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Influence of light-curing mode on the sealing of resin composite restorations

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Abstract: This study investigated the effect of light-curing modes on cervical sealing of resin composite restorations. Sixty cavities with the occlusal margins in enamel and the gingival margins in dentin, prepared on the labial and lingual surfaces of human premolars were treated with Single Bond adhesive system and restored using a bulk technique with three resin composites (A110, P60 and Point 4). For each composite, two groups of 10 cavities were created according to the two light-curing modes: Standard (S)-500 mW/cm^2 / 40 seconds and Soft-start (SS) - 250 mW/cm^2 / 40 seconds + 500 mW/cm^2 / 20 seconds. The specimens were submitted to thermocycling prior to immersion in 2% neutral solution of methylene blue for 24 hours. The teeth were sectioned and the degree of dye penetration was scored on a 0-3 ordinal scale. The data were analyzed by Kruskal-Wallis and Mann-Whitney tests ($\alpha = 0.05$). No significant difference in the microleakage scores was observed among the groups polymerized with the two light-curing modes. The microleakage was greater in dentin margins than in enamel margins ($p < 0.01$). These results suggest that soft-start light-curing mode did not have any influence on resin composite restoration sealing.

Keywords: *Microleakage; resin composites; light-curing mode.*

Resumo: O propósito deste estudo foi avaliar a influência do protocolo de fotoativação no selamento de restaurações classe V com compósitos. Sessenta cavidades com margem oclusal em esmalte e margem apical em dentina, preparadas nas superfícies vestibular e lingual de pré-molares humanos, foram hibridizadas com o sistema adesivo Single Bond e restauradas com três compósitos (A110, P60 e Point 4). Para cada compósito, foram produzidos dois grupos de acordo com os protocolos de fotoativação (n = 10): Convencional-500 mW/cm^2/40 segundos e Softstart-250 mW/cm^2/40 segundos + 500 mW/cm^2/20 segundos. Após acabamento/polimento das restaurações e armazenagem durante 7 dias em água destilada a 37 °C, os dentes foram submetidos à termociclagem. Os espécimes foram impermeabilizados com esmalte de unha e imersos em solução neutra de azul de metileno a 2% por 24 horas. Os dentes foram seccionados e o grau de penetração do corante foi avaliado em uma escala ordinal de 0-3. Os dados foram submetidos aos testes de Kruskal-Wallis e Mann-Whitney ($\alpha = 0,05$). Não houve diferença estatística entre os grupos ativados com os dois protocolos de fotoativação. A microinfiltração foi maior nas margens em dentina do que nas margens em esmalte ($p < 0,01$). Esses achados sugerem que o protocolo de fotoativação soft-start não apresentou influência no selamento de cavidades restauradas com compósitos fotopolimerizáveis.

Palavras-chave: *Microinfiltração; resinas compostas; protocolo de fotoativação.*

Introduction

The optical characteristics and mechanical properties of light-curing resin composites make them safe to use in both anterior and posterior restorations. Nevertheless, one of the problems that can interfere in the clinical performance of this material is shrinkage stress generated during polymerization[1,2]. Rupture of the carbon double bonds of methacrylate monomers present in organic matrixes results in a reduction of 0.3 to 0.4 nm in the space maintained between polymer ranges by Van der Waals attraction forces, and in the establishment of 0.15 nm long covalent bonds. Moreover, the simple bonds generated allow free rotation and higher mobility of polymer chains[3]. The contraction generated during polymerization can lead to gap development, fluid penetration and bacterial invasion at the tooth-composite interface and also to post-operative sensitivity[4,5]. Variables like resin monomer, type and concentration of fillers and photo-initiators influence this phenomenon[6,7]. Clinically, the light-curing mode and the energy density provided by the light source can influence the polymerization shrinkage stress the material develops[8]. Activation with a higher intensity light creates a rapid light-curing process, leading to higher shrinkage stress in the composite[9,10]. On the other hand, in spite of reduced leakage observed with low light intensities at the tooth-composite interface[11,12], the conversion degree of composites and their mechanical properties can be affected[13-17]. Recent studies have shown that techniques, such as soft-start polymerization, in which the composite is first submitted to a low light irradiance, followed by increased light intensity, are able to decrease shrinkage stress without interfering with the degree of conversion and mechanical properties of the material[18-22].

