FACULDADE DE ODONTOLOGIA DE PIRACICABA
UNIVERSIDADE ESTADUAL DE CAMPINAS

Flávio Henrique Baggio Aguiar

ESTUDO DE FATORES INFLUENTES NA DUREZA SUPERFICIAL DE UM COMPÓSITO FOTOATIVADO

Tese apresentada à Faculdade de Odontologia de Piracicaba, da Universidade Estadual de Campinas, para obtenção do Título de **Doutor** em Clínica Odontológica. Área de Dentística

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Dedicatória

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SUMÁRIO

RESUMO:

A qualidade de polimerização dos compósitos dentais é um importante parâmetro a ser considerado para o sucesso clínico da restauração realizada. Muitos fatores podem interferir na quantidade de energia luminosa que um incremento de compósito recebe, entre eles, a distância entre a ponta do aparelho de fotoativação e a superfície do compósito, a intensidade do aparelho de fotoativação, a especificidade de luz emitida pelo aparelho de fotoativação, o tempo de fotoativação, cor, opacidade e espessura do compósito. Assim, o objetivo deste trabalho, composto por quatro experimentos, foi avaliar as influências: **1)** da cor do compósito na dureza superficial de topo e fundo, em simulação clínica na qual a ponta do aparelho de fotoativação estava distante 2, 4 e 8mm da superfície de topo do compósito; **2)** do modo e do tempo de polimerização na dureza superficial de topo e fundo, em simulação clínica na qual a ponta do aparelho de fotoativação estava distante 8mm da superfície de topo do compósito; **3)** da espessura do compósito na dureza superficial de topo e fundo, em simulação clínica na qual a ponta do aparelho de fotoativação estava distante 2, 4, 6 e 8mm da superfície de topo do compósito; **4)** da espessura do compósito e do modo de polimerização na dureza superficial de topo e fundo, em simulação clínica na qual a ponta do aparelho de fotoativação estava distante 8mm da superfície de topo do compósito. Com base nos resultados obtidos e sob as condições experimentais deste estudo, pôde-se concluir que: 1) a dureza da superfície de topo foi pouco afetada pelos fatores estudados, não sendo um parâmetro adequado para mostrar a eficácia de polimerização do compósito, entretanto a dureza da superfície de fundo foi consideravelmente afetada pelos fatores analisados; 2) a distância entre a ponta do aparelho de fotoativação e a superfície do compósito foi um fator relevante, pois quanto maior esta distância, menor foi a dureza da superfície de fundo do compósito; 3) o compósito teve a capacidade de reduzir a penetração da energia luminosa, e conseqüentemente reduzir significativamente a dureza da superfície de fundo, independentemente dos fatores estudados; 4) quando a distância entre a ponta do aparelho de fotoativação e a superfície do compósito for superior a 4mm, deve-se triplicar o tempo de polimerização; utilizar cores claras, desde que não haja comprometimento de estética e fontes de luz eficientes,

comprovada por estudos científicos com credibilidade; 5) quando a distância entre a ponta do aparelho de fotoativação e a superfície do compósito for igual ou superior a 2mm, deve-se utilizar incrementos de até 1mm de espessura, e, se a distância for igual ou superior a 8mm, a espessura do incremento deve ser de 0,5mm.

ABSTRACT

Adequate resin composite polymerization is a crucial factor in obtaining optimal physical performance of these materials. Several variables can affect the amount of light energy received at the top and bottom surfaces of a resin composite increment, such as, distance of the light guide tip from the resin composite, power density, light energy mode, exposure duration, shade and opacity of the resin composite and increment thickness. Thus, the aim of this study composed of four manuscripts was to evaluate the influence: 1) of the resin composite thickness on top and bottom microhardness, in a clinical simulation when the light curing tip was 2, 4, 6 and 8mm distant from the resin composite top surface; 2) of the resin composite shade on top and bottom microhardness, in a clinical simulation when the light curing tip was 2, 4, and 8mm distant from the resin composite top surface; 3) of light curing modes and light curing time on top and bottom microhardness, in a clinical simulation when the light curing tip was 8mm distant from the resin composite top surface; 4) of light curing modes and resin composite sample thickness on top and bottom microhardness, in a clinical simulation when the light curing tip was 2, 4, and 8mm distant from the resin composite top surface. Based on the results, within the experimental limits of this study, it can be concluded that: 1) the top surface microhardness was a little affected by the experimental factors, and it was not an adequate parameter to show the polymerization effectiveness of the resin composite, mainly of the bottom surface. However, the bottom surface microhardness was substantially affected by the studied factors; 2) the distance between of the light guide tip and the resin composite top surface is a factor that must be carefully analyzed, because as higher was the distance, as lower was the microhardness of the resin composite bottom surface; 3) resin composite has the capacity of reducing the light energy penetration, and consequently, the polymerization effectiveness of the bottom surface of the sample, independent of the others factors studied; 4) when the distance between of the light guide tip and the resin composite top surface is superior to 4mm, it should increase the light curing time at least three times; use light resin composite shades, since they do not have any esthetic involvement; and use efficient light curing devices; 5)

when the distance between of the light guide tip and the resin composite top surface is superior or equal to 2mm, it should use resin composite increments of 1mm thick.

1- INTRODUÇÃO GERAL

A reação de polimerização do compósito dental ocorre pela conversão de moléculas de monômeros numa estrutura de polímeros com ligações cruzadas (Friedl *et al.*, 2000; Feilzer *et al.*, 1990). Quando a canforoquinona, molécula responsável por iniciar a reação de polimerização, absorve um fóton de luz (unidade final da energia luminosa) de comprimento de onda de aproximadamente 467 nm, um elétron desta molécula é impulsionado para um nível de energia maior, deixando-a num estado excitado (Lehninguer, 1991). Assim, a canforoquinona colide com uma amina, e um radical livre é formado. Este radical pode reagir com uma ligação dupla de carbono (C=C) de uma molécula de monômero iniciando assim a reação de polimerização (Price *et al.*, 2002), na qual os monômeros que tiveram a dupla ligação de carbono quebrada em um ou nos dois extremos desta molécula reagem com outros monômeros na mesma situação, formando-se moléculas de polímeros.

A formação de macromoléculas de polímeros está associada à contração de polimerização do compósito (Friedl *et al.*, 2000; Feilzer *et al.*, 1990). Quanto maior a intensidade da energia luminosa (quantun) usada no processo de fotoativação, mais fótons irão reagir com as moléculas de canforoquinona dentro da matriz resinosa do compósito, aumentando assim o grau de conversão, isto é, a quantidade de monômeros convertidos em polímeros. Desta forma, a quantidade de energia luminosa é o fator principal para o grau de conversão do compósito (Abade *et al.*, 2001).

Entretanto, tem se verificado que o material resinoso não é totalmente polimerizado, pois contém pequena quantidade de monômeros residuais entre as estruturas de polímeros formadas (Asmussen & Peutzfeldt, 2001, Silikas *et al.*, 2002). Assim como o grau de conversão está relacionado com as propriedades físicas do compósito (Rueggeberg, *et al.*, 1994), a quantidade de monômeros remanescentes é um co-determinante das propriedades físicas do polímero resultante (Asmussen & Peutzfeldt, 2001).

Há muitos fatores que podem afetar a quantidade de energia luminosa que a superfície de topo e de fundo de um incremento de compósito recebe, como tipo e tamanho da ponta do aparelho de fotoativação, distância entre a ponta do aparelho de fotoativação e a superfície do compósito, intensidade de luz emitida pelo aparelho de fotoativação, a especificidade de luz emitida pelo aparelho de fotoativação, interação entre o comprimento de onda da luz do aparelho de fotoativação e o agente iniciador da reação de polimerização, tempo de fotoativação, composição, cor, opacidade e espessura do compósito (Shortall *et al.*, 1995; Correr Sobrinho *et al.*, 2000 (a); Correr Sobrinho *et al.*, 2000 (b); Yap, 2000; Leloup *et al.*, 2002; Prati *et al.*, 2002;). Se o incremento do compósito não receber energia total suficiente para uma adequada reação de polimerização, vários problemas podem surgir, determinando o insucesso clínico da restauração. Entre eles, pode-se citar: alteração das propriedades físicas, aumento na taxa de pigmentação, aumento na taxa de desgaste, aumento do potencial de citotoxidade pela presença do monômero residual, diminuição do módulo de elasticidade, fraca união entre dente, adesivo e compósito, e maior probabilidade de colapso na interface dente-restauração (Ferracane & Grener, 1984; Yap, 2000; Price *et al.*, 2002; Asmussen & Peutzfeldt, 2002; Asmussen & Peutzfeldt, 2003).

A quantidade de energia também pode determinar a estrutura de polímero formado. Segundo Asmussen & Peutzfeldt (2001), uma alta intensidade de energia pode ativar muitas moléculas de canforoquinona ao mesmo tempo, o que poderia levar à quebra de muitas ligações duplas de carbono em um mesmo polímero, resultando numa rede de polímero com estrutura parecida a uma escada.

Entretanto, quando a intensidade de energia é baixa, poucas moléculas de canforoquinona são ativadas, levando à formação de poucos centros de crescimento de polímeros. Conseqüentemente, a propagação de polimerização será predominantemente formada com a adição de um monômero após o outro, formando cadeias lineares de polímeros. Se a intensidade de polimerização for aumentada, outras moléculas de canforoquinona serão ativadas, levando à formação de outros centros de crescimento de polímeros, criando uma cadeia de polímeros ramificados com o formato de um galho de árvore (Asmussen & Peutzfeldt, 2001).

Porém, se a intensidade de energia luminosa for baixa e conseqüentemente afetar poucas moléculas de canforoquinona, haverá poucos centros de formação de polímeros. Este processo levará à formação de cadeias lineares de modo que na camada mais profunda do incremento do compósito, estes polímeros lineares não se interligarão, diminuindo assim as propriedades físicas do compósito (Asmussen & Peutzfeldt 2001).

Dentre os fatores que podem reduzir a intensidade de luz que atinge um compósito, o único que não pode ser controlado pelo cirurgião dentista durante a realização de uma restauração de uma cavidade profunda é a distância entre a ponta do aparelho de fotoativação e a superfície do incremento do compósito. Segundo Prati *et al.* (1999), apenas 1mm de ar interposto entre a ponta do aparelho de fotoativação e a superfície do compósito reduz a intensidade de energia luminosa em aproximadamente 10%.

Em situações clínicas na qual se têm cavidades profundas, é comum a distância entre o primeiro incremento de compósito e a ponta do aparelho de fotoativação ser maior do que 8 mm, o que reduziria a intensidade de luz que atinge a superfície do compósito, diminuindo o grau de conversão e/ou levando à formação de polímeros com estruturas lineares. Em ambas as situações, o compósito apresentará propriedades físicas inferiores, descoloração superficial e da interface, e resultará no enfraquecimento da restauração (Atmadja & Bryant, 1990). Quando em contato com o meio bucal, este compósito não polimerizado adequadamente poderá ser solubilizado, acelerando o processo de solubilidade do adesivo, possibilitando infiltração marginal e cárie secundária (Asmussen & Peutzfeldt 2001).

Além disso, se este adesivo e/ou compósito polimerizado inadequadamente estiver em contato com as paredes axiais e pulpares do preparo cavitário, o monômero remanescente poderá provocar sensibilidade pós-operatória devido à sua toxidade. Estes monômeros podem facilmente se difundir pelos túbulos dentinários e causar reação inflamatória na polpa dentária, resultando em sensibilidade (Costa *et al.*, 2003). Se este processo persistir sem nenhuma providência clínica, o processo inflamatório pode levar a necrose pulpar (Brännström, 1986).

Como a distância entre a ponta do aparelho de fotoativação e a superfície do incremento do compósito é difícil de ser controlada, pois depende da extensão da cárie e da profundidade da cavidade após o preparo cavitário, deve-se atentar para outros fatores, como: intensidade de luz da fonte do aparelho de fotoativação, a especificidade de luz emitida pelo aparelho de fotoativação, tempo de fotoativação, cor, opacidade e espessura do compósito, na tentativa de se minimizar a redução na intensidade de luz provocada pelo distanciamento da ponta do aparelho de fotoativação. Assim, torna-se importante analisar a influência destes fatores na polimerização do compósito quando a situação acima citada não puder ser evitada.

