwise comparisons for the following variables: (1) enamel mean gap width (in micrometers), (2) total mean gap width (in micrometers), and (3) bottom mean gap width (in micrometers). The means for the top and bottom KHNs were analyzed by two-way, repeated-

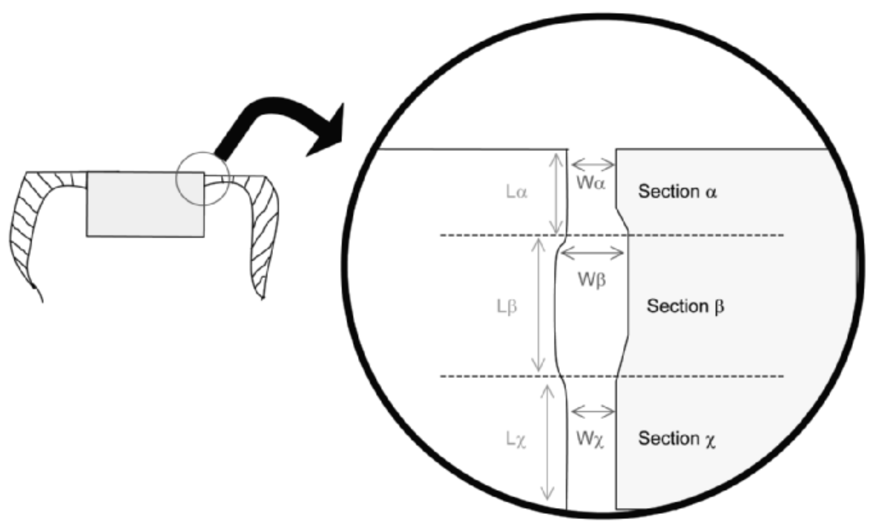

Figure 2. Mean gap width measurement. Inset shows a closer view of the adhesive interface. In each of the approximately rectangular sections (α, β, and χ), the length (L) and respective width (W) were measured. The sum of all partial areas (Lα × Wα) divided by the total length of the interface (Lα + Lβ + Lχ + Ln) resulted in the mean gap width in each section. Ln = any other sections that can be included in the formula to evaluate the total length of the interface.

measures ANOVA and a post hoc test (Tukey's test at $\alpha = .05$) for pairwise comparisons. The local measurement (top or bottom) was the repeated factor. The experimental unit in this study was the tooth. The number of repetitions was five. The statistical program used to analyze the data was Statistical Software for Windows (Version 5.0, StatSoft, Inc., Tulsa, OK, USA).

TABLE 3. MEANS AND SDs OF TOTAL, BOTTOM, AND ENAMEL MEAN GAP WIDTHS FOR EACH GROUP.

Group	Total Mean Gap Width (μm)*	Bottom Mean Gap Width (μm)*	Enamel Mean Gap Width (μm)*
1	7.5 (1.0)[a]	4.4 (1.2)[b]	2.6 (0.9)[c]
2	5.3 (0.5)[a]	2.7 (0.5)[b]	3.6 (0.4)[c,d]
3	6.7 (0.7)[a]	2.9 (0.7)[b]	5.7 (0.8)[d]
4	4.7 (0.5)[a]	2.8 (1.5)[b]	5.5 (0.8)[d]

*In each column, the results marked with the same letters are statistically similar ($p > .05$).

RESULTS

The results and their respective SDs are shown in Tables 3 and 4. No significant difference was detected between the total and the bottom mean gap widths ($p > .05$). Group 1 was similar to group 2 ($p > .05$); however, group 1 had a lower enamel mean gap width than that for groups 3 and 4. Groups 2, 3, and 4 showed statistically similar enamel mean gap widths.

In regard to KHN measurements, only the main factors, groups and surface, were statistically significant ($p < .05$). Group 1 showed higher KHN values than those for groups 3 and 4 ($p < .05$) but similar to those for group 2 ($p > .05$). The KHN was generally higher at the top surface, except in group 4, where the top and bottom KHN values were statistically similar ($p > .05$).

DISCUSSION

Whereas several studies have documented enhanced composite-to-tooth adaptation or decreased marginal gap or microleakage with reduced light intensity curing,[9–13] the present investigation failed to demonstrate this trend for the total mean gap width measured after 24 hours of resin placement. This finding is in line with other investigations.[14,15]

The improvement in the composite-to-tooth adaptation cannot be achieved at the expense of a lower degree of monomer-to-polymer conversion. It is generally accepted that a minimum intensity of 400 mW/cm^2 with an exposure time of 40 to 60 seconds should be used for routine resin composite polymerization.[17–19] This means that an energy density of 18 to 24 J/cm^2 is required to ensure adequate mechanical properties of the resin composites.

The hardness measurement is an excellent tool to provide an indirect evaluation of the conversion degree of resin composites since this method can employ the resin composite activated within the cavity and it was already demonstrated that there is a good correlation between KHN and infrared spectroscopy for monomer conversion.[29,30] Besides that, the hardness number can be measured using the same experimental unit employed for the gap evaluation.

The similarity among groups in respect to the KHN values in the bottom of the cavity indicates that regardless of the technique, the monomer-to-polymer conversion was similar among the groups.

TABLE 4. MEANS AND SDs OF KNOOP HARDNESS NUMBER ON TOP AND BOTTOM SURFACES FOR EACH GROUP.

Group*	Local Measurement* (kg/mm^2)		Pairwise Comparison[†]
	Top[c]	Bottom[d]	
1[a]	100.2 ± 0.8	94.2 ± 0.9	Not statistically similar
2[b]	93.7 ± 1.2	89.8 ± 1.2	Not statistically similar
3[b]	94.2 ± 0.8	90.0 ± 1.1	Not statistically similar
4[b]	94.2 ± 2.1	93.8 ± 1.7	Statistically similar

*The results of the groups marked with the same letter are statistically similar.
[†]Pairwise comparison between the top and bottom hardness in each row.