The purpose of this study was to evaluate the influence of soft-start polymerization on dentin and enamel margin sealing in class V cavities restored with light-cured composites.

Material and method

The adhesive system and the composite resins used in this study are presented in Table 1. The choice of composite resins was based on their different compositions (filler particle v%, polymeric matrix and type of filler particle). Thirty human premolars extracted for orthodontic reasons and stored in a 1% chloramine solution for a week were used in this in vitro study. Sixty standardized cylindrical class V cavities (4.0 mm in diameter and 1.4 mm in depth / C factor = 2.4) with occlusal margins in enamel and gingival margins in dentin were prepared at the cemento-enamel junction (CEJ) level of lingual and buccal premolars surfaces. Diamond burs (3053, KG Sorensen, São Paulo, Brazil) in a high-speed hand piece fixed in a special sample-aligning device were used to prepare the cavities. Hand cutting instruments (hoes – 12 5 8 26, Duflex, São Paulo, Brazil) were used to provide adequate cavity finishing and to remove enamel prisms without support. Cavity depths were controlled by using a digital caliper (MPI/E-101, Mitutoyo, Tokyo, Japan). The teeth were randomly assigned to six groups of five teeth each (10 cavities).

Enamel and dentin were etched with 37% phosphoric acid for 15 s and rinsed thoroughly for 30s with an air-water spray. Excessive moisture was removed by blotting with tissue paper. After hybridization with Single Bond adhesive system, in accordance with the manufacturers' instructions, the cavities were restored with A110 (3M), P 60 (3M) and Point 4 (Kerr) composite resins, using a bulk technique. The composite resins were light-cured using either standard (S) or soft-start (SS) mode. In standard mode, the composite resins were light-cured for 40 seconds at 500 mW/cm^2 (QHL75, Dentsply / Caulk, Milford, DE, USA). In soft-start mode, the composite resins were initially light-cured for 40 seconds at 250 mW/cm^2, followed by a final exposure of 20 seconds at 500 mW/cm^2 (Degulux Soft-Start, Degussa-Hüls, Hanau, Germany). The light-curing unit power density

Table 1. Composition of the resin composites and adhesive system used in this study

Material	Manufacturer	Composition
Single Bond	3M ESPE, St Paul, MN, USA	Ethanol, water, HEMA, Bis-GMA, dimethacrylates, polialkenoic acid with methacrylate groups pendants, Photoinitiator.
A 110	3M ESPE, St Paul, MN, USA	**Filler**: 40 vol% of silica particles with mean size of 0.04 µm (varying from 0.01 to 0.09 µm). **Organic matrix**: Bis-GMA and TEGDMA.
Point 4	Kerr Corp., Orange, CA, USA	**Filler**: 57 vol% of silica particles and barium glasses with mean size of 0.4 µm. **Organic matrix**: Bis-GMA, TEGDMA, EBADM.
P-60	3M ESPE, St Paul, MN, USA	**Filler**: 61 vol% of zircon silicate particles with distribution between 0.01 – 3.5 µm and mean particle size of 0.6 µm. **Organic matrix**: Bis-GMA, Bis-EMA, TEGDMA, UDMA.