2- PROPOSIÇÃO:

O objetivo deste estudo *in vitro*, composto por quatro artigos científicos, foi avaliar a influência:

- da cor do compósito na dureza superficial de topo e fundo, na qual a ponta do aparelho de fotoativação estava distante 2, 4 e 8mm da superfície de topo do compósito (Capítulo 1);
- do modo e do tempo de polimerização na dureza superficial de topo e fundo, na qual a ponta do aparelho de fotoativação estava distante 8mm da superfície de topo do compósito (Capítulo 2);
- da espessura do compósito na dureza superficial de topo e fundo, na qual a ponta do aparelho de fotoativação estava distante 2, 4, 6 e 8mm da superfície de topo do compósito (Capítulo 3);
- da espessura do compósito e do modo de polimerização na dureza superficial de topo e fundo, na qual a ponta do aparelho de fotoativação estava distante 8mm da superfície de topo do compósito (Capítulo 4);

3- CAPÍTULO

Capítulo 1

TITLE:

Effect of light curing tip distance and resin shade on microhardness of a hybrid composite resin

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TITLE

Effect of light curing tip distance and resin shade on microhardness of a hybrid composite resin.

ABSTRACT

Composite resin shades and composite resin polymerization performed with a distanced light tip are factors that can affect polymerization effectiveness. This *in vitro* study aimed to evaluate the influence of curing tip distance and resin shade on microhardness of a hybrid composite resin (Z250 – 3M ESPE). Forty-five composite resin specimens were randomly prepared and divided into nine experimental groups (n=5): three curing tip distances (2mm; 4mm and 8mm) and three resin shades (A1; A3.5; C2). All samples were polymerized with a continuous output at 550mW/cm^2. After 24 hours, Knoop microhardness measurements were obtained on top and bottom surface of the sample, with load of 25 grams for 10 seconds. Five indentations were performed in each surface of each sample. Results showed that bottom surface samples light cured at 2mm and 4mm presented significantly higher hardness than samples light cured at 8mm. For the top surface, there were no statistical differences among the curing tip distances. Resin shade A1 presented higher hardness and was statistically different from C2, and A3.5 did not present statistical differences from A1 and C2. For all experimental conditions, top surface showed higher hardness than bottom surface. It was concluded that light curing tip distance and resin shade are important factors to be considered for obtaining adequate polymerization.

CLINICAL SIGNIFICANCE

In deeper cavities, the distance between the tip of the light curing unit and the resin composite may be detrimental, mainly for bottom surface polymerization. In this situation, the use of light shade resin composite increments will improve the bottom surface polymerization of these increments.

INTRODUCTION

Light-activated resin composite, introduced in the 1970s, revolutionized clinical dentistry by maximizing working time and minimizing setting time (Yap & Seneviratne, 2001). Improvements in composite resin mechanical properties and light curing devices have permitted their use in posterior teeth with greater reliability than was the case some years ago. (Leinfelder, Bayne & Swift Jr, 1999; Manhart & others, 2000). In order to obtain optimal physical properties and clinical performance in resin composite restorations, it is necessary for a dental resin composite to have all of its monomer converted to polymer during polymerization reaction (Yoon & others, 2002). Effective polymerization of the adhesive bond system and resin composite is required to obtain long-term clinical success.

However, there are many variables that affect the amount of light energy received at the top and bottom surfaces of a resin composite restoration, resulting in ineffective polymerization, such as the design and size of the light guide, distance of the light guide tip from the resin composite, power density, exposure duration, shade and opacity of the resin composite, increment thickness and material composition (Yap, 2000; Sobrinho *et al,* 2000;

Price & others, 2002). If the restoration does not receive sufficient total energy, various problems may arise, e.g., reduced degree of conversion, increased cytotoxicity, reduced hardness, increase pigmentation, decreased dynamic elasticity modulus, increased wear, increased marginal breakdown and weak bond among the tooth, adhesive and the restoration (Ferracane & Grener, 1984; Yap, 2000; Price & others, 2002).

The distance of the light guide tip from the resin composite is a factor that is difficult to control, because it depends on the caries progression and the cavity size. When the distance is greater than 2mm, the light dispersion of the light curing unit increases, and it becomes difficult to obtain effective polymerization. Clinically, deficient polymerization can happen in deeper Class I and Class II cavities, due the dispersion of light energy that occurs because of the distance between the light curing tip and the first resin composite increment (Prati *et al*., 1999). In a deeper Class II cavity, the interface between the first increment of resin composite and the tooth structure may be less polymerized, and exposure of this interface to the oral environment can generate marginal discoloration, restoration fractures and resin composite and adhesive solubility, leading to microleakage and secondary caries. If the less polymerized resin composite comes into contact with the pulp and axial walls of the cavity, the remaining monomer can result in post-restorative sensitivity, because of its toxicity. These monomers can easily diffuse inward beyond the dentin and cause an inflammatory reaction in the pulp, resulting in sensitivity. If this process continues unchecked, the inflammatory process can cause pulp necrosis (Brännström, 1986).

Few studies have been carried out with the purpose of testing the depth resin

composite cure in situations in which the light curing tip is distanced from the filling material, as in the above-mentioned clinical situations. Thus, this study hypothesizes that in the deeper increments of a cavity, light shade resin composites can be used to obtain adequate polymerization, since they do not have any esthetic involvement. When the increment is close to the light cutting tip (last increment), the correct resin composite shade (usually darker shades) can be used. Thus, the aim of this *in vitro* study was to evaluate the effect of light curing tip distance and resin shade on the top and bottom resin composite surfaces hardness.

METHODS AND MATERIALS

To conduct this study, a hybrid composite resin Z250 (3M-ESPE Dental Products, St. Paul, MN, USA) was used. Forty five cylindrical specimens were prepared in Teflon ring molds, 4.0mm in internal diameter and 2 mm depth, held between two glass slabs separated by milar matrix strips, and then pressed with a 500g static load. The cavity was randomly filled in one increment and polymerized according to the nine experimental groups (n=5): three curing tip distances (2mm; 4mm and 8mm) and three resin shades (A1; A3.5; C2) (Table 1). All samples were polymerized with a continuous output at 550mW/cm^2 (XL 3000 – 3M Espe – Grafenau, Germany) for 20 seconds. Polymerization was performed with the light tip positioned in a device, the light curing tip being 2mm, 4mm or 8mm distant from the top surface of the sample (controlled by an electronic digital caliper).

Each specimen was removed from the mold and stored in a lightproof container at 37°C and 95% ± 5 relative humidity for 24 hours. After this period, the samples were washed and the hardness on the bottom and top of each specimen was tested using a Knoop hardness test (FM - Future Tech Corp., Japan) under a 25 g load for 10 s. Five measurements were taken at the approximate center of the specimen (Price, 2002). The values obtained in micrometers were converted to Knoop Hardness Number (KHN) in a computer software (Excel for Windows® - Microsoft Ind. – CA).

The results of the top and bottom surface Knoop hardness were submitted to subdivided parcels ANOVA (Split Plot) test (p=0.05) and Tukey test at the 5% significance level. The factors light curing modes and polymerization times were considered in the parcels and the factor surface (top and bottom surfaces) was considered in the sub-factor.

RESULTS

The microhardness test results are presented in Tables 2 and 3 and Figure 1. ANOVA revealed significant differences among the factors light curing tip distance and resin shade, and a double interaction between curing tip distance and surface. Tukey test was applied to individual comparisons (p=0.05). Within the light curing tip distance, bottom surface samples light cured at 2mm and 4mm presented higher hardness than samples light cured at 8mm (Table 3). For the top surface, there were no statistical differences among the curing tip distances (Table 2). Within the factor resin shade, there were statistical differences only on the bottom surface (Table 2 and 3). A1 showed higher hardness and it was statistically different from C2, and A3.5 did not show any statistical

differences from A1 and C2 (Table 3). For all experimental conditions, the top surface showed higher hardness than the bottom surface.

DISCUSSION

This investigation evaluated the influence of the resin composite shades and the distance between the resin composite and the light-curing tip on the microhardness of the top and the bottom resin composite surfaces. The results showed that for the top surface, there were no statistical differences for the studied factors. However, in the bottom surface, there were differences in the two factors studied. For all experimental conditions, the top surface showed higher hardness than the bottom surface. These results demonstrated that there was a need to use light resin composite shades in all experimental distances of the light-curing tip from the top surface of the resin composite.

Adequate polymerization is a crucial factor in obtaining the optimal physical performance of these materials (Knezevic & others, 2001), and it is related to better clinical performance. However, there are many variables that affect the amount of light energy received at the top and bottom surfaces of a resin composite restoration. Among these factors, the distance of the light guide tip from the resin composite and shade and opacity of the resin composite were analyzed in this study. The results of this study showed that these two factors were capable of affecting polymerization efficacy. Clinicians must be careful when they are faced with a clinical situation in which the pulpal, axial or the gingival wall of the cavity is distant from the light guide tip and a dark resin shade is to be used.

Results showed that resin shade is a factor that can alter polymerization efficacy. In this study, for the bottom surface, A1 showed highest hardness means and was statistically different from C2. A3.5 resin shade presented intermediate hardness means and did not show statistical differences from A1 and C2. Light transmission through the dark shades is diminished because of opacity (Sakaguchi & others, 1992). Opaque shades decrease the capacity of the light to penetrate into the bulk of the resin composite (Leloup & others, 2002). However, different resin composites of the same Vita shade have different color values and large quantitative color differences were detected among different resin composites of the same Vita shade (Shortall, Wilson & Harrington, 1995). Thus, it is possible find different results in the literature, and these results can vary according to the composition of the resin composite used. In Shortall, Wilson & Harrington study (1995), for the resin composite Z100, A2 showed statistical differences from A3.5 and C2.

Another factor studied was the light guide tip distance. Results showed that, for the bottom surface, 2mm and 4mm light tip guide distance did not show statistical differences, but both distances were statistically different from 8mm light tip distance. These results were in agreement with Correr Sobrinho & others (2000) and Caldas & others (2003) who stated that resin composite polymerization depends greatly on the distance from the curing tip. Prati & others (1999) demonstrated that the distance between the light guide and the composite resin can affect the light intensity and that 1mm of air reduces light intensity by approximately 10%. In addition to the distance, another factor that attenuates light intensity is the composite resin. This may explain why only the bottom surface was affected by the two factors studied.

On the top surface, no significant difference in hardness was observed among the experimental groups. This statement is in agreement with the Yap Wong & Siow (2003) study, which concluded that the top surface hardness of resin composites was less dependent on light intensity than the bottom surface. In this study, both factors did not influence the hardness of the top surface. However, the results showed that, on the bottom surface, the distance of 8mm and the C2 resin shade significantly decreased the hardness of the resin composite. The resin composite has the property of dispersing the light of the curing unit, thus when the light passes through the bulk of the composite, light intensity is reduced due to the light being scattered by filler particles and the resin matrix (Prati & others 1999; Sobrinho & others, 2000; Yoon & others, 2002; Yap Wong & Siow, 2003).

Yap & others, (2003) stated that the hardness ratio between bottom and top surface should be "1" to consider the polymerization completely effective, but a ratio of up to "around 0.8" can be considered to be adequate polymerization. In this study, the results showed that the ratio was between 0.49 and 0.42 for groups in which the light guide was 2 and 4 mm distant, and between 0.32 and 0.27 for groups in which the light guide was 8mm distant (Table 4). This lower ratio was affected for both resin composite increment (2mm) and the high distance from the resin composite to the light source. Both Soh, Yap & Siow (2003) and Yap & others (2003) studies showed the ratio between bottom and top surface of 1 to 0.84 for the former and 0.97 to 0.69 for the latter, but in both studies, the light guide tip was closed to the resin composite top surface. In some situations, clinicians can be faced with cavities 8mm deep or more, and as the distance between the light guide and the floor of the cavity is a factor that is difficult to control, mainly in Class II cavities, the 2mm

increment should be considered. Rueggeberg, Caughman & Curtis (1994) suggested an increment of 1mm as a way of improving resin composite polymerization and Atmadja & Bryant (1990) concluded that optimum polymerization is obtained with a greater degree of certainty by reducing the thickness of the increment rather than by increasing the exposure time. Atmadja & Bryant (1990) and Prati & others (1999) recommended increasing the polymerization time when the cavity is deep. The present study suggested that in deep cavities, dark shade resin composites must be avoided, and the dark shade must only be used for the last increment when it is esthetically necessary. Therefore, further studies are necessary.

