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ORIGINAL ARTICLE

Impact of the distance of light curing on the degree of conversion and microhardness of a composite resin

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Abstract

Objective. This study evaluated the impact of the distance between the light guide tip of the curing unit and material surface on the degree of conversion and Knoop microhardness of a composite resin. ***Materials and methods.*** Circular samples were carried out of a methacrylate micro-hybrid resin-based composite and light cured at 0, 2 and 4 mm distance. Monomer conversion rate was measured using a Fourier-transform Raman spectrometer and Knoop hardness number was obtained using a microhardness tester on the top and bottom surfaces. Data were statistically analyzed by analysis of variance and Tukey's test ($\alpha = 0.05$). ***Results.*** Overall, the increase of curing distance reduced the microhardness ($p \leq 0.05$), but did not influence the carbon double bond conversion rate ($p > 0.05$) of the composite resin tested; and the top surface showed better properties compared to the bottom ($p \leq 0.05$). ***Conclusions.*** The light curing at distance can reduce mechanical properties and could affect long-term durability of the composite restorations. Thus, the use of a curing device with high irradiance is recommended.

Key Words: *dental materials, polymerization, physical properties*

Introduction

Currently, the demand for resin-based esthetic restorations has been increased and successfully used in operative dentistry, mainly as an alternative to the amalgam in posterior teeth [1,2]. However, the optimal monomer conversion into polymer throughout the bulk of a light-activated composite resin is acknowledged to be important to dental restorations longevity [2]. Inadequate polymerization can reduce the physical properties [3,4], resulting in the elution of components from cured resinous materials such as residual monomer, which may irritate soft tissues and jeopardize the long-term clinical success of composite restorations [5].

Dentist professionals, in daily clinical practice, found deep cavities that result in the light curing away from the surface of light-activated resin-based materials. Thereby, the light power intensity that reaches the restorative material is decreased in this situation, reducing the C=C monomer conversion [6] and/or resulting in formation of a higher linear polymer content, which is more susceptible to the softening and degradation than cross-linked structure [7]. A previous study reported that 1 mm of distance between the light guide tip of the curing unit and light-activated material surface decreases light power intensity by ~10% [8].

The degree of conversion (DC) of composite resins is directly related to mechanical properties [9]. Microhardness values have shown a strong correlation with the DC measurements obtained by vibrational methods, such as Fourier-transformed infrared (FT-IR) and FT-Raman spectroscopy [10–12]. In addition, the DC alone is not enough to characterize completely the three-dimensional dental composite structure,

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whereas different carbon double bond concentrations co-exist in the same polymer [13]. A similar monomer conversion rate may result in different linear polymer content, which is more susceptible to softening than a more cross-linked polymer network [2,14].

Thus, the aim of this study was to evaluate the DC and hardness of a composite resin at different distances of light curing. The tested hypothesis was that the C=C conversion rate and microhardness would decrease according to the increase distance of curing.

Materials and methods

The experimental design of this study was one factor split-plot randomized complete block arrangement. The factor considered was light curing distance in three levels (0, 2 and 4 mm) and, as a sub-factor, surface analyzed in two levels (top and bottom).

The Filtek Z250 (shade A2, Lot. # N144001BR; 3M Espe, St. Paul, MN) micro-hybrid composite resin was evaluated. A Teflon mold of 5 mm in diameter and 2 mm in thickness was filled with one increment of composite, covered with a polyester strip, pressed with a 500-g load and cured for 20 s using a second-generation light-emitting diode (LED) curing unit (Bluephase 16i; Ivoclar Vivadent, Bürs, Austria) at 1390 mW/cm^2, monitored by a radiometer (Kerr Demetron, Danbury, CT).

The light curing was performed at 0 (control), 2 and 4 mm of distance between the material surface and light guide tip of the device, simulating the clinical restorative procedure in a deep cavity. A holder coupled to the light-curing unit (LCU) was used to standardize the curing distance, controlled by a digital caliper. Then, the samples were removed from the mold and dry stored in a lightproof vial at 37°C for 24 h. After this period, both surfaces of each sample were polished with 1200-grit silicon carbide (SiC) abrasive paper (CarbiMet 2 Abrasive Discs; Buehler, Lake Bluff, IL).

The double carbon bonds conversion rate of top and bottom surfaces ($n = 5$) was measured using a Fourier Transform Raman (FT-Raman) spectrometer (RFS 100/S, Bruker Optics Inc., Billerica, MA), equipped with a Nd:YAG laser. Absorption spectra of uncured and cured material was recorded in the region between 2000–1000 cm^{-1} frequency range, with 16 scans at 4 cm^{-1} of resolution using a baseline technique [15], based on the bands 1638 cm^{-1} (aliphatic C=C bonds) and 1608 cm^{-1} (aromatic component group) as an internal standard. DC was calculated according to the formula: DC (%) = [1 – (R polymer/R monomer)] ×100, where R represents the ratio between aliphatic and aromatic band absorptions, respectively.