was monitored with a radiometer (Model 100, Demetron Res Corp., CT, USA). After 7 days of storage in distilled water at 37 °C, finishing and polishing procedures were performed with sequential Sof-Lex discs (3M ESPE, St Paul, MN, USA). Next, the teeth were thermal cycled (water baths at 5 and 55 °C for 1000 cycles with a dwell time of 30 seconds in each bath and a transfer time of 15 seconds). Root apices were sealed with a cyanoacrylate adhesive (Superbonder, 3M, São Paulo, SP, Brazil) and the teeth were coated with two layers of nail varnish, up to approximately 0.5 mm from the restoration margins. The specimens were immersed in a 2% neutral solution of methylene blue at 37 °C for 24 hours and then rinsed in tap water. The teeth were sectioned in the bucco-lingual direction through the center of the restorations with a low speed diamond saw (7016, KG Sorensen, São Paulo, Brazil). The cut surfaces were embedded in epoxy resin and polished with 600 and 1200-grit SiC abrasive paper (DPU – 10, Struers, Copenhagen, Denmark). Microleakage was evaluated under a stereomicroscope (SZ 40, Nikon, Tokyo, Japan) at a magnification of 40x. The extent of methylene blue penetration at the enamel and dentin margins was scored by three calibrated examiners according to the following criteria[23]:

0 = No methylene blue penetration at restoration interface;
1 = methylene blue penetration up to 1/2 of the cavity depth;
2 = methylene blue penetration greater than 1/2 of the cavity depth;
3 = methylene blue penetration extending to the axial wall of the cavity.

Statistical analysis

All statistical analyses were performed using Statgraphics 5.1 Software (Manugistics, Rockville, MD, USA). Kappa statistics were used to evaluate inter-examiner agreement. As the experiment involved an ordinal variable, data were submitted to non-parametric statistical tests. The resin composite factor was analyzed using the Kruskal-Wallis H-test. The factors light-curing mode and restorations margins were individually analyzed, using the Mann Whitney U-test. All tests were performed at a significant level of $\alpha = 0.05$.

Result

The microleakage scores are given in Table 2. The Kruskal-Wallis H-test did not reveal significant differences in microleakage among cavities restored with the three light-curing composite resins. The Mann-Whitney U-test showed that there were no significant differences between microleakage scores observed in groups S and SS ($p > 0.05$). With regard to the cavity margins, the Mann-Whitney *U-test* detected significant statistical difference ($p < 0.01$), the higher incidence of microleakage being observed in dentin margins.

Discussion

Shrinkage stress generated during composite resin polymerization can result in leakage at the tooth-composite interface and consequent restoration failure[1]. The light-curing reaction is comprised of three phases: pre-gel, gel and post-gel. In the pre-gel phase, the composite is viscous, and shrinkage stresses generated during the polymerization reaction can be released by material flow[1,24]. Previous studies have demonstrated that the highest stress associated with the polymerization shrinkage develops during the first 30 to 40s of light irradiation[9,25]. However, light-curing the material according to protocols using lower irradiance at the beginning can extend the pre-gel phase, allowing polymerization shrinkage stress relief[24,25]. In accordance with these findings, Feilzer et al.[11] demonstrated that polymerization with low irradiance was related to better marginal sealing of cavities restored with light-curing composite resins. On the other hand, light-curing with low irradiance may promote a decrease in the degree of conversion and negatively influence the mechanical properties of the material[12,15].

In the present study, cavity sealing was assessed by the extent of methylene blue penetration at enamel and dentin margins. While some researchers still consider the dye penetration technique as an important tool in assessing

Table 2. Results of microleakage scores evaluation

Light-curing mode	Composite	Enamel margins				Dentin margins			
		0	1	2	3	0	1	2	3
Standard	A 110	19	1	-	-	4	8	2	6
	Point 4	18	1	1	-	4	4	4	8
	P 60	15	1	2	2	8	5	-	7
Soft-start	A 110	17	1	-	2	7	6	2	5
	Point 4	19	-	-	1	9	4	2	5
	P 60	11	4	-	5	6	5	2	7

marginal adaptation of composite restorations[17,18,21,22], this method presents several drawbacks such as, conflicting results of thermocycling, bi-dimensional analysis and the use of scores to quantify the dye penetration. Moreover, Vandewalle et al.[17] have found no correlation between gap formation and microleakage[17]. On the other hand, Mehl et al.[18] have shown a trend to similar results between dye penetration and marginal integrity of resin composite restorations. These conflicts suggest caution to interpret the results from microleakage studies.