In the present investigation, the combination of exposure times varying from 18 to 180 seconds and light exposures from 100 to 1,000 mW/cm^2 has not caused any detrimental effect on the hardness of the resin composite, which is in agreement with other studies.[31,32]

Most of the studies that demonstrated superior marginal adaptation with low light intensities have overlooked the mechanical properties of the resin composites within the cavity. For instance, Unterbrink and Muessner, and Feilzer and colleagues investigated the effect of different light intensities on the marginal continuity of resin composite restorations and concluded that the use of high light intensities (450–650 mW/cm^2) led to significantly more interfacial defects than did a low light intensity (250 mW/cm^2).[10,11] However, the above studies employed the same exposure time for both groups, overlooking the concept of minimal energy density for the achievement of adequate mechanical properties.

The energy density employed in the low light intensity groups in these studies, that is, 4 to 10 J/cm^2, was rather inferior to the minimal needed to ensure adequate mechanical properties for the composite material.[10,11,13] Thus, the superior marginal adaptation observed when low light intensity was used could be attributed to the lower polymerization shrinkage that occurred as a result of insufficient monomer-to-polymer conversion. In agreement with this statement are the findings of Bouschlicher and colleagues.[4] The authors have evaluated the polymerization shrinkage stresses of low and high light intensities under similar exposure times and demonstrated high polymerization shrinkage stress when high light intensities were used. Had the previous studies maintained the same energy density in the low and high light intensity groups,[10,11] the marginal adaptation could have been equal among the tested conditions since the maximum polymerization shrinkage stress is similar when different light intensities are used under constant energy density.[33]

It cannot be ruled out that group 1 showed a lower enamel mean gap width than did the other groups (Table 3). The lower the light intensity, the lower the amount of photons that reaches the composite surface. Thus, the rate of free radicals formed is reduced, providing time for the composite to flow on the surface. This reduced rate of free radical formation can diminish the polymerization shrinkage stress in the enamel interface, reducing the gap formation in the surface.

Despite the fact that group 1 received the lowest light intensity, the KHN was higher for this group. This, in fact, seems to indicate that the exposure time might have a more profound effect on the polymerization conversion than the light intensity or the energy density itself. Further studies should be conducted to investigate this hypothesis.

Another finding in Table 4 is that the difference in top and bottom KHNs was more pronounced in group 1, which suggests that more light attenuation through the composite occurs when an initial low light intensity is used. Deeper in the composite, light attenuation results in fewer excited camphoroquinone (CQ) molecules, and the probability of a collision with an amine decreases dramatically. Obviously, to accommodate for this decreased potential, the duration of exposure time can be increased, providing an enhanced opportunity for an excited CQ molecule to collide with the amine and result in a free radical formation.[34] Thus, the lower part of the mass, farthest from the light source, will reach the gel point slower than the top part, where the light intensity and the rate of polymerization are higher.

Interestingly, group 1 showed a trend toward having a higher bottom mean gap width, and this fact can also be explained by the lower rate of polymerization. A resin composite placed in a high C-factor cavity (like the one in the present study) cannot flow itself completely to compensate for the volume reduction caused by polymerization shrinkage. Thus, the stress relief can only be accomplished through debonding from the cavity walls or formation of internal cracks in the composite material.[22,35] Since the bonding to the cavity walls is weaker than the cohesive strength of resin composites, gap formation is more likely to occur.[23]

The low initial light intensity with a more extended flow period was sufficient to solidify the surface layer and minimize the potential for gap formation in enamel margins but not on the bottom of the cavity. The light intensity of the curing light is highest at the surface and decreases as it penetrates deeper into the composite. The lower part of the mass, farthest from the light source, will reach the gel point slower than the top part (mainly when low light intensity is used). Therefore, the resin composite in the bottom of the cavity from group 1 remained viscous for more time than in the other groups and tended to deflect in the bottom-to-top direction.[36–38]

This hypothesis is supported by the study of Suh and Wang,[39] who also observed more composite deflection at the bottom of the cavity when the material was bonded laterally and light cured at the opposed surface. In another study, the acid-etching of only the enamel margins allowed a high mean gap width in the bottom of the cavity in comparison with a group in which total bonding was performed.[22] This may indicate that the relief by flow at the surface is lower than for regions farther away from the light source, such as the bottom of a cavity.

Recently, two clinical evaluations did not find any differences between composite restorations light cured with high or low light intensity, which agrees with the present investigation.[40,41]

The structure of a polymer network under the different polymerization techniques should be also evaluated. It was recently demonstrated that the use of low light intensities can form a more linear polymer, which is likely influenced to a higher degree by food or substances that can soften the more linear polymer or by an enzymatic attack,[42] which in turn may reduce the long-term stability of resin composites.

Although this is one of the few studies that controls for energy density used to light cure composites, the extrapolation of the results from this study to clinical practice should be done carefully. Marginal integrity is a function of several factors, such as adhesive placement, rate of modulus formation of the composite, the gel point and flow of the resin composite, the finishing method, the amount of photoinitiators, and the amount of double conversion. This means that several other factors, apart from the ones evaluated, might play a role in marginal integrity and deserve to be investigated.

CONCLUSIONS

In summary, curing composites with several variations in light intensity and exposure times with constant energy density resulted in adequately produced composites with similar hardness. The use of a low light intensity reduces only the enamel mean gap width but has no effect on the overall gap formation along the composite-tooth interface.

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