The Effect of Light-curing Source and Mode on Microtensile Bond Strength to Bovine Dentin

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Purpose: The purpose of this study was to evaluate the effects of different light-curing techniques on the microtensile bond strength of hybrid and packable resin composite to dentin. The null hypotheses were that different light-curing techniques do not affect the adhesion of resin composites to tooth structure and that different resin composites do not have a similar bond to dentin.

Materials and Methods: One hundred four box-shaped buccal preparations were made and dentin/enamel adhesive was applied according to the manufacturer's instructions (Single Bond 3M ESPE). A hybrid resin composite (Filtek Z250, A2, 3M ESPE) or a packable resin composite (Solitaire 2, A2, Heraeus Kulzer) were inserted in bulk and polymerized using one of these techniques (n = 13): (a) Soft-start (SS) using a halogen lamp (QTH); (b) LED low intensity; (c) Plasma arc (PAC) curing for 6 s for packable resin composite and 3 s for the hybrid resin composite; (d) Conventional (C) QTH curing for 40 s. Afterwards, specimens were thermocycled 1,000 times between 5°C and 55°C in tap water, and were sectioned into beams with a rectangular cross-sectional area of approximately 1 mm^2. Microtensile bond strength testing was performed using a universal testing machine at a crosshead speed of 0.5 mm/min.

Results: Bond strength means ± (SD) in MPa were: Filtek Z250: SSQTH = 17.9 (5.4); LED = 17.9 (6.4); PAC = 16.8 (6.8); CQTH = 16.1 (4.6). Solitaire 2: SSQTH = 12.4 (6.4); LED = 15.5 (4.3); PAC = 16.2 (4.4); CQTH = 13.8 (5.7). The data were structured in a split-plot design and analyzed by a two-way ANOVA and Tukey's tests (α = 0.05).

Conclusion: The light-curing method did not significantly affect bond strengths. However, the bond strengths of the packable resin composite were significantly lower than those of the hybrid resin composite for all polymerization techniques, suggesting that the restorative material itself might be a more critical factor in adhesion than the curing method.

Keywords: light curing, resin composite, bond strength.

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Most composite restorations placed today involve the use of dentin/enamel adhesives and light-cured restorative materials.[28] Despite many improvements in composite materials, polymerization shrinkage remains a major problem in light-cured restorations.[13] The polymerization shrinkage of resin composite creates contraction stresses that can disrupt the bond to preparation walls and margins.[5] This competition between stresses within polymerizing resin composites and the adhesion to preparation walls is one of the main causes of marginal failure and subsequent microleakage.[8]

Many factors affect the amount of stress generated during polymerization of resin composites, including the restriction of polymerization shrinkage within a confined space.[5,7,12] When the resin composite is attached to more than two preparation walls, flow capacity is severely limited,[7,8,12] and shrinkage stress can exceed bond strength.[8,12]

One of the most well-researched means of controlling the shrinkage stresses is a reduced rate of conversion, controlling the flow capacity during polymerization.[21] This can be done, for example, with the soft-start technique that involves light activation at low light intensity, followed

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by final cure at high intensity.[21,32] Flow within the material can reduce contraction stress, potentially resulting in better marginal adaptation of the resin composite material and decreased microleakage.[21,32,36,37] However, some studies have observed no significant improvement in marginal adaptation[1,8,13,28] and no significant reduction in polymerization shrinkage with soft-start polymerization.[17,33-35]

The introduction of new light curing devices has further complicated the area of dental restorative material curing. Among these are the plasma arc curing (PAC) units, which provide a very high light intensity and may reduce the time spent polymerizing the resin composite by 75% or more.[4] Some studies[24,25] have shown that the PAC units cause no more polymerization shrinkage than conventional units, nor did they damage the marginal integrity in dentin cavities.[1,9,14]