The microhardness readings ($n = 10$) were performed on the top and bottom surfaces of each sample using a microhardness tester (HMV-2T E; Shimadzu Corporation, Tokyo, Japan) with a Knoop diamond indenter under a 50-g load for 15 s. Five Knoop hardness number (KHN) measurements were made on the surface of each sample by the same operator, one at the sample center and the other four at a distance of ~100 μm from the central location. The average of the five values was calculated as the KHN for each sample.

The DC and KHN data were tabulated and evaluated for normality by the Kolmogorov-Smirnov test. Normal distributions were observed, so the data were statistically analyzed by the one-way analysis of variance (ANOVA) in a split-plot arrangement and Tukey's test for pairwise comparisons at a pre-set alpha of 0.05. The factor (parcel) considered was light curing distance in three levels and, as sub-factor (sub-parcel), the surface analyzed in two levels.

Results

For DC, ANOVA showed a statistical difference only for sub-factor surface ($p = 0.0028$). There was no significant difference for factor curing distance ($p > 0.05$) or for interaction of the factor and sub-factor ($p = 0.2213$).

The increased distance of light curing did not reduce the DC values. However, the top surface presented a higher conversion rate than the bottom, independently of factor in study (Table I).

For KHN, both factor and sub-factor studied, as well as for interaction of the same, ANOVA showed statistical difference ($p \leq 0.05$).

The top surface presented higher microhardness than the bottom ($p < 0.001$), except when the composite was light cured at 4 mm distance. Overall, the curing of the composite resin with the light tip device

Table I. Degree of conversion and Knoop hardness number means (SD) according to distance of light curing and surface analyzed.

	DC (%)		KHN (Kgf/mm^2)	
Distance (mm)	Top	Bottom	Top	Bottom
0	67.48 (6.06)^{Aa}	60.54 (7.59)^{Ba}	35.90 (3.03)^{Aa}	27.51 (3.43)^{Ba}
2	63.35 (6.36)^{Aa}	59.08 (3.19)^{Ba}	30.55 (1.94)^{Ab}	25.31 (2.03)^{Ba}
4	60.37 (4.94)^{Aa}	58.65 (6.10)^{Ba}	21.91 (2.70)^{Ac}	20.28 (1.31)^{Ab}

Distinct letters (capital case in the row and lower case in the column) are statistically different ($p \leq 0.05$).

resting against the material surface resulted in higher KHN ($p < 0.001$). These findings are illustrated in Table I.

Discussion

The clinical success of composite restorations over an extended period of time has been reported by several studies [1,16,17]. An adequate monomer conversion rate of light-activated resinous materials is related to better physical properties and improvement of the longevity of dental restorations. A lower C=C conversion has been related to compromise mechanical properties [4,18]. The DC of resin-based materials can be measured in a number of ways, microhardness test is one of the most frequently used indirect methods and vibrational spectroscopy is a direct method to verify the degree of cure [12].

The hypothesis tested was rejected, since an increase in the distance of light curing reduced the KHN, but did not affect the DC. Although there is a tendency of decreasing on the monomer conversion with the increase of distance, this difference was not statistically significant. However, for the microhardness test there was a reduction on the KHN values, in this case the attenuation of irradiance that reached the material by the light scattering in accordance with the increase of distance of curing impaired this physical property. A previous study showed that ~10% of light power intensity is reduced with 1 mm of air between the guide tip of the LCU and the material surface [8]. Furthermore, an equal monomer conversion rate may result in different linear and cross-linked polymer content [2], which could result in the difference on the DC and KHN values.

The top surface showed higher DC and KHN compared to the bottom, except for the microhardness assay, when the light curing was performed at 4 mm distance. The result observed is due to the decline of the irradiance achieved on the bottom surface of the restorative material by the increase of distance between the guide tip of the LCU and resin-based material surface, light scattering by the filler particles and resinous matrix and the thickness of the composite [6,19].

The polymerization effectiveness is directly proportional to irradiant exposure [19] and can be affected by factors such as exposure time, light power intensity, distance of the guide tip of the LCU from the resinous material surface and others [6]. The extended exposure time can increase the irradiant energy, even without changes in the light power intensity [20], thus the higher radiant exposure available for the carbon double bond conversion can improve the physical properties of light-activated resin-based materials [14,20,21]. Therefore, the use of LCU with high irradiance, principally when the light curing is performed at a distance of irradiated material, can improve the long-term durability of adhesive restorations, due to improvements on the physical properties [1].

The performance of two posterior composite resins after 22 years was evaluated by a previous retrospective longitudinal study [1], both restorative materials showed good clinical behavior with the lowest annual failure rate for the composite with more filler load content, suggesting that physical properties of the material may have some impact on the restoration durability. Therefore, small differences on the physical properties in the short-term could result in similar clinical performance, but not over an extended period of time.

Thus, it is possible to conclude that light curing at a distance can influence negatively the physical properties and could affect the long-term durability of composite restorations, so the use of curing device with higher irradiance is recommended in this situation.

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***Declaration of interest*: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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