CONCLUSION

Within the limits of this study, it can be concluded that:

1- Resin composite has the capacity of reducing light penetration, decreasing light intensity and consequently, polymerization effectiveness of the bottom surface of the sample.

2- Light curing tip distance and resin shade are important factors to be considered for obtaining adequate polymerization.

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TABLE

Table 1- Experimental groups

Groups	Light curing tip distance (mm)	Resin shades
1	2	A1
2	4	A1
3	8	A1
4	2	A3.5
5	4	A3.5
6	8	A3.5
7	2	C2
8	4	C2
9	8	C2

Table 2 – Hardness media for the top surface (KHN). Mean values with the same letter were not statistically different ($p<0.05$) (same lower case letter were not statistically different for comparison among the same tip distance groups, and same upper case letter were not statistically different for comparison among different resin shades).

Hardness media of top surface (± SD)

Resin Shade	Light curing tip distance (mm)		
	2	4	8
A1	78,10 (8,35) Aa	72,38 (9,2) Aa	77,52 (9,17) Aa
A3.5	70,18 (13,69) Aa	71,50 (9,62) Aa	73,24 (9,74) Aa
C2	73,93 (13,95) Aa	70,73 (8,62) Aa	73,56 (11,69) Aa

Table 3 – Hardness media for the bottom surface (KHN). Mean values with the same letter were not statistically different ($p<0.05$) (same lower case letter were not statistically different for comparison among the same tip distance groups, and same upper case letter were not statistically different for comparison among different resin shades).

Hardness media of bottom surface (± SD)

Resin Shade	Light curing tip distance (mm)		
	2	4	8
A1	37,35 (6,52) Aa	34,18 (7,06) Aa	23,39 (7,75) Ab
A3.5	36,72 (7,55) ABa	33,55 (6,66) ABa	22,72 (6,63) ABb
C2	33,05 (6,22) Ba	32,72 (5,64) Ba	20,15 (7,76) Bb

Table 4 – Hardness ratio between bottom and top surface hardness media (KHN).

	2 mm			4 mm			8 mm		
	Top	Bottom	Ratio	Top	Bottom	Ratio	Top	Bottom	Ratio
A1	78.1	37.35	0.4782	71.34	34.18	0.4791	73.93	23.39	0.3164
A3,5	74.36	36.72	0.4938	71.69	33.55	0.4679	70.53	22.72	0.3221
C2	77.92	33.05	0.4242	71.84	32.19	0.4481	72.36	20.15	0.2785

FIGURES

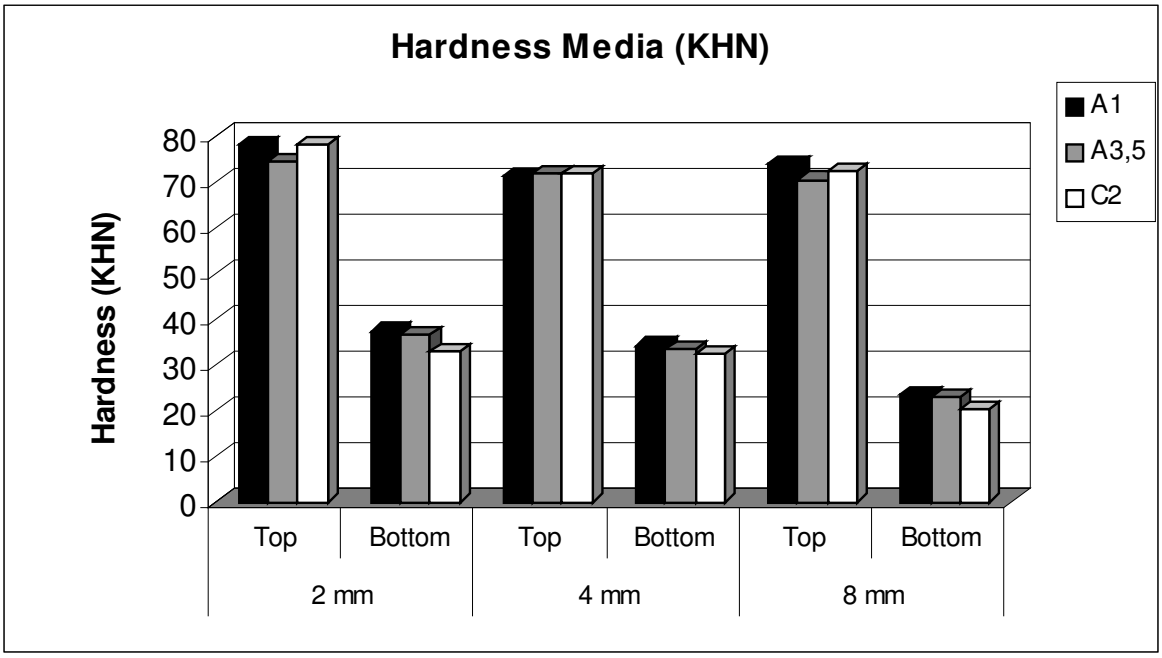

Figure 1 – Results of microhardness (KHN) for experimental groups.

Capítulo 2

TITLE:

Effect of light curing modes and light curing time on microhardness of a hybrid composite resin

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TITLE

Effect of light curing modes and light curing time on microhardness of a hybrid composite resin

CLINICAL RELEVANCE

In posterior tooth restorations with deep cavities, it is important to increase the time of light curing activation in the first increments for an acceptable polymerization.

SUMMARY

The aim of this *in vitro* study was to evaluate the influence of light curing modes and light curing time on microhardness of a hybrid composite resin (Z250 – 3M ESPE) shade A1. Forty-five composite resin specimens were randomly prepared and divided into nine experimental groups (n=5): three polymerization modes (conventional - 550 mW/cm^2; high intensity - 1160mW/cm^2; Led - 360mW/cm^2) and three light curing times (manufacturer's recommended time – 1X, twice the manufacturer's recommended time – 2X and thrice the manufacturer's recommended time – 3X). All samples were polymerized with the light tip 8mm distant. After 24 hours, Knoop microhardness measurements were obtained on top and bottom surface of the sample, with load of 25 grams for 10 seconds. Five indentations were performed in each surface of each sample. Results showed that conventional and LED polymerization modes presented higher hardness means and were statistically different from high intensity in almost all experimental conditions. Thrice the

light curing time showed higher hardness means and was statistically different from the other times for all polymerization modes in bottom surface and for high intensity in top surface. Conventional and LED at top surface did not show statistical differences from any light curing time. For all experimental conditions, top surfaces showed higher hardness than bottom surfaces. It was concluded that it is important to increase the light curing time and use appropriate light curing devices to polymerize resin composite in deep cavities.

INTRODUCTION

An important milestone in the history of modern restorative dentistry was the development of light-cured composite resins for direct procedures (Hammesfahr, O'Connor & Wang, 2003). Improvements in composite resin mechanical properties and light curing devices have permitted their use in posterior teeth with greater reliability than was the case some years ago. (Leinfelder, Bayne & Swift Jr, 1999; Manhart & others, 2000). Composite resin polymerization occurs by the conversion of the monomer molecules into a polymer network, accompanied by a closer packing of the molecules, causing contraction in the composite (Friedl & others, 2000; Feilzer, de Gee & Davidson, 1990). When more intense light energy is used to cure resin a composite, more photons reach the camphorquinone photoinitiator molecules within the resin and more photoinitiator molecules are activated and raised to the excited state. In this excited state, camphorquinone collides with an amine, and a free radical is formed, which can then react with the carbon to carbon double bond (C=C) of a monomer molecule and initiate polymerization (Price & others, 2002).

Adequate polymerization is a crucial factor in obtaining optimal physical performance of these materials (Knezevic & others, 2001), and is related to a better clinical performance. However, there are many variables that affect the amount of light energy received on the top and bottom surfaces of a resin composite restoration, such as design and size of the light guide, distance of the light guide tip from the resin composite, power density, exposure duration, shade and opacity of the resin composite, increment thickness and material composition (Yap, 2000; Price & others, 2002; Sobrinho & others, 2000). If the restoration does not receive sufficient total energy, various problems may arise, e.g., reduced degree of conversion, increased cytotoxicity, reduced hardness, increased pigmentation, decreased dynamic elasticity modulus, increased wear, increased marginal breakdown and weak bond among the tooth, adhesive and the restoration (Ferracane & Grener, 1984; Yap, 2000; Price & others, 2002).

Clinically, deficient polymerization can happen in deeper Class I and Class II cavities, due the dispersion of light energy that occurs because of the distance between the light curing tip and the first resin composite increment (Prati & others, 1999). In a deeper Class II cavity, the interface between the first increment of resin composite and the tooth structure may be less polymerized, and exposure of this interface to the oral environment can generate marginal discolorations, restoration fractures and resin composite and adhesive solubility, leading to microleakage and secondary caries.

Therefore, adequate polymerization is necessary to achieve the physical and mechanical properties of the material (Tarle & others, 1998). Over the last few years, the widespread use of light sources has given rise to manufacturers producing several varieties

of light curing units (Sobrinho & others, 2000). High intensity quartz tungsten halogen (QTH) and light-emitting diodes (LED) were recently introduced as an option for polymerization. A manner of overcoming the reduction in light intensity with distance is to use light curing units with high light intensity rate (Prati & others, 1999). Wang & Sang (2001) concluded that a resin composite polymerized with a high intensity rate significantly increased the bottom surface hardness of resin composite. Curing by high intensity light units occurs very quickly and is recommended because of the curing depth and physical properties that occur when these systems are used. High light curing can polymerize the resin composite in a shorter time, because it is compensated by the intensity. However, high light intensities do not allow enough flow for reducing internal stress, contributing to high polymerization shrinkage (Mehl, Hickel & Kunzelmann, 1997; Althoff & Hartung, 2000)

LED units feature very narrow spectral ranges and are therefore highly efficient light sources (Hofmann, Hugo & Klaiber, 2002). Operating around 470nm, with a bandwidth of about 20nm, blue LEDs have all the spectral purity for highly efficient curing of resin composites (Kurachi & others, 2001). Some studies have demonstrated a good performance of these units, like an adequate depth of cure, flexural strength and surface hardness (Jandt & others, 2000; Mills, Jandt & Ashworth, 1999). However, further studies are necessary in order for these light curing units to be used with safety, mainly when the light-curing tip is distant from the filling material.

Another way of overcoming the reduction in light intensity due to distance may be to increase the light curing time. According with Sobrinho & others (2000), the curing time recommended by manufacturers should be extended to cure the resin composite regardless

of the restoration depth. According to Prati *et al.* (1999), the clinician should adjust the light curing time to the cavity depth and light curing unit intensity.

However, few studies have been realized with the purpose of testing the depth of resin composite curing in situations where the light curing tip is distant from the filling material, like in the above-mentioned clinical situations. Thus, it becomes important to evaluate the minimum light curing time required for correct polymerization, in accordance with the light curing unit used. Thus, the objective of this *in vitro* study was to evaluate the influence of the light curing time and the polymerization mode on the top and bottom resin composite surface hardnesses, in a clinical simulation when the light curing tip was 8mm distant from the resin composite and the resin composite thickness was 2mm.