Recently, solid-state light emitting diode (LED) technology also has been introduced for curing dental materials. LED light-curing units have some advantages over conventional halogen lamps, including an expected lifetime of several thousand hours, no requirement for filters to produce blue light, and an emission spectrum that coincides well with the absorption spectrum of camphorquinone, the main photoinitiator in resin-based dental materials.[15,22] Studies have shown that LED light curing units can adequately polymerize different resin composites.[22,27,31]

There are few studies evaluating adhesion of composite resins to different substrates when different light-curing techniques are used. The adhesion to metal surfaces using soft-start polymerization has been evaluated, but the results only suggest that material flow is higher using the two-step approach, which could reduce contraction stresses in the prepared cavity during polymerization and could consequently preserve marginal integrity.[17] Thus, it would be important to evaluate whether different light-curing techniques affect shrinkage stress and bond strength in dental preparations, where the flow capacity of resin composites is restricted, rather than on flat surfaces, where it is not. The microtensile bond strength test, which allows bond strength to be measured in a small region and in preparations,[30] makes this possible.

Therefore, the primary purpose of this study was to evaluate the effects of soft-start, LED, plasma-arc, and conventional halogen (QTH) curing techniques on the microtensile bond strength of hybrid and packable resin composite restorations. The null hypotheses were that different light-curing techniques do not affect the adhesion of resin composites to tooth structure and that different resin composites do not have a similar bond to dentin.

MATERIALS AND METHODS

One hundred four extracted bovine incisors stored in a 1% thymol solution at 5°C ± 1°C were used in this study. The teeth were rinsed in running water, and any debris was removed. Standardized box-shaped buccal preparations with parallel walls were made using diamond burs (#1095, KG Sorensen, São Paulo, Brazil) in a high-speed water-cooled handpiece mounted in a custom alignment device. The dimensions (Fig 1a) were: 4 mm in the mesio-distal and inciso-cervical directions, with a depth of 1.6 mm. The preparation margins were in enamel, but the floors of the preparations were in dentin. The teeth were randomly assigned to 8 groups of 13 teeth each (Table 1).

Table 1 Polymerization techniques and resin composites use

Group	n	Polymerization technique	Resin composite
1	13	Soft-start QTH	Hybrid
2	13	Soft-start QTH	Packable
3	13	LED	Hybrid
4	13	LED	Packable
5	13	PAC	Hybrid
6	13	PAC	Packable
7	13	Continuous intensity QTH	Hybrid
8	13	Continuous intensity QTH	Packable

Single Bond (3M ESPE, St Paul, MN, USA) dentin/enamel adhesive was applied according to the manufacturer's instructions. Dentin and enamel were etched using 35% phosphoric acid gel (3M ESPE) for 15 s. After rinsing for 10 s and blotting excess moisture, two consecutive coats of the adhesive were applied, lightly air dried, and light cured for 10 s. The adhesive was polymerized with the same technique used for resin composite polymerization in each group. For the soft-start group, the adhesive was polymerized with final intensity (560 mW/cm^2). A hybrid resin composite (Filtek Z250, A2, 3M ESPE) or a packable resin composite (Solitaire 2, A2, Heraeus Kulzer, Armonk, NY, USA) was inserted in bulk and was polymerized using one of the following techniques:

- Soft-start halogen (QTH) unit (VIP, Bisco, Schaumburg, IL, USA): 10 s at 160 mW/cm^2 + 30 s at 560 mW/cm^2
- LED (Ultrablue III; DMC Equipamentos, São Carlos, Brazil): 40 s at 120 mW/cm^2
- Plasma arc curing (PAC) (Apollo 95E Elite with 470 nm tip; DMD, Westlake Village, CA, USA): 6 s at 1760 mW/cm^2 for the packable resin composite and 3 s at 1760 mW/cm^2 for the hybrid resin composite (as recommended by PAC light manufacturer)
- Continuous cure QTH (VIP): 40 s at 560 mW/cm^2 (control)

Three different radiometers were used in this study to measure the light intensity. For the QTH units, a conventional radiometer was used (Demetron/Kerr, Danbury, CT, USA), for the LED unit, a LED curing radiometer (Demetron, Danbury, CT, USA) was employed, and for the PAC unit, a high intensity radiometer (Hilux Light Meter, First Medica, Greensboro, NC, USA) was used.

