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Research Article

Does Low LED Power Density Affect Wear Resistance of Composite?

Wagner Baseggio[1], Flávia Pardo Salata Nahsan[2], Cassiana Koch Scotti[3]*, José Carlos Pereira[3] and Eduardo Batista Franco[3]

[1]DDS, MS, PhD, Professor at Paranaense University, UNIPAR, Cascavel, Paraná, Brazil

[2]DDS, MS, PhD, Professor at Federal University of Sergipe

[3]Department of Operative Dentistry, Endodontic and Dental Materials, Bauru School of Dentistry, University of São Paulo, Bauru, Brazil

***Corresponding author:** Cassiana Koch Scotti, Octávio Pinheiro Brisola, 9-75 - Bauru - SP - Brazil - 17012-901; Tel: (14) 3235-8000; E-mail: cassiscotti@usp.br/Al

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Abstract

Objective: This *in vitro* study assesses the initial curing light intensity effect on resin composite wear resistance.

Methods: Device Ultra blue IS (DMC), that it makes possible independent commands of power density and time was selected. Four different photo activation methods were investigated: Conventional A (CA: 600mW/cm2 X 40s), Conventional B (CB: 300mW/cm2 X 80s), Pulse-delay (PD: 300mW/cm2 X 3s 3 min wait 600mW/cm2 X 37s), and Soft-start (SS: 300mW/cm2 X 10s 600mW/cm2 X 30s). Samples were prepared and stored in the dark for one week in distilled water at 37ºC prior to simulated tooth brushing. The data were analyzed by statistical tests one-way ANOVA and Tukey.

Results: Ranking the abrasive wear values were as follows: CA>CB>PD>SS.

Conclusion: The findings indicated that a low initial curing light intensity did not compromised the abrasive resistance of the resin composite tested.

Keywords: Polymerization; Dental restoration wear; Composite resins

Introduction

Polymerization shrinkage still remains an ultimate drawback and is a critical limitation of light-activated resin composites, once this process can disrupt the marginal seal between the composite and the tooth structure [1,2]. Polymerization shrinkage stress and its relieving mechanisms have become important research topics in dentistry and are positively correlated with irradiance, as well as the rate of stress force development, since in adhesive restorations the developing shrinkage stress of the setting material competes with the bond strength of adhesive to dentin [3].

Attempts have been made to reduce the stresses generated during polymerization shrinkage or minimize its effects. New methodologies of light application, so called "soft-start" methods, have been developed in order to overcome problems associated with polymerization. These strategies consist of a low-intensity initial irradiance followed by a stepped or ramped increase to higher-intensity irradiance, or a short and low-intensity irradiance pulse followed several minutes later by a longer exposure to high-intensity irradiance. These methods have been developed in order to decrease shrinkage stress and improve marginal integrity, without compromising the physical properties and quality of the restorations, allowing the restoration some freedom of movement between the cavity walls and the center of the contraction [4-6].

The purported reason for applying this new methodology in light curing, is to lengthen the pre-gelation phase by lowering the polymerization rate, thus providing more time for the resin composite to flow, relieve stress and, subsequently, result in an improved adaptation of the restoration [7,8]. Since contraction force is proportional to the degree of conversion, the exposure duration of the energy application sequence can be modified in order to promote similar degrees of conversion for proper light-curing of the resin composite, while trying to reduce or minimize the shrinkage stress during polymerization reaction [9]. This may be achieved with extended exposure times at low irradiance [5].

To date, the majority of studies have evaluated the so called "soft-start" polymerization technique in effectiveness to reduce gap formation or shrinkage stress, but fewer studies have evaluated its influence on polymer mechanical properties, such as wear resistance. Wear resistance is a very important property of the final resin composite posterior restoration and there is no consensus regarding which initial low-irradiation step should be applied.This study was outlined to verify the curing light intensity effects on wear resistance of a resin composite from a low irradiance LED light-curing unit.

Material and Methods

A hybrid resin composite (Z250, 3M-ESPE, St Paul, MN, USA) of A_2 shade and a light-emitting-diode (LED) Ultra blue IS (DMC, Plantation, Florida, USA) were selected for this study. Ultra blue IS has an output wavelength range of 475 ± 15 nm and is programmed with exposure times of 20 to 40 seconds. The power settings or intensity are 300 and 600 mW/cm^2. This allows for manual selection of any time and intensity combinations for the curing. Four different photo activation methods were investigated and are detailed in Table 1. The Conventional A method (CA) involves light irradiation at 600 mW/cm^2 for 40 seconds. Conventional B method (CB) involves light irradiation at 300mW/cm^2 for 80 seconds. Pulse Delay (PD) uses an initial low energy dose (300 mW/cm^2) for 3 seconds followed by a three minutes waiting time and a final cure at high energy dose at 600 mW/cm^2. The Soft-start (SS) method uses initial low-light intensity (300 mW/cm^2) for 10 seconds immediately followed by final cure at high light intensity (600 mW/cm^2) for 30 seconds. Light intensities were periodically checked with a commercial radiometer (100P/N-150503, Demetron Research Corp., Danbury, CT, USA) before the

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Table 1: The different light-curing methods examined.