METHODS AND MATERIALS

To conduct this study, a hybrid composite resin Z250 shade A1 (3M-ESPE Dental Products, St. Paul, MN, USA) was used. Forty five cylindrical specimens were prepared in Teflon ring molds, 4.0mm in internal diameter and 2 mm depth, held between two glass slabs separated by milar matrix strips, and then pressed with a 500g static load. The cavity was randomly filled in one increment and polymerized according to the nine experimental groups (n=5): three polymerization modes (Conventional - 550 mW/cm^2; High intensity - 1160mW/cm^2; LED (1 led) - 360mW/cm^2) and three light curing times (manufacturer's recommended time – 1X; twice the manufacturer's recommended time– 2X time; and thrice the manufacturer's recommended time – 3X) (Table 1). Polymerization was performed with

the light tip positioned in a device, the light-curing tip being 8mm distant from the top surface of the sample (controlled by an electronic digital caliper).

Each specimen was removed from the mold and stored in a lightproof container at 37°C and 95% ± 5 relative humidity for 24 hours. After this period, the samples were washed and the hardness on the bottom and top of each specimen was tested using a Knoop hardness test (FM - Future Tech Corp., Japan) under a 25 g load for 10 s. Five measurements were taken at the approximate center of the specimen (Price & others, 2002). The values obtained in micrometers were converted to Knoop Hardness Number (KHN) in a computer software (Excel for Windows® - Microsoft Ind. – CA).

The results of the top and bottom surface Knoop hardness were submitted to subdivided parcels ANOVA (Split Plot) test (p=0.05) and Tukey test at the 5% significance level. The factors light curing modes and light curing times were considered in the parcels and the factor surface (top and bottom surfaces) was considered in the sub-factor.

RESULTS

The microhardness test results are presented in Tables 2 and 3 and Figure 1. ANOVA revealed significant differences among the factors light curing mode, light curing time and surface, and a triple interaction between light curing mode, light curing time and surface. Tukey test was applied to individual comparisons (p=0.05). For the top surface, there were no statistically differences among the light curing times for conventional and LED polymerization modes. For high intensity, 3X light curing time showed higher

hardness means and were statistically different from 2X and from the manufacturer's recommended time (Table 2). Within the factor light curing mode, Conventional and LED polymerization modes showed higher hardness means and were statistically different from high intensity for 1X and 2X light curing times, and for 3X light curing time, there were no statistical differences among the three polymerization modes (Table 2).

For the bottom surface. 3X presented higher hardness means there were statistical differences from 2X and 1X for Conventional and LED polymerization modes. In the high intensity group, 3X and 2X showed the highest means and were statistically different from 1X (Table 3). The Conventional polymerization mode was found to be significantly higher than high intensity in 1X and 3X light curing times. LED showed no statistical differences from any polymerization mode in 1X and 2X. For all experimental conditions, the top surface showed higher hardness than the bottom surface.

DISCUSSION

Adequate polymerization is a crucial factor in obtaining the optimal physical performance of these materials (Knezevic & others, 2001). Several studies have been performed with the intention of checking a method of polymerization, a light curing device or whether a restorative material was adequately polymerized. The effectiveness of composite polymerization may be assessed by a direct or an indirect method (Yap, Wong & Siow, 2003). Direct methods, such as laser Raman and infrared spectroscopy, are not used routinely as they are complex, expensive and time consuming (Yap, Wong & Siow, 2003; Soh, Yap & Siow, 2003). Indirect methods, which include scraping, visual and surface

hardness, are more commonly employed (Atmadja & Bryant, 1990; Yap, Wong & Siow, 2003; Soh, Yap & Siow, 2003). Incremental surface hardness has been shown to be an indicator of the degree of conversion (Asmussen, 1982; Atmadja & Bryant, 1990; Yap & others, 2003; Soh & others, 2003), and it correlated well with the infrared spectroscopy (De Wald & Ferracane, 1987; Neves & others, 2002). Therefore, this method was used in this study to evaluate the influence of the light curing time and the polymerization mode on the top and bottom resin composite surface hardnesses, in a clinical simulation when the light curing tip was 8mm distant from the resin composite.

The results of this study showed that in the above-mentioned situation, the time recommended by the manufacturers of light curing devices and resin composites was not sufficient for better polymerization, mainly on the bottom surface. On this surface, the resin composite has the property of dispersing the light of the light curing unit, thus when the light passes through the bulk of the composite, light intensity is reduced due the light scattering by filler particles and the resin matrix (Prati & others 1999; Sobrinho & others, 2000; Yoon & others, 2002; Yap & others, 2003). On the top surface, the light intensity is usually sufficient for adequate polymerization (Yap & others, 2003). The results of this study showed that, for all experimental situations, the top surface showed higher hardness than the bottom surface.

The bottom surface has been shown to be problematic in relation to the polymerization degree, and the thicker the resin composite increment is, the worse the polymerization degree will be (Atmadja & Bryant, 1990; Rueggeberg, Caughman & Curtis Jr, 1994). In this study, an increment of 2mm thickness was used due to the fact of being

indicated as adequate (Yap, 2000; Emani & Söderholm, 2003), but these studies were realized with light curing tip almost in contact with the top composite resin surface. However, the greater distance from the tip of the light-curing unit was detrimental to adequate polymerization. The ratio between the bottom and top hardness for all experimental groups (Table 4) was much lower than that considered as ideal = 0.8 or greater (Yap & others, 2003), even when the light curing time was thrice that recommended by the manufacturers. Thus, as the distance between the light curing tip and the resin composite is a factor that is difficult to control clinically, because it depends on the caries progression and the cavity size, it is possible that a thin increment would lead to a better polymerization degree. Increments thinner than 2mm were recommended by Atmadja & Bryant (1990) and Rueggeberg & others (1994). The disadvantages of thin increments are the long cure times, which are inconvenient for the patient, impractical with children, uncomfortable for the dentist and make the treatment more expensive because of the extra time spent in the chair (Peutzfeldt, Sahafi & Asmussen, 2000).

Atmadja & Bryant (1990) & Prati & others (1999) recommended increasing the light curing time when the cavity is deep. The results of this study showed an improvement of the hardness means with the increase of the light curing time, mainly on the bottom surface (Figure 1 and Tables 2 and 3). Thrice the time of light curing showed significantly higher hardness means than twice the time and the time recommended by the manufacturer, for all light curing modes on the bottom surface. Increasing the light curing time means increasing the total energy delivered at the resin composite increment, and this increase may have partly compensated the energy lost by dispersion of light because of the distance

between the resin composite and the tip of the light curing unit. On the top surface, only for the high intensity group, thrice the time showed significantly higher hardness means than twice the time and manufacturer's recommended time, supporting the statement that the top surface hardness of composites is less dependent on light intensity than the bottom surfaces (Yap & others, 2003).

When the light curing modes were compared, the conventional light unit mode showed the higher hardness means, with statistical differences for high intensity in the manufacturer's recommended time and thrice the time on the bottom surface and in the manufacturer's recommended time and twice the time on the top surface. High intensity mode presents an intensity of 1160mW/cm^2, but a low manufacturer's recommended time of 10 seconds (total energy of 11.60 J/cm^2), and a conventional mode presents an intensity of 550mW/cm^2 and a light curing time of 20 seconds (total energy of 11.00 J/cm^2). The total energy is almost the same for both light-curing times used in this study. However, two points may be the cause of the lower hardness means for high intensity mode: 1- the dispersion of intensity because of the distance leveled the intensity to that of the conventional model, and so the light curing time was the difference between both; or 2- high intensity mode lead to very fast polymerization, constituting short chain length and consequently, the elasticity modulus may have been reduced, thus decreasing the hardness (Asmussen & Peutzfeldt, 2003). The former explanation seems to be clearer in this study, mainly when it is considered that the distance between the resin composite and the light-curing tip was large and it reduced the intensity for the above-mentioned light curing modes.

The LED mode showed similar results to the conventional mode for almost all groups, except for twice the time on the top surface. On the bottom surface, LED did not differ statistically from conventional mode for any time, and it differed from high intensity in the thrice the time group. LED (light emitting diode) has a narrow spectral range with a peak around 470nm, which matches the optimum absorption wavelength for the activation of the camphorquinone (CQ) photoinitiator (Emani & Söderholm, 2003; Tsai & Meyers & Walsh, 2003). The LED mode usually presents lower intensity than the other light curing modes; however it provides a good degree of conversion because of the high degree of overlap with the absorption spectrum of CQ (Asmussen & Peutzfeldt, 2002). Therefore, it is possible that the LED mode, in spite of the experimental distance and presenting the lowest intensity of the experimental modes of this study, showed similar hardness to the conventional mode because of the similar spectrum to CQ and the light curing time recommended by the manufacturer (40s).

This study suggested that in deep cavities, it is important increase the light curing time by at least three times to improve the polymerization in the bottom surface of the first increments, and opt for an adequate light curing unit for a satisfactory polymerization of the resin composite.

CONCLUSION

Within the limits of this study, it can be concluded that:

1- Resin composite has the capacity of reducing the light penetration, decreasing the light intensity and consequently, the polymerization effectiveness of the bottom surface of the sample.
2- In deep cavities, it is important increase the light curing time at least three times to improve the polymerization in the bottom surface of the first increment.
3- It is important opt for a light curing unit and an adequate time for a satisfactory polymerization of the resin composite, mainly in restorations in deep cavities.

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TABLE

Table 1- Experimental groups (XL 3000 – 3M Espe – Grafenau Germany 28352; Elipar Freelight - 3M-Espe; Demetron – Sds Kerr – Danbury CT USA 06810-4153).

Groups	Polymerization Mode	Light Curing Time	Light Curing Time (s)	Intensity (mW/cm^2)	Light Curing Unit
1	Conventional	1X	20	550	XL 3000
2	Conventional	2X	40	550	XL 3000
3	Conventional	3X	60	550	XL 3000
4	LED	1X	40	360	Elipar Freelight
5	LED	2X	80	360	Elipar Freelight
6	LED	3X	120	360	Elipar Freelight
7	High Intensity	1X	10	1010	Optlux 501 C
8	High Intensity	2X	20	1010	Optlux 501 C
9	High Intensity	3X	30	1010	Optlux 501 C

Table 2 – Hardness media (KHN) for the top surface. Mean values with the same letter were not statistically different ($p<0.05$) (same lower case letter were not statistically different for comparison among different light curing modes, and same upper case letter were not statistically different for comparison among different light curing times).

Hardness media of top surface (± SD)

Light Curing Modes	Light Curing Time		
	manufacturer's recommended time	twice the manufacturer's recommended time	thrice the manufacturer's recommended time
Conventional	102.31 (8.76) Aa	105.68 (4.52) Aa	101.69 (9.57) Aa
LED	95.95 (4.40) Aa	95.63 (5.35) Ab	103.61 (9.95) Aa
High Intensity	87.01 (3.82) Bb	92.64 (6.07) Bb	106.70 (8.75) Aa

Table 3 – Hardness media (KHN) for the bottom surface. Mean values with the same letter were not statistically different ($p<0.05$) (same lower case letter were not statistically different for comparison among different light curing modes, and same upper case letter were not statistically different for comparison among different light curing times).

Hardness media of bottom surface (± SD)

Light Curing Modes	Light Curing Time		
	manufacturer's recommended time	twice the manufacturer's recommended time	thrice the manufacturer's recommended time
Conventional	25.86 (1.83) Ba	31.23 (5.41) Ba	48.56 (6.26) Aa
LED	21.71 (1.88) Bab	28.46 (4.35) Ba	45.27 (1.21) Aa
High Intensity	13.57 (2.45) Bb	24.41 (1.23) Aa	30.50 (3.61) Ab

Table 4 – Hardness ratio between bottom and top surfaces.