Following the restorative procedures, all teeth were thermocycled in a thermal cycling machine (MSCT-3Plus, Marcelo Nucci Automação, São Carlos, Brazil) for 1000 cy-

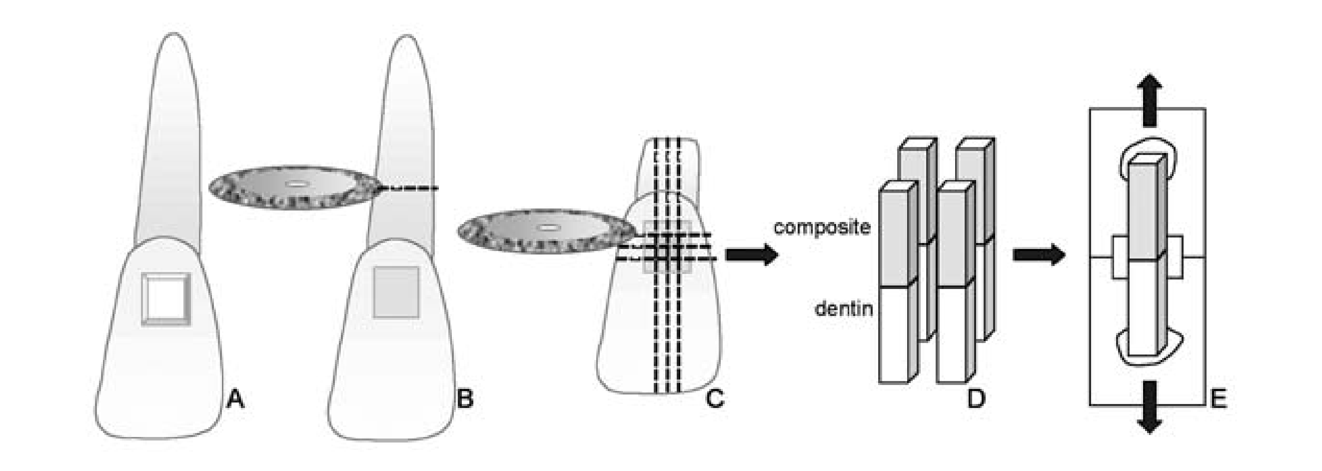

Fig 1 (a) Location of the preparation. (b) Sectioning the root from the coronal portion of the restored tooth. (c) Sectioning of coronal portion of tooth into small beams. (d) Beams taken from the central portion of restoration, each with a rectangular cross-sectional area of approximately 1 mm^2. (e) Beam fixed to matrix with cyanoacrylate adhesive and positioned in a testing device for the microtensile bond test.

cles between 5°C and 55°C in tap water. The dwell times were 60 s, with a 5-s transfer time.

Seven days after the restorative procedures, the teeth were sectioned using a double-sided diamond disk (KG Sorensen, Barueri, Brazil) to separate the root from the crown (Fig 1b). Using a diamond saw (Isomet 1000, Buehler, Lake Bluff, IL, USA), the coronal portions of teeth were sectioned into small beams (Fig 1c) with a rectangular cross-sectional area of approximately 1 mm^2. The orientation of the sections was such that testing would involve the resin-dentin interface at the pulpal floor of the restorations. Four beams from the central area of each restoration were used for microtensile testing (Fig 1d).

The bonded surface area of each beam was calculated before testing by measuring the width and thickness using digital calipers (Mahr 16 ES, Carl Mahr, Esslinger, Germany). The beams were fixed to matrices with cyanoacrylate adhesive and placed in a testing device (Fig 1e). The microtensile test was performed in a universal testing machine (Emic, Sao José dos Pinhais, Brazil) at a crosshead speed of 0.5 mm/min. The failure load and bonded area were used to calculate the bond strength (MPa) of each beam.