Light-curing method	Exposure regimen
Conventional A (CA)	600mW/cm^2 (40 seconds)
Conventional B (CB)	300mW/cm^2 (80 seconds)
Pulse Delay (PD)	300mW/cm^2 (3 seconds) – 3 minutes waiting time – 600mW/cm^2(37 seconds)
Soft-start (SS)	300mW/cm^2 (10 seconds) –600mW/cm^2(30 seconds)

start of each experimental session to ensure consistency of light output. Specimens were built using a steel mold (15 mm long x 5 mm wide x 4 mm deep), corresponding to the accurate measure of the existing space in the toothbrushing machine´s metallic bar for the setting of each specimen. A first portion of the resin composite with 2 mm of thickness and 7.5 mm of length was accommodated in the mold, representing half of the length and half of the height of the internal socket, corresponding to ¼ of its total dimensions. Three more portions were used for the specimen finalization (Table 1).

The specimens were then removed from their molds and stored in distilled water for one week at 37ºC and 100% relative humidity. After this period, polishing was performed using a sequence of 320, 600, 800 and 1200 grit silicon carbide abrasive paper with water-cooling for 60 seconds each, polished with 1μm and 0.3μm aluminum oxide pastes to produce uniform composite surface, necessary condition for posterior wear measurement. The specimens were prepared and submitted to the wear resistance testing methodology used for tooth brushing simulation. The automatic tooth brushing simulation apparatus (M.N.) presents reciprocating and independent motion on 10 toothbrush heads under a controlled ambient temperature of 37 ± 2ºC. Toothbrush heads (Oral-B Indicator 40 Soft, Oral-B Laboratories, Delmont, Ca, USA) with straight, soft bristles were placed in special attachments aligned parallel to the base. Half of each specimen´s top surface was protected with a polyethylene film, serving as a reference surface and allowing for a clear identification between the brushed and the protecting areas: essential condition for the identification of the consumed surface. Each specimen was subjected to cyclic brushing at a stroke rate of 4.5 strokes per seconds and a vertical load of 300 g in abrasive slurry. The slurry consisted of a deionized water and dentifrice Colgate (Colgate Palmolive, Co. Osasco/SP), prepared by mixing 2:1 by weight, immediately before testing. This slurry was injected independently and automatically by the machine next to each toothbrush head at a frequency of 0, 4 mL per 2 minutes. A total of 100.000 strokes were performed for each specimen, being representative of 4, 2 years of service, and toothbrushes were renewed every 50.000 strokes. After the simulated tooth brushing test, the specimens were cleaned with running water followed by an ultrasonic bath for 10 minutes and surface profile tracings were taken using a profile meter Tester Hommel Tester T100 basic (Hommelwerke GmbH ref. # 240851 – Schwenningem – Germany). For the surface profile evaluation, tracing parameters were established at Lt: 4.8 mm and Lc: 0.8 mm. On each evaluated surface, five different traces in random directions along its length were performed to assure linear profile pattern, and the average of these readings was established as the total wear of the specimen. Values were expressed in micrometers, as the average mean distance between the peaks and valleys of the surface profile. This device is accurate to 0.01 μm. A 5 μm diamond tip needle was used to record surface wear measurements with constant speed of 0.15 mm/s and a force of 0.8 mN. Data was submitted to one-way ANOVA/Tukey's test. All statistical analysis was carried out at significance level 0.05.

Results

Table 2 shows the mean of abrasive wear values of the groups and the statistical analysis of wear variation (Table 2).

Based on one-way analysis of variance, the data showed significant differences in mean wear resistance for initial curing light intensities used ($p<0.0013$). When evaluating the abrasive wear of the various light curing modes, the values were found to range from 7.94 to 11.26 μm for SS and CA, respectively. The higher wear values were observed for CA and CB, while the lowest were for PD and SS.

When the wear resistance of the experimental groups were compared, ranking the abrasive wear values were as follows: CA>CB>PD>SS. The data also provided evidence that there was no significant difference among PD and SS methods.In general, the techniques which had used low initial power density had demonstrated better mechanical behavior in comparison to those of higher power density.

Discussion

Even though a laboratory study is not able to reproduce all the conditions of the oral environment, it is still relevant for prediction of clinical performance. To assess the role of photo activation methods on wear resistance, factors influencing the transmission of light such as the thickness of the restorative material, the presence and size of filler particles and the distance of the light tip to the restoration surface were all standardized in the present study. Thus, any differences in wear may be attributed to the light curing regimens.