	1X			2X			3X		
	Top	Bottom	Ratio	Top	Bottom	Ratio	Top	Bottom	Ratio
Conv	102.31	25.86	0.2528	105.68	31.23	0.2955	101.69	48.56	0.4775
HI	87.01	13.57	0.1560	92.64	28.46	0.3072	106.70	30.50	0.2858
LED	95.95	21.71	0.2263	95.63	24.41	0.2553	103.61	45.27	0.4369

FIGURES

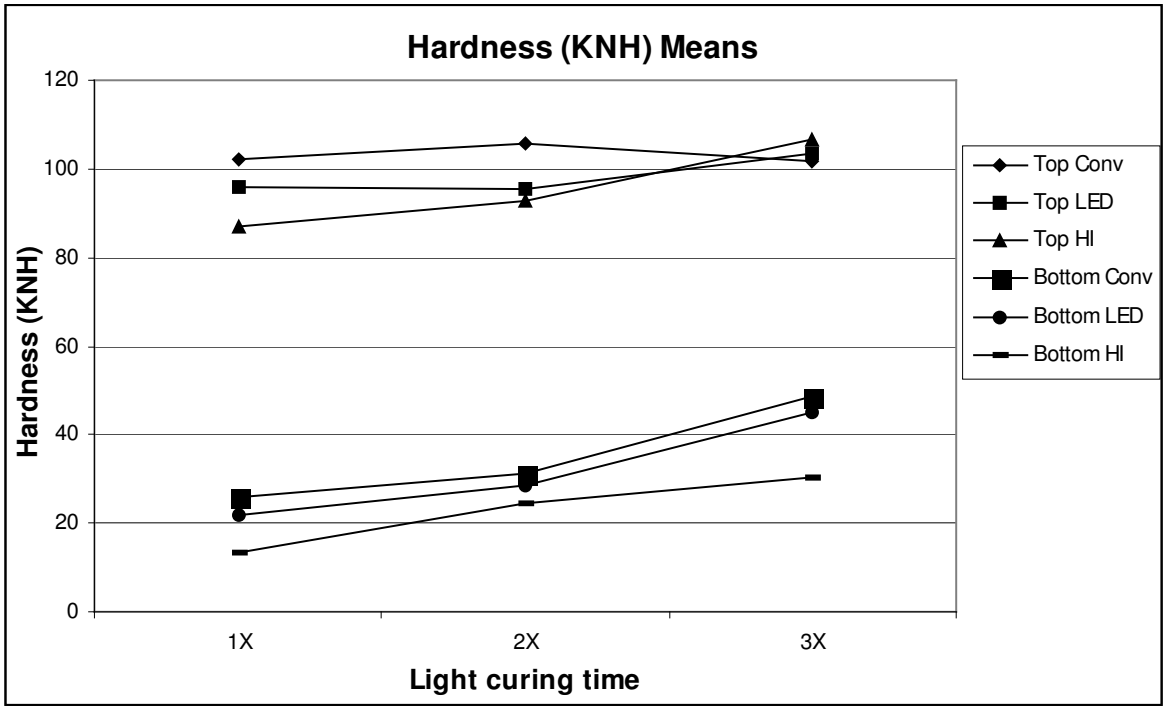

Figure 1 – Results of microhardness (KHN) for experimental groups in agreement with the light curing time.

Capítulo 3

TITLE:

Microhardness of resin composite of different thicknesses polymerized by conventional light curing at different distances

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TITLE

Microhardness of resin composite of different thicknesses polymerized by conventional light curing at different distances

SUMMARY

The aim of this *in vitro* study was to evaluate the influence of light curing modes and polymerization time on microhardness of a hybrid composite resin (Z250 – 3M ESPE). Sixty composite resin specimens were randomly prepared and divided into twelve experimental groups (n=5): four curing tip distances (2mm; 4mm; 6mm and 8mm) and three sample thicknesses (0.5mm, 1mm and 2mm). All samples were polymerized with a continuous output at 550mW/cm^2. After 24 hours, Knoop microhardness measurements were obtained on top and bottom surfaces of the sample, with load of 25 grams for 10 seconds. Five indentations were performed in each surface of each sample. Subdivided parcels ANOVA test and Tukey test were performed (p=0.05). For the top surface, there were no statistical differences among the experimental groups. For the bottom surface, 0.5 and 1mm sample thicknesses showed significantly higher hardness means than 2mm for all light curing tip distances. For the factor light curing tip distance, 2 and 4 mm showed significantly higher hardness means than 8mm for all sample thicknesses. For all experimental conditions, top surface showed higher hardness than bottom surface. It was concluded that it is important to decrease the resin composite increments to improve the polymerization of the resin composite bottom surface in deep cavities.

CLINICAL RELEVANCE

In deeper cavities, the distance between the tip of the light curing unit and the resin composite damages mainly the polymerization of the bottom surface. In this situation, the use of thinner resin composite increments will improve the polymerization of the bottom surface of these increments.

INTRODUCTION

Adequate polymerization is a crucial factor in obtaining optimal physical performance of these materials (Knezevic & others, 2001), and it is related to a better clinical performance. However, there are many variables that affect the amount of light energy received at the top and bottom surfaces of a resin composite restoration, such as design and size of the light guide, distance of the light guide tip from the resin composite, power density, exposure duration, shade and opacity of the resin composite, increment thickness and material composition (Yap, 2000; Prati & others, 2002; Correr Sobrinho & others, 2000; Correr Sobrinho & others, 2000). If the restoration does not receive sufficient total energy, various problems may arise, e.g., reduced degree of conversion, increased cytotoxicity, reduced hardness, increased pigmentation, decreased dynamic elasticity modulus, increased wear, increased marginal breakdown and weak bond among the tooth, adhesive and the restoration (Ferracane & Grener, 1984; Yap, 2000; Price & others, 2002; Asmussen & Peutzfeldt, 2000; Asmussen & Peutzfeldt, 2003).

The above-mentioned variables directly affect the depth of cure of the resin composite. The resin composite at the top surface usually receives an adequate power density of curing light during irradiation while the deeper parts, because of the absorption and dispersion of the light, receive lower power density (Prati & others 1999; Correr Sobrinho & others, 2000; Yoon & others, 2002; Yap Wong & Siow, 2003; Asmussen & Peutzfeldt, 2003). Top surface hardness of composites is less dependent on light intensity than that of bottom surfaces (Yap & others, 2003). Thus, greater attention should be given to the bottom surface of the resin composite increment. Some studies have suggested increments of 2mm (Yap, 2000; Emani & Söderholm, 2003) in order to get adequate polymerization on the bottom surface. However, these studies were performed with a light-curing tip close to the top surface. Clinically, this is not possible in almost all situations. The distance of the light guide tip from the resin composite is a factor that is difficult to control, because it depends on caries progression and cavity size.

Deficient polymerization can happens in deeper Class I and Class II cavities, as a result of the dispersion of light energy that occurs due to the distance between the light curing tip and the first resin composite increment (Prati & others, 1999). In a deeper Class II cavity, the interface between the first increment of resin composite and the tooth structure may be less polymerized, and exposure of this interface to the oral environment can generate marginal discoloration, restoration fractures and resin composite and adhesive solubility, leading to microleakage and secondary caries. If the less polymerized resin composite comes into contact with the pulp and axial walls in both Class I and II cavities, the remaining monomer can result in post-restorative sensitivity because of its toxicity.

These monomers can easily diffuse inward beyond the dentin and cause an inflammatory reaction in the pulp, resulting in sensitivity. If this process continues unchecked, the inflammatory process can cause pulp necrosis (Brännström, 1986).

To minimize these problems, increments thinner than 2mm were recommended (Atmadja & Bryant, 1990; Rueggeberg, Caughman & Curtis Jr,1994). The disadvantage of thin increments is the long cure times, which are inconvenient for the patient, impractical with children, uncomfortable for the dentist and make the treatment more expensive because of the extra time spent in the chair (Peutzfeldt, Sahafi & Asmussen, 2000; Oberholzer & others, 2003).

Thus, this study hypothesizes that in the deeper increments of a cavity, the resin composite thickness should be thinner than 2mm for adequate polymerization (0.5 or 1mm). At the same time as the increments get closer to the light curing tip, the thickness of composite resin increases (1 or 2mm). The objective of this *in vitro* study was to evaluate the influence of the resin composite thickness on the top and bottom resin composite surface hardnesses, in a clinical simulation when the light curing tip was distanced from the resin composite by 2, 4, 6 and 8mm.

METHODS AND MATERIALS

To conduct this study, a hybrid composite resin Z250 (3M-ESPE Dental Products, St. Paul, MN, USA) shade A1, was used. Sixty cylindrical specimens were prepared in Teflon ring molds, 4.0mm in internal diameter and 0.5, 1 or 2 mm depth, held between two glass slabs separated by milar matrix strips, and then pressed with a 500g static load. The

cavity was randomly filled in one increment and polymerized according to the twelve experimental groups (*n*=5): *four curing tip distances* (2mm; 4mm; 6mm and 8mm) and *three sample thicknesses* (0.5mm, 1mm and 2mm) (Table 1). All samples were polymerized with a continuous output at 550mW/cm^2 for 20 seconds (XL 3000 – 3M Espe – Grafenau Germany 28352). Polymerization was performed with the light tip positioned in a device, the light-curing tip being distanced 2mm, 4mm, 6mm or 8mm from the top surface of the sample (controlled by an electronic digital caliper).

Each specimen was removed from the mold and stored in a lightproof container at 37°C and 95% ± 5 relative humidity for 24 hours. After this period, the samples were washed and the hardness on the bottom and top of each specimen was tested using a Knoop hardness test (FM - Future Tech Corp., Japan) under a 25 g load for 10 s. Five measurements were taken at the approximate center of the specimen (Prati & others 1999). The values obtained in micrometers were converted to Knoop Hardness Number (KHN) in a computer software (Excel for Windows® - Microsoft Ind. – CA).

The results of the top and bottom surface Knoop hardness were submitted to subdivided parcels ANOVA (Split Plot) test (p=0.05) and Tukey test at the 5% significance level. The factors sample thickness and light curing tip distances were considered in the parcels and the factor surface (top and bottom surfaces) was considered in the sub-factor.

RESULTS

Results of the microhardness test are presented in Tables 2, 3 and 4 and Figure 1. ANOVA revealed significant differences among the factors curing tip distance, sample thickness and surface, and a triple interaction among them. Tukey test was applied to individual comparisons (p=0.05). For the top surface, there were no statistical differences among the factors curing tip distance and sample thickness (Table 2). For the bottom surface, there were statistical differences between the two factors studied, curing tip distance and sample thickness. For all curing tip distances, 0.5 and 1mm sample thicknesses showed statistically higher hardness than 2mm. For the 0.5mm sample thickness, only the 8mm curing tip distance showed statistically lower hardness than 6, 4 and 2mm. For 1mm sample thickness, 2 and 4mm showed higher hardness means and were statistically different from 6 and 8 mm curing tip distance. For 2mm sample thickness, 2 and 4mm showed higher hardness means and were statistically different from 6 and 8 mm curing tip distance, and 6 mm showed statistically higher hardness means than 8mm (Table 3). For all experimental conditions, top surface showed higher hardness than bottom surface.

DISCUSSION

This investigation evaluated the influence of the resin composite thickness and the distance between the resin composite and the light-curing tip on the microhardness of the top and the bottom resin composite surfaces. The results showed that for the top surface, there were no statistical differences for the studied factors. However, on the bottom

surface, there were differences in the two factors studied. And for all experimental conditions, top surface showed higher hardness than bottom surface. These results demonstrated that there was the need for increments thinner than 2mm at all experimental distances of the light-curing tip from the top surface of the resin composite.

The top surface was not affected by the light curing tip distance. The energy that gets to the top surface, even when decreased by the air (Price & others, 2002) , was sufficient for adequate polymerization. This statement is in agreement with the Yap & others (2003) study, who concluded that the top surface hardness of resin composites was less dependent on light intensity than that of the bottom surface.

However, on the bottom surface, there were statistical differences for the two factors studied. For all experimental distances, resin composite of 2mm thickness showed lower hardness means than 0.5 and 1mm. The hypothesis that it would be possible use a resin composite thickness of 2mm at low distances (4mm or 2mm) was refuted. The resin composite has the property to disperse the light of the curing unit, thus when the light passes through the bulk of the composite, light intensity is reduced due the light scattering by filler particles and the resin matrix (Correr Sobrinho & others, 2000; Price & others, 2002; Asmussen & Peutzfeldt, 2003; Yap & others, 2003).