Mean bond strength for each tooth was calculated from the bond strengths of the 4 individual beams. Means were submitted to split-plot ANOVA and Tukey's tests ($p = 0.05$) to compare the groups.

The fractured surfaces of the specimens were examined visually with a stereomicroscope (EMZ-TR, Meiji Techno, Tokyo, Japan) at 25X magnification by two independent evaluators to determine the type of failure that occurred during the debonding procedure. Failure modes were classified as: adhesive (cohesive in adhesive interface failure); cohesive in dentin (dental substrate failure); cohesive in RBC (RBC failure); or mixed (cohesive and adhesive failure).

Table 2 Mean microtensile bond strengths by light-curing technique and type of composite

Light-curing Technique	Resin composite			
	Hybrid		Packable	
	Mean (MPa)	SD	Mean (MPa)	SD
Soft-start QTH	17.9 $^{A, a}$	5.4	12.4 ^{A,b}	6.4
LED	17.9 $^{A, a}$	6.4	15.5 ^{A,b}	4.3
PAC	16.8 $^{A, a}$	6.8	16.2 ^{A,b}	4.4
Continuous QTH	16.1 $^{A, a}$	4.6	13.8 ^{A,b}	5.7

Means followed by different superscript letters are significantly different ($p < 0.05$, Tukey's test). Capital letters indicate comparisons between curing techniques (down). Lower-case letters indicate comparison between resin composites (across).

RESULTS

The results are summarized in Table 2. Mean microtensile bond strengths ranged from 16.1 (± 4.6) to 17.9 (± 5.4) MPa for the hybrid resin and from 12.4 (± 6.4) to 16.2 (± 4.4) MPa for the packable resin. The bond strength of 2 samples of group 6, 1 of group 5, and 1 of group 8 was recorded as zero, due to failure before testing. The statistical analysis (two-way ANOVA) showed that the differences in bond strengths based on light-curing technique were not statistically significant ($p = 0.56$), nor was the interaction between the two main factors "composite type" and "curing technique" ($p = 0.48$). The bond strength of the packable resin composite restorations was significantly lower ($p < 0.05$) than that of the hybrid resin composite restorations for all light-curing techniques. Thus, the null hypotheses were accepted based on these results.

The fracture mode results are presented in Table 3. All groups presented predominantly adhesive failures.

Table 3 Frequency of fracture modes by group

Light-curing technique	Fracture modes (52 beams per group)			
	Adhesive	Cohesive resin	Cohesive dentin	Mixed
Soft-start QTH packable	49/52	0/52	1/52	2/52
LED hybrid	50/52	0/52	0/52	2/52
LED packable	51/52	0/52	0/52	1/52
PAC hybrid	47/52	0/52	2/52	3/52
PAC packable	48/52	0/52	0/52	4/52
Continuous QTH hybrid	52/52	0/52	0/52	0/52
Continuous QTH packable	51/52	0/52	0/52	1/52

DISCUSSION

In this study, shrinkage stress generally did not exceed the bond strength of resin composite restorations for any light-activation method, at least at a visually apparent level. However, in some beams, the bond to dentin was disrupted before the beam could be positioned in the universal testing machine. The bond strength of these beams was recorded as zero, and this value was included to calculate the mean bond strength of the tooth specimen.

Serial sections commonly yield widely different bond strengths in the microtensile test.[29,30] However, it is not clear whether the lack of consistency is due to specimen preparation, material properties, heterogeneity of the bonding substrate, or technique sensitivity.[29]

All of the light-curing techniques used in this study resulted in similar microtensile bond strength values. Thus, compared to polymerization with a conventional unit, none of the methods changed the shrinkage stress enough to affect bond strength.