The soft-start light-curing mode was introduced in an attempt to reduce the shrinkage stress generated during the polymerization reaction of composite resins[26]. Moreover, low irradiance in the beginning of light-curing process would allow long polymer chains with few cross-links to develop[27]. In addition, shrinkage stress would be minimized without decreasing the degree of conversion and the mechanical properties of the material[14,18,19,25]. Theoretically, this light-curing mode would provide better marginal sealing in cavities restored with light-curing composites, and based on this, reduced microleakage was expected in SS group. Hypothetically, two-step mode (250 mW/cm^2 / 40 seconds + 500 mW/cm^2 / 20 seconds) would increase the pre-gel phase and would promote a reduction in shrinkage stresses[8,20]. However, there was no difference in microleakage observed in groups S and SS, as reported by Kubo et al.[28]. Moreover, Lim et al.[25] reported a reduction in shrinkage stress from 26.5 to 15 and from 26.5 to 0%, using a two-step mode, when initial irradiance was increased from 60 to 100 and from 60 to 150 mW/cm^2 respectively. Furthermore, according to Feilzer et al.[11] shrinkage stress relief would be more accentuated in the first 10 seconds of light-curing. Based on these findings it was possible to postulate that, irrespective of the use of a two or three-step soft-start mode, it would only be possible to reduce shrinkage stresses, if the initial irradiance was reduced to values lower than 100 mW/cm^2.

Another hypothesis that should be considered to explain the similar performance between groups S and SS, is that in spite of the differences in light-curing protocols, the final energy density used in both techniques was the same: 20 J.cm^{-1} [2,20]. According to Rueggeberg et al.[13] this energy density would be adequate for light-curing restorative composite resins.

The microleakage in dentin margins was higher than that observed in enamel margins. This behavior could be due to dentin substrate heterogeneity. Although current adhesive systems and dentin hybridization mechanisms are very efficient, high water concentration and 20-30% of protein content continue to be obstacles to the establishment of dentin-composite adhesive interfaces without failures and able to withstand the stresses generated during the polymerization reaction[29]. Previous studies have indeed demonstrated that the sealing capacity of adhesive systems in dentin was lower than that obtained in enamel[21,28]. The comparison between the results of these studies and the present study, allowed the authors to conclude that in spite of the advances in adhesive systems, adhesion mechanisms are still more efficient for sealing the tooth-resin composite restoration interface in enamel.

Filler content, type of organic matrix and elasticity modulus directly influence shrinkage stresses and marginal adaptation in cavities restored with light-curing composite resins[12]. Due to the compositions of the materials used in this experiment (Table 1), a difference in microleakage scores among composite factor groups was expected. However, the results obtained were similar. P60 and Point 4 are hybrid composites with the same filler content (Table 1). This aspect could justify the similar behavior observed in relation to shrinkage stress and microleakage scores. A110 is a microfilled composite with 40% filler volume that implies a lower elasticity modulus of the material[30], which would possibly permit a greater reduction in shrinkage stresses during light-curing and a lower degree of microleakage. In the present study, specimens were only submitted to thermal cycling, but clinically, class V cavities are usually submitted to stresses under masticatory loads. From this point of view, it is possible to postulate that mechanical load cycling, before microleakage score observations, would lead to differences related to the behavior of the evaluated composites[18,28]. Further investigations are necessary to support this hypothesis.

Conclusion

Within the limitations of this *in vitro* study, it was possible to conclude:

1. Soft-start polymerization in a two-step-mode was not efficient for reducing microleakage in cavities restored with light-curing composite resins;
2. There was higher microleakage in dentin margins than that observed in enamel margins, which also had a more efficient enamel adhesive mechanism.

The results suggest that further investigations should be conducted in order to identify a light-curing protocol that presents a higher efficiency related to eliminating the microleakage phenomenon in cavities restored with light-curing composite resins.

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