The ideal situation looked for professional is the attainment of a restoration with high performance from the mechanical requests, and at the same time, with a proper marginal sealing. However, the conciliation of such characteristics seems to be contradictory, where as its opposition is related to the degree of conversion.

While a high degree of conversion manifests itself by means of a restoration with good mechanical properties [10], a low degree of conversion leads to a lesser polymerization shrinkage, when the amount of monomers linked to each other in a polymer chain is minor [4].

Table 2: Mean of abrasive wear values (μm) of the groups and the statistical analysis of wear variation. Same letters show no statistical differences.

Groups	Wear* (standard deviation)
G1 – Conventional A	11.26a (0.96)
G2 – Conventional B	9.31b (1.03)
G3 – Pulse Delay	8.50c (0.82)
G4 – Soft Start	7.94c (1.27)

The efficacy of polymerization reaction is related to the energy application sequence, when the depth of polymerization and mechanical performance are considered [6]. Techniques are used to control shrinkage, improving the restoration´s final behavior [4].

The aim of the techniques, which comprise initiation of light-curing at a low light intensity and time delay, is to allow the occurrence of a more evident pre-gel phase, which would provide a lower rate of conversion of monomers and thus allow material flow, yielding lower internal stress from shrinkage and providing better marginal adaptation. One major hypothesis supporting the application of soft-start curing is that the viscoelastic composites cured with lower initial light intensity take longer time to reach the vitrification stage, during which the shrinkage stress developed can be partially relaxed by the viscous flow and molecular relaxation. At the final stage of these techniques, completion of curing at a high light intensity would provide a proper degree of conversion, which is required for the achievement of satisfactory physical and mechanical properties [4,12].

The irradiance output of the light sources, also known as energy density, constitutes one important factor to be considered in the polymerization process; therefore it represents thenumber of photons emitted per unit of time, in a distance of one centimeter squared of theocclusal surface of the resin composite. This distance and a high exposure time of then light can compensate the energy application, once the data from SS technique of this study do not demonstrate lower wear resistance for this technique.

This study verified an indirect correlation between energy application sequence and wear resistance. It may be hypothesized that a rapid conventional continuous cure or high intensity light lead to fast polymerization reaction of the resin composite. This will lead to the increase of the material´s modulus of elasticity [1], rendering a limitation of the mobility of monomers [6]. When the material is subjected to the abrasion tooth brushing process, these unreacted monomers would compromise the resistance of the restoring material, facilitating the wear process. In turn, a polymerization initiated with low power density light, characterized in this study for “pulse delay” and “soft start”, proved to be more favorable to the formation of a more abrasion resistant polymer, possibly due to longer time period for molecular rearrangements.

Chen et al. demonstrated that the first ten second of light curing process are essential for the photoinitiator´s photon absorption in the restoring material [17]. After this period, a significant reduction of this absorption capacity occurs. When a initial high power density is irradiated to the resin composite, a good amount of the energy is absorbed, speeding up the polymerization reaction and contributing for the reduction of the pre-gel phase.

In this study, the results of wear resistance of pulse delay low-irradiation were not significantly lower than the standard conventional high light intensity. Those findings are in line with Witzel et al. [9] who found that “soft start” and “pulse delay” techniques did not affect neither monomer conversion nor flexural strength of a resin composite. Asmussen et al., however, found that the degree of conversion and hardness obtained with standard conventional light were significantly greater than those obtained with “stepped” curing light and “soft start” light exposure regimen [10]. Moreover, Soh et al. suggested that polymerization with “pulse delay” resulted in a lower crosslink density and gave rise to polymers with an increased susceptibility to softening in ethanol [13].

This study, however, does not corroborate with the conceptions displayed for authors who report that low-intensity curing regimens result in polymers with increased susceptibility to ethanol degradation and, consequently, with a more fragile mechanical behavior, based in micro hardness tests before and after the storage in solution of ethanol and glass transition temperature analysis [10,13-15].

Different light curing modes can result in a different result of composite resin wear resistance. The *American Dental Association* signs the indication of a wear until 50 micrometers in one year [18]. Considering this parameter, all the analyzed groups demonstrated values located inside it.

What is important to look out is that although there is a numerical difference between groups, probably, of the clinical point of view, it could not be consider as isolated element to affect the behavior of the restoration, once the parameter signaled for the *American Dental Association* for acceptance of the resin composites to be used in posterior teeth is the indication of a wear until 50micrometers in one year [18]. Considering this parameter, all the analyzed groups demonstrated values located inside it.

Conclusions

The use of low intensity light, such as “pulse delay” and “soft start” photo activation methods, may be a clinically useful polymerization method, once this study suggested it did not affect the abrasive wear resistance of the resin composite tested.

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