Regardless of curing mode, composite continues to shrink after removing the light source. This can be attributed to the post curing of the resin.[35] Polymerization is approximately 75% complete at 10 min after light exposure and continues for a period of at least 24 h.[23]

Soft-start light-curing units frequently use a final cure of 500 mW/cm^2 or more. The beneficial effect of the initial low intensity cure therefore might be negated by the high intensity final cure.[17,35] In the present study, adhesion values associated with soft-start polymerization were similar to those associated with the other polymerization techniques (Table 2).

Previous studies have reported a reduced depth of cure,[15] hardness,[10,18] and degree of conversion[16] in resin composites cured with LED light-curing units compared to conventional QTH units. Therefore, longer exposure times or thinner increments were recommended[18] to achieve reasonable hardness values due to the reduced irradiance of LED light-curing units. However, these studies were done using the earliest dental LED curing units; newer units have significantly greater output.[31] In another study,[2] it was observed that LED curing units resulted in slower and less shrinkage for two resin composite materials, but not for a third.

Concerning PAC light curing, this technique provided similar adhesion values to the other methods tested in this study. The high intensity and rapid cure associated with PAC lights might be expected to cause problems at the adhesive interface. It should be expected that the different curing time could change polymerization rates and polymerization shrinkage of each resin composite, resulting in reduced bond strength. However, because of the short exposure times, the PAC technique can result in a lower degree of conversion.[26] Thus, it could be argued that the rapid cure was compensated by the low degree of conversion, resulting in less polymerization shrinkage than that obtained with conventional QTH curing methods[25] and marginal gaps similar to those seen with conventional polymerization methods.[14,26]

Although in this study the light-curing techniques did not affect adhesion, the type of resin composite (hybrid or packable) did. The restorative material might be more critical than the curing technique,[34] and the performance of some materials may be more dependent on light intensity than others.[33]

The degree of contraction stress depends on the extent of the reaction, the stiffness and the viscoelastic properties of composite, and its ability to flow.[8] Less rigid materials are more capable of reducing contraction stresses than more rigid materials, and packable resin composite is more rigid than hybrid resin composite.[12] Thus, the shrinkage stress produced during the curing of packable resin composite may have been greater, reducing the adhesion to tooth structure. Packable resin composites exhibit significantly higher maximum contraction stress and a higher rate of contraction force than more conventional hybrid composite resins.[6] Furthermore, it has already been demonstrated that Solitaire 2 presents higher shrinkage than Filtek Z250.[11] Furthermore, packable composites usually present a stiffer and drier consistency than hybrid resin composites, which can result in a poorer adaptation of the restoration[24] and potentially an adverse effect on the bond strength.

In this study, the bond strengths of resin composite restorations cured with various light-activation techniques were similar to those achieved using a conventional QTH method, and also exhibited essentially the same percentages of the different fracture modes (Table 3). Although

PAC lights can reduce exposure times, these light-curing units are more expensive than QTH and LED units. Moreover, because of the short exposure times typically used, PAC lights may produce a reduced degree of conversion and less stress; however, this can decrease microhardness, and perhaps other physical properties, in depth.[25,26] Further research is necessary to improve the performance of LED light-curing units regarding mechanical properties of resin composite, because this technology is less expensive than QTH units and presents inherent advantages.

Thus, in this in vitro study, the soft-start (QTH), LED, and PAC light-activation techniques did not affect the bond strength of resin composite restorations compared with a conventional method (QTH). However, the packable resin composite restorations (Solitaire 2) had lower bond strengths than hybrid resin composite restorations (Filtek Z250) for all light-curing methods.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions can be made:

– For the resin composites tested, the light-curing sources and exposure mode did not affect microtensile bond strength to bovine dentin.
– For all light-curing methods, the hybrid resin composite had greater adhesion to dentin than the packable resin composite.

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Clinical relevance: The selection of the resin composite can be more critical for the success of a restoration than the light source used for curing.