Previous studies stated that resin composite thickness of 2mm was adequately polymerized (Yap, 2000; Prati & others, 2002; Enami & Söderholm 2003), however in these studies, the light tip was touching on the top surface. In this study, even when the light tip was at 2mm distance from the resin composite, 0.5 and 1mm showed statistically higher hardness means than 2mm. Prati & others, (2002) observed that 1mm of distance

between the light tip and the resin surface may reduce the light intensity by approximately 10%. Thus, this low distance (2mm) may be damaging to the bottom surface polymerization. Another explanation may be the different intensity of the light curing units used in the studies. This study used a device with 550mW/cm^2, which was within the range that is considered to be adequate.

With regard to the distance between the light tip and the surface, 2mm and 4mm did not present statistical differences between them for all resin composite thicknesses, but these distances showed higher hardness means than 6 and 8mm. The larger the distance was, the lower was the hardness means. It was seen that composite resin polymerization depends greatly on the distance from the light tip (Correr Sobrinho & others, 2000). Differences were shown with 0.5, 1 and 2mm thicknesses in relation to distance. 0.5 mm showed less interference by the distance than 1mm and both showed less than 2mm (Table 3). The ratio between the bottom and top hardness for all experimental groups (Table 4) was lower than that considered to be ideal = 0.8 or greater (Yap & others, 2003), even at 2mm distance. On the other hand at 6 and 8mm distance, 0.5mm thickness showed a better ratio than 1mm and 2mm. It could be a suggestion to use 0.5mm for deeper cavities, but this thickness did not differ from 1mm, and using 0.5mm thickness would increase the attendance time, delaying the dentist in his consulting room.

In conclusion, within the limits of this study, the distance between the light guide tip and the resin composite was greatly damaging to polymerization. In these situations, a resin composite should be at least 1mm thick, in an attempt to minimize the damaging effect of distance.

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TABLE

Table 1- Experimental groups.

Groups	Light curing tip distance (mm)	Thickness sample (mm)
1	2	0.5
2	2	1
3	2	2
4	4	0.5
5	4	1
6	4	2
7	6	0.5
8	6	1
9	6	2
10	8	0.5
11	8	1
12	8	2

Table 2 – Hardness media (KHN) for the top surface. Mean values with the same letter were not statistically different ($p<0.05$) (same lower case letter were not statistically different for comparison among the sample thicknesses, and same upper case letter were not statistically different for comparison among different light curing tip distances).

Hardness media of top surface (± SD)				
	Light curing tip distance (mm)			
Sample Thickness (mm)	2	4	6	8
0.5	76.03 (8.81) Aa	69.78 (9.02) Aa	69.00 (8.02) Aa	72.18 (7.85) Aa
1.0	75.59 (8.30) Aa	65.31 (9.92) Aa	75.15 (10.2) Aa	74.29 (10.2) Aa
2.0	79.24 (10.7) Aa	72.43 (5.54) Aa	71.37 (10.0) Aa	63.24 (9.05) Aa

Table 3 – Hardness media (KHN) for the bottom surface. Mean values with the same letter were not statistically different ($p<0.05$) (same lower case letter were not statistically different for comparison among the sample thicknesses, and same upper case letter were not statistically different for comparison among different light curing tip distances).

Hardness media of bottom surface (± SD)				
	Light curing tip distance (mm)			
Sample Thickness (mm)	2	4	6	8
0.5	42.77 (2.86) Aa	44.31 (5.35) Aa	38.60 (2.07) Aa	31.19 (5.12) Ba
1.0	44.91 (2.24) Aa	43.53 (5.64) Aa	34.06 (2.08) Ba	29.61 (1.75) Ba
2.0	20.92 (2.80) Ab	20.42 (2.64) Ab	16.61 (1.66) Bb	11.86 (0.57) Cb

Table 4 – Hardness ratio between bottom and top surfaces.

	2mm			4mm			6mm			8mm		
	Top	Bottom	Ratio	Top	Bottom	Ratio	Top	Bottom	Ratio	Top	Bottom	Ratio
0.5	76.03	42.77	0.5625	69.78	44.31	0.6350	69.00	38.6	0.5594	72.18	31.19	0.4321
1.0	75.59	44.91	0.5941	65.31	43.53	0.6665	75.15	34.06	0.4532	74.29	29.61	0.3986
2.0	79.24	20.92	0.2640	72.43	20.42	0.2819	71.37	16.61	0.2327	63.24	11.86	0.1875

FIGURE

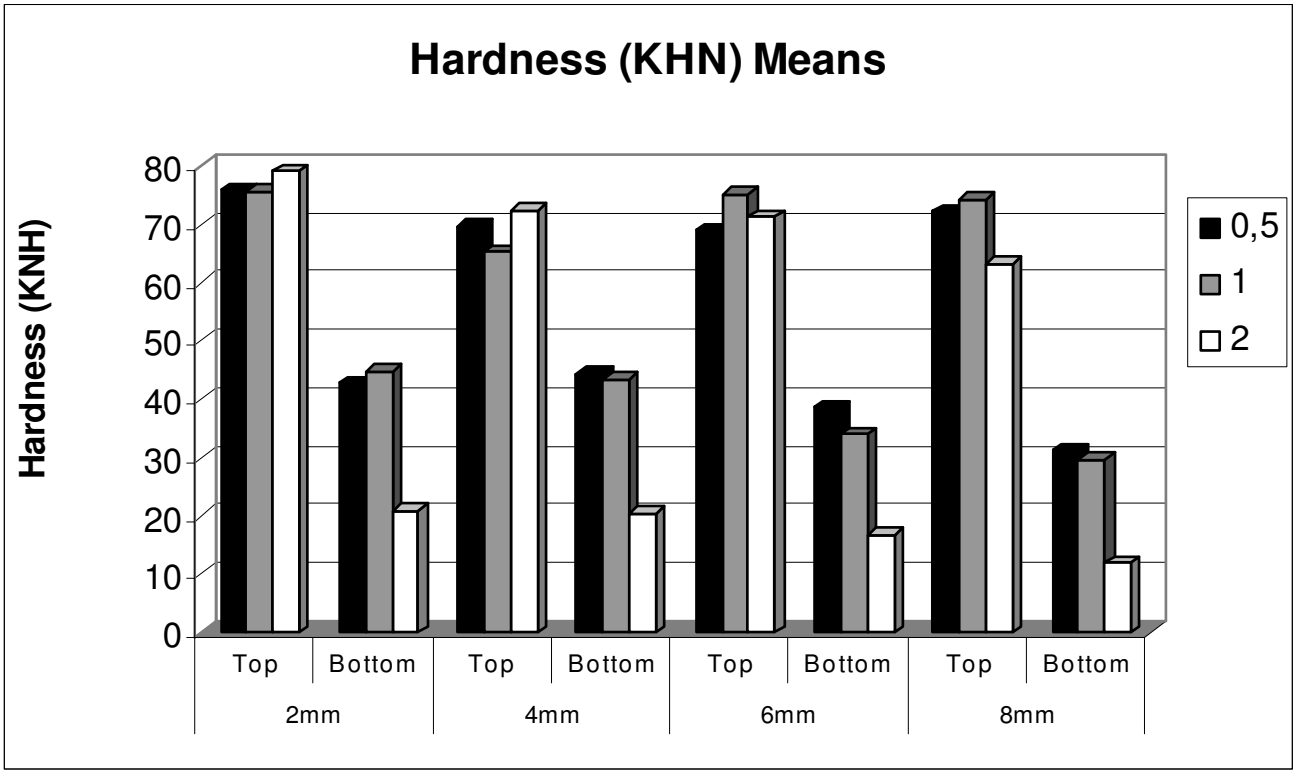

Figure 1 – Results of microhardness (KHN) for experimental groups.

Capítulo 4

TITLE:

Influence of light curing modes and sample thickness on microhardness of a hybrid composite resin

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ABSTRACT

Objective: The aim of this *in vitro* study was to evaluate the influence of polymerization mode and sample thickness on microhardness of a composite resin. ***Method and Materials:*** Forty-five composite resin specimens were randomly prepared and divided into nine experimental groups (n=5): three polymerization modes (conventional - 550 mW/cm^2 / 20 s; high intensity - 1160mW/cm^2 – 10 s; Led - 360mW/cm^2 – 40 s) and three sample thicknesses (0.5mm, 1mm and 2mm). All samples were polymerized with the light tip at 8mm distance. After that, Knoop microhardness measurements were obtained on top and bottom surfaces of the sample. ***Results*:** On top surface, with some exceptions, were almost similar. However, in the bottom surface, there were differences in the two factors studied. In all experimental conditions, 0.5 showed statistically higher hardness than 1mm and 2mm, and conventional mode and LED polymerization modes showed higher hardness means and were statistically different from high intensity mode. ***Conclusion:*** For all experimental conditions, top surface showed higher hardness than bottom surface. It was concluded that the choice of an adequate light curing unit and the use thinner resin composite increments improved polymerization of the bottom surface of these increments.

Key Words: photopolymerization; distanced light curing; light curing units; resin composite; composite thickness; microhardness;

CLINICAL RELEVANCE

In deeper cavities, the distance between the tip of the light curing unit and the resin composite damages mainly the polymerization of the bottom surface. In this situation, the use of thinner resin composite increments will improve the polymerization of the bottom surface of these increments.

INTRODUCTION

An important milestone in the history of modern restorative dentistry was the development of light-cured composite resins for direct procedures[1]. Improvements in composite resin mechanical properties and light cure devices have permitted their use in posterior teeth with greater reliability than some years ago[2,3]. Composite resin polymerization occurs by the conversion of the monomer molecules into a polymer network, accompanied by a closer packing of the molecules, causing contraction in the composite[4,5]. When more intense light energy is used to cure resin composite, more photons reach the camphorquinone photoinitiator molecules within the resin and more photoinitiator molecules are activated and raised to the excited state. In this excited state, camphorquinone collides with an amine, and a free radical is formed, which can then react with the carbon to carbon double bond (C=C) of a monomer molecule and initiate polymerization[6].

Adequate polymerization is a crucial factor in obtaining optimal physical performance of these materials[7], and it is related to a better clinical performance. However, there are many variables that affect the amount of light energy received at the top and bottom surfaces of a resin composite restoration, such as design and size of the light guide, distance of the light guide tip from the resin composite, power density, exposure duration, shade and opacity of the resin composite, increment thickness and material composition[6,8,9]. If the restoration does not receive sufficient total energy, various problems may arise, e.g., reduced degree of conversion, increased cytotoxicity, reduced hardness, increased pigmentation, decreased dynamic elasticity modulus, increased wear, increased marginal breakdown and weak bond among the tooth, adhesive and the restoration [6,8,10-12].

The above-mentioned variables directly affect the cure depth of the resin composite. The resin composite on the top surface usually receives an adequate power density from the curing light during irradiation while the deeper parts, because of light absorption and dispersion, receive lower power density [9,11-15]. Top surface hardness of composites is less dependent on light intensity than that of the bottom surfaces[15]. Thus, greater attention should be given to the bottom surface. Some studies have suggested increments of 2mm[8,16] in order to get adequate polymerization on the bottom surface. However, these studies were performed with a light-curing tip close to the top surface. Clinically, this is not possible in almost all situations. The distance of the light guide tip from the resin composite is a factor that is difficult to control, because it depends on caries progression and cavity size,

Deficient polymerization can happen in deeper Class I and Class II cavities, as a result of the dispersion of light energy that occurs due to the distance between the light

curing tip and the first resin composite increment[13]. In a deeper Class II cavity, the interface between the first increment of resin composite and the tooth structure may be less polymerized, and this interface, exposure to the oral environment, can generate to marginal discolorations, restoration fractures and resin composite and adhesive solubility, leading to microleakage and secondary caries. If the less polymerized resin composite comes into contact with the pulp and axial walls in both Class I and II cavities, the remaining monomer can result in post-restorative sensitivity because of the its toxicity. These monomers can easily diffuse inward beyond the dentin and cause an inflammatory reaction in the pulp, resulting in sensitivity. If this process continues unchecked, the inflammatory process can cause pulp necrosis.

Therefore, adequate polymerization is necessary to achieve the physical and mechanical properties of the material[17]. A manner of overcoming the reduction in light intensity with distance is to use light curing units with a high light intensity rate [13]. WANG & SANG[18] concluded that resin composite polymerized with a high intensity rate significantly increased the bottom surface hardness of a resin composite.

Over the last few years, the widespread use of light sources has given rise to manufacturers producing several varieties of light curing units[18]. High intensity quartz tungsten halogen (QTH) and light-emitting diodes (LED) were recently introduced as an option for polymerization. Curing by high intensity light units occurs very quickly and is recommended because of the curing depth and physical properties that occur when these systems are used. High light curing, which is compensated for by the intensity, can polymerize the resin composite in a shorter time. However, high light intensities do not

allow enough flow for reducing internal stress, contributing to high polymerization shrinkage[20,21].

LED units features very narrow spectral ranges and are therefore a highly efficient light source[22]. Operating around 470nm, with a bandwidth of about 20nm, blue LEDs have all the spectral purity for highly efficient resin composite curing[23]. Some studies have demonstrated the good performance of these units, such as adequate depth of cure, flexural strength and surface hardness[24,25]. However, further studies are necessary so that these light curing units can be safely used, mainly when the light curing tip is distant from the filling material.

Another way of overcoming the reduction in light intensity with distance may be to decrease the resin composite increment thickness. According to RUEGGEBERG *et al.*[26], the light intensity decreases greatly when the light passes through the resin composite. PRATI *et al.*[13] and YAP[8] demonstrated that the resin composite is capable of retaining light energy, decreasing the light intensity that gets to the deeper part of a resin composite increment. Thus, resin composite increments greater than 2mm should be avoided, in order to obtain proper polymerization. Increments thinner than 2mm were recommended by ATMADJA, BRYANT[27] and RUEGGEBERG, CAUGHMAN, CURTIS JR[26]. The disadvantage of thin increments is the long cure times, which are inconvenient for the patient, impractical with children, uncomfortable for the dentist and make the treatment more expensive because of the extra time spent in the chair [28, 29].

However, a few studies have been carried out with the purpose of testing the cure depth of resin composites in situations where the light curing tip is distant from the filling material, as in the clinical situations mentioned above. Consequently, it becomes important

to evaluate the minimum resin composite thickness required for correct polymerization, according to the light curing unit used. Thus, in this study it was hypothesized that in deeper increments of a cavity, the resin composite thickness should be thinner than 2mm to ensure adequate polymerization (0.5 or 1mm), and that different polymerization modes may show different hardness means.

The objective of this *in vitro* study was to evaluate the influence of the resin composite thickness and the polymerization mode on the top and bottom resin composite surface hardnesses, in a clinical simulation when the light curing tip was at a distance of 8mm from the resin composite.

METHOD AND MATERIALS

To conduct this study, a hybrid composite resin Z250 (3M-ESPE Dental Products, St. Paul, MN, USA) shade A1, was used. Forty five cylindrical specimens were prepared in Teflon ring molds, 4.0mm in internal diameter and 0.5, 1 or 2 mm depth, held between two glass slabs separated by milar matrix strips, and then pressed with a 500g static load. The cavity was randomly filled in one increment and polymerized according to the nine experimental groups (n=5): three polymerization modes (conventional - 550 mW/cm^2 / 20 s; high intensity - 1160mW/cm^2 – 10 s; Led – 360 mW/cm^2 – 40 s) and three sample thicknesses (0.5mm, 1mm and 2mm) (Table 1). Polymerization was performed with the light tip positioned in a device, the light-curing tip being 8mm distant from the top surface of the sample (controlled by an electronic digital caliper).

Each specimen was removed from the mold and stored in a lightproof container at 37°C and 95% ± 5 relative humidity for 24 hours. After this period, the samples were washed and the hardness on the bottom and top of each specimen was measured using a Knoop hardness test (FM - Future Tech Corp., Japan) under a 25 g load by 10 s. Five measurements were performed at the approximate center of the specimen[13]. The values obtained in micrometers were converted to Knoop Hardness Number (KHN) in a computer software (Excel for Windows® - Microsoft Ind. – CA).

The results of the Knoop hardness were submitted to subdivided parcels ANOVA (Split Plot) test (p=0.05) and Tukey test at the 5% significance level. Top and bottom hardness measurements were submitted to subdivided parcels ANOVA (Split Plot) test (p=0.05). The factors light curing modes and sample thickness were considered in the parcels and the factor surface (top and bottom surfaces) was considered in the sub-factor.

RESULTS

Results of the microhardness test are presented in Tables 2, 3 and 4 and Figure 1. ANOVA revealed significant differences among the factors polymerization modes, sample thickness and surface, and a triple interaction among them. Tukey test was applied to individual comparisons (p=0.05). For the top surface, there were statistical differences for polymerization modes. For all polymerization modes, there were no significant differences among the three sample thickness (Table 2). Conventional mode showed higher hardness means and was statistically different from high intensity for 1 and 2mm. LED showed no significant differences from any group in 0.5 and 1mm (Table 2). For the

bottom surface, there were statistical differences between the two factors studied, curing tip distance and sample thickness. For all experimental factors, 0.5 showed statistically higher hardness than 1mm and 2mm, and 1mm sample thickness showed statistically higher hardness than 2mm (Table 3). Conventional mode and LED polymerization modes showed higher hardness means and were statistically different from high intensity. For all experimental conditions, the top surface showed higher hardness than the bottom surface.

DISCUSSION

This investigation evaluated the influence of the resin composite thickness and the polymerization modes on the microhardness of the top and the bottom resin composite surfaces. The results showed that for the top surface, there were no statistical differences between polymerization modes. In general, the results were almost similar, with some exceptions. However, on the bottom surface, there were differences in the two factors studied. In all experimental conditions, 0.5 showed statistically higher hardness than 1mm and 2mm, and conventional mode and LED polymerization modes showed higher hardness means and were statistically different from high intensity mode. For all experimental conditions, the top surface showed higher hardness than the bottom surface. These results demonstrated that in deep cavities there was a need for increments thinner than 2mm for all polymerization modes to obtain better polymerization.

The top surface was less affected by the two experimental factors when the light curing tip was 8mm distant from the top surface. The energy that gets to the top surface, even when decreased by the air[13], was sufficient to show better polymerization for all

sample thicknesses than for the bottom surface. The sample thickness did not affect the top surface hardness of resin composites for all polymerization modes. Only for polymerization modes was there statistical difference for the top surface. Conventional mode showed higher hardness means and was statistically different from high intensity for 1 and 2mm. LED showed no significant differences from any group in 0.5 and 1mm (Table 2).

On the bottom surface, there were statistical differences for the two factors studied. For all experimental polymerization modes, 0.5 showed statistically higher hardness than 1mm and 2mm, and 1mm sample thickness showed statistically higher hardness than 2mm (Table 3). The hypothesis that when the light curing tip was distant from the resin composite (e.g. deeper increments of a cavity), the resin composite thickness should be thinner than 2mm for adequate polymerization (0.5 mm) was accepted. The resin composite has the property of dispersing the curing unit light, thus when it passes through the bulk of the composite, light intensity is reduced due the light scattering by filler particles and the resin matrix [9,11-15]. Thus, the reduction in resin composite thickness decreased this scattering effect. But, on the other hand, the use of 0.5mm increment thicknesses in the deeper cavities may be uncomfortable for patients and not economical for dentists[28,29]. Therefore, the 0.5mm resin composite thickness may be used only for the deeper increments, and when the increments are close to the light curing tip, composite resin thickness may be increased to 1 or 2 mm.

When the light curing modes were compared, the conventional mode light unit mode showed the higher hardness means, with statistical differences for high intensity for all sample thickness on the bottom surface and for 1 and 2mm on the top surface. High

intensity mode presents an intensity of 1160mW/cm^2, but a low manufacturer's recommended time of 10 seconds (total energy of 11.60 J/cm^2), and a conventional mode presents an intensity of 550mW/cm^2 and a light curing time of 20 seconds (total energy of 11.00 J/cm^2). The total energy is almost the same for both light-curing times used in this study. However, two points may be the cause of the lower hardness means for high intensity mode: 1- the dispersion of intensity because of the distance leveled the intensity to that of the conventional model, thus the light curing time was the difference between both; or 2- high intensity mode lead to very fast polymerization, constituting short chain length, and consequently, the elasticity modulus may be reduced, thus decreasing the hardness[11]. The former explanation seems to be clearer in this study, mainly when it is considered that the distance between the resin composite and the light-curing tip was large and it reduces the intensity for the light curing modes mentioned above.

The LED mode showed similar results to the conventional mode for all groups. On the bottom surface, LED showed statistical differences from high intensity for sample thickness, and on the top surface it differed from high intensity at 2mm thickness. LED (light emitting diode) has a narrow spectral range with a peak around 470nm, which matches the optimum absorption wavelength for the activation of the camphorquinone (CQ) photoinitiator[15, 29]. LED modes usually present lower intensity than others light curing modes, however it provides a good degree of conversion because of the high degree of overlap with the absorption spectrum of CQ[31]. Therefore, it is possible that LED mode, in spite of the experimental distance and presenting the lowest intensity of the experimental modes of this study, showed similar hardness to the conventional mode because of the

similar spectrum with CQ and the light curing time recommended by the manufacturer (40s).

Within the limits of *in vitro* study, this investigation suggested that in deep cavities, it is important to use thinner increments (0.5mm) to improve polymerization on the bottom surface of the first increments, and opt for a light curing unit for satisfactory polymerization of the resin composite, even though it increases the time spent in the dentist's chair.

CONCLUSION

Within the limits of this study, it can be concluded that:

1- Resin composite has the capacity of reducing light penetration, decreasing light intensity and consequently, polymerization effectiveness of the bottom surface of the sample.

2- In deep cavities, it is important to use thinner resin composite increments to improve polymerization on the bottom surface of the first ones.

3- It is important opt for a suitable light curing unit and an adequate time to ensure satisfactory polymerization of the resin composite, mainly for restorations in deep cavities.

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TABLE

Table 1: Experimental groups (**XL 3000** – 3M Espe – Grafenau Germany 28352; **Elipar Freelight** – 3M Espe; **Optilux 501C** - Demetron – Sds Kerr – Danbury CT USA 06810-4153).

Groups	Sample thickness (mm)	Polymerization modes	Light Curing Unit
1	0.5	Conventional	XL 3000 – 3M Espe
2	1	Conventional	XL 3000 – 3M Espe
3	2	Conventional	XL 3000 – 3M Espe
4	0.5	LED	Elipar Freelight – 3M Espe
5	1	LED	Elipar Freelight – 3M Espe
6	2	LED	Elipar Freelight – 3M Espe
7	0.5	High Intensity	Optilux 501C – Demetron
8	1	High Intensity	Optilux 501C - Demetron
9	2	High Intensity	Optilux 501C - Demetron

Table 2 – Hardness media (KHN) for the top surface. Mean values with the same letter were not statistically different ($p<0.05$) (same lower case letter were not statistically different for comparison among the same sample thicknesses, and same upper case letter were not statistically different for comparison among different light curing modes).

Hardness media of top surface (± SD)

Light Curing Modes	Sample Thickness (mm)		
	0.5	1	2
Conventional	51.80 (3.12) Aa	54.87 (3.26) Aa	56.64 (1.54) Aa
LED	58.11 (3.40) Aa	50.96 (3.89) Aab	59.87 (4.11) Aa
High Intensity	51.86 (4.17) Aa	47.76 (3.14) Ab	49.89 (5.23) Ab

Table 3 – Hardness media for the bottom surface (KHN). Mean values with the same letter were not statistically different ($p<0.05$) (same lower case letter were not statistically different for comparison among the same sample thicknesses, and same upper case letter were not statistically different for comparison among different light curing modes).

Hardness media of bottom surface (± SD)

Light Curing Modes	Sample Thickness (mm)		
	0.5	1	2
Conventional	41.67(1.38) Aa	32.39 (2.20) Ba	17.94 (1.89) Ca
LED	43.66 (3.40) Aa	36.25 (3.89) Ba	16.72 (4.11) Ca
High Intensity	34.23 (4.17) Ab	27.34 (3.89) Bb	9.11 (5.23) Cb

Table 4 – Hardness ratio between bottom and top surfaces.

	Conventional			LED			High Intensity		
	Top	Bottom	Ratio	Top	Bottom	Ratio	Top	Bottom	Ratio
0.5	51.8	41.67	**0.8044**	58.11	43.66	**0.7513**	51.86	17.94	**0.3459**
1.0	54.87	32.39	**0.5903**	50.96	36.25	**0.7113**	47.76	16.72	**0.3501**
2.0	56.64	17.94	**0.3167**	59.87	16.72	**0.2793**	49.89	9.11	**0.1826**

FIGURES

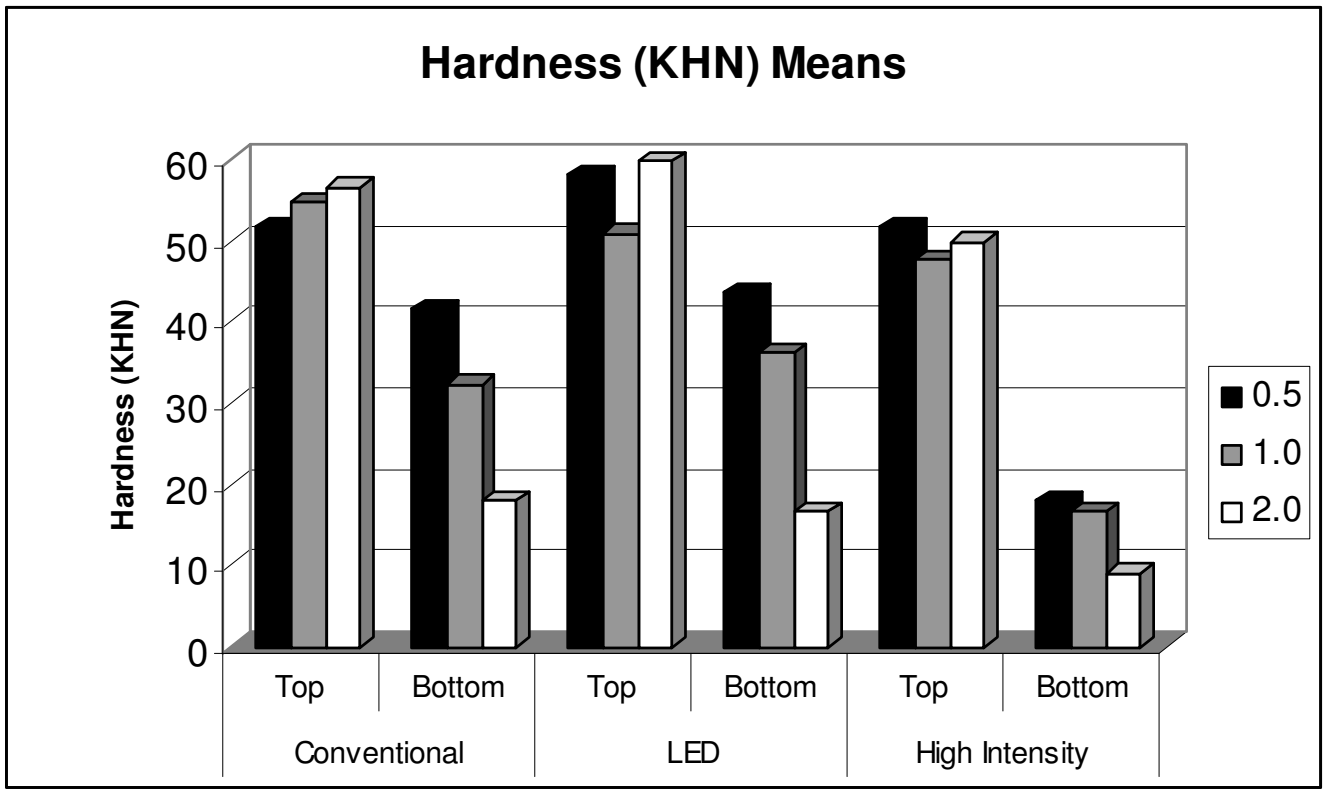

Figure 1 – Results of microhardness (KHN) for experimental groups.

4 – CONSIDERAÇÕES GERAIS

Um alto grau de polimerização do compósito é essencial para o sucesso da restauração. Desta forma, a energia luminosa é elemento principal para o grau de conversão do compósito fotoativado, interferindo de forma direta nas suas propriedades físicas (Rueggeberg *et al.*, 1994). Entretanto, todos os monômeros exibem consideráveis níveis de insaturação residual (duplas ligações não quebradas) no final da reação de polimerização do compósito, com o grau de conversão variando de 55 a 80% (Ferracane & Greener, 1986; Silikas *et al.*, 2000). Quanto maior for a quantidade de duplas ligações residuais, maior será a solubilidade do compósito (Asmussen & Peutzfeldt, 2001). Além da solubilidade, outros fenômenos poderão ocorrer em virtude da inadequada polimerização, como: alteração das propriedades físicas, aumento na taxa de pigmentação, aumento na taxa de desgaste, aumento do potencial de citotoxidade do monômero residual, diminuição do módulo de elasticidade, fraca união entre dente, adesivo e compósito, e maior probabilidade de colapso na interface dente-restauração (Ferracane & Grener, 1984; Yap, 2000; Price *et al.*, 2002; Asmussen & Peutzfeldt, 2002; Asmussen & Peutzfeldt, 2003).

Vários fatores podem interferir na intensidade de luz que atinge a superfície do compósito, durante a confecção de uma restauração direta (Price *et al.* 2002), afetando diretamente as propriedades físicas do compósito. Entre estes, a distância entre a ponta do aparelho de fotoativação e a superfície do compósito deve ser analisada cuidadosamente, pois esta afeta adversamente a quantidade de energia recebida pela superfície de topo do compósito (Price *et al.*, 2000). Pires *et al*. (1993) relataram que para 2mm de distância, a intensidade luminosa ficará reduzida em 22%, enquanto que para 6mm, a redução será da ordem de 53 %. Já para Prati *et al.* (1999) a distância de 6mm pode diminuir a intensidade em 77% da intensidade original.

Embora, o ideal seja posicionar a ponta do aparelho de fotoativação junto à superfície do compósito, clinicamente isto é improvável de acontecer (Correr Sobrinho *et al.*, 2000; Price *et al.*, 2000). A distância entre a ponta do aparelho de fotoativação e a superfície do compósito depende da profundidade da cavidade em um determinado dente e do tamanho da cavidade após o preparo cavitário. Nos capítulos 3 e 4, testou-se apenas a

dureza superficial do compósito na distância de 8mm, simulando o primeiro incremento de um compósito. Com a mesma finalidade de se testar o efeito da distância, Price *et al.*(2000) utilizaram a distância de 6,3mm, simulando uma cavidade tipo Classe II. Yearn (1985) afirmou que a distância entre as pontas das cúspides e a parede gengival de uma cavidade tipo Classe II normalmente excede 7mm.

Nos capítulos 1 e 3, testou-se o efeito da distância na dureza de superfície do topo e do fundo do compósito. Observou-se que não houve diferenças estatísticas entre as distâncias de 2 e 4 mm, porém estas foram diferentes das distâncias de 6 e 8 mm, no que se refere à superfície de fundo do compósito. Correr Sobrinho *et al.*(a) (2000), e Caldas *et al.* (2003) concluíram que a reação de polimerização do compósito depende substancialmente da distância da ponta do aparelho de fotoativação, pois quanto maior for a distância, menor será a quantidade de fótons que atingem a superfície de topo do compósito. Nesta situação, é importante aumentar a energia que chega na superfície de fundo do incremento, pois quando a restauração é realizada em incrementos, o resultado de uma má polimerização do primeiro incremento pode comprometer o sucesso de toda a restauração.

Outro fator a ser considerado é que a quantidade de fótons que atinge a superfície de topo do compósito não é a mesma da que chega até a superfície de fundo. O compósito tem a propriedade de dispersar a luz do aparelho de fotoativação, pois quando a luz passa através dele, a intensidade dessa luz é reduzida devido às propriedades de absorção e difusão de energia pelas partículas de carga e pela matriz resinosa (Prati *et al.,* 1999; Correr Sobrinho *et al.,* 2000 (b); Yoon *et al.,* 2002; Yap *et al.,* 2003). Desta forma, quando a fotoativação é realizada à distância, e conseqüentemente com uma intensidade de luz reduzida, deve-se esperar uma baixa quantidade de fótons que chegará à superfície de fundo. Assim, a espessura e a cor do compósito deve ser analisada com o intuito de minimizar este efeito.

Estudos prévios têm relatado que uma espessura de 2mm do compósito permite adequada reação de polimerização (Yap, 2000; Prati *et al.,* 2002; Emani & Söderholm, 2003). Entretanto, nestes estudos, a ponta do aparelho de fotoativação estava situada numa

distância inferior a 0,5mm da superfície do compósito. Nos capítulos 1 e 2, a distância mínima foi de 2mm, e nos capítulos 3 e 4, foi de 8mm.

A espessura do incremento de compósito foi analisada nos capítulos 3 e 4. No capítulo 3, levantou-se a hipótese de que quanto maior for a distância entre a ponta do aparelho de fotoativação e a superfície do compósito, menor deve ser a espessura do compósito. E a medida que esta distância diminui, ou seja, mais incrementos são colocados na cavidade, a espessura de cada incremento poderia ser aumentada, com o intuito de diminuir o tempo clínico dispensado para finalizar este procedimento. Contudo, neste estudo, notou-se que o fator distância não foi dependente do fator espessura do incremento e vice-versa, ou seja, em qualquer distância os incrementos de 0,5 e 1mm apresentaram maiores valores de dureza, com diferenças significativas do incremento de 2mm. Porém, no capítulo 4, quando testou-se a influência da espessura e do aparelho de fotoativação com a distância de 8mm da ponta do aparelho à superfície do compósito, observou-se que os maiores resultados de dureza na superfície de fundo foram obtidos nas amostras de 0,5mm, e estas apresentaram diferenças estatísticas para as amostras de 1 e 2mm. Desta forma, seria prudente utilizarmos incrementos de 0,5mm em cavidades com profundidade igual ou superior de 8mm.

A espessura, a cor e opacidade do compósito também são fatores que podem determinar um maior ou menor grau de conversão do compósito na superfície de fundo (Sakagushi *et al.*, 1992). A cor e opacidade do compósito foram testadas no capítulo 1, com distância de fotoativação de 8mm. O compósito de cor A1 (escala do fabricante) apresentou maiores médias de dureza, e com diferenças estatísticas significativas das médias do compósito C2, na superfície de fundo. O compósito A3,5 apresentou resultados intermediários, sem diferenças estatísticas dos compósitos A1 e C2. A redução na transmissão de energia é diminuída devido à opacidade do compósito. Cores opacas diminuem a capacidade de transmissão de energia pelo corpo do compósito, reduzindo assim o grau de conversão e a dureza da superfície de fundo (Leloup *et al.*, 2002). Entretanto, diferentes marcas de compósito com semelhança de cor, verificada com a escala Vita, apresentam valores de opacidade variados e diferem na cor, devido às desigualdades

na composição destes (Shortall, Wilson & Harrington, 1995). Assim, pode-se sugerir a utilização de cores claras em cavidades profundas, desde que não haja comprometimento da estética.

Além da espessura e da cor do compósito, outro fator que pode determinar maior energia de polimerização é o tempo de fotoativação. Neste estudo, levantou-se a hipótese de que, em situações na qual a ponta do aparelho de fotoativação está distante 8mm da superfície do compósito, o tempo de fotoativação poderia ser aumentado, com o intuito de se aumentar a quantidade de energia que atingiria o compósito. Assim, mais moléculas de canforoquinona poderiam ser ativadas, aumentando a possibilidade de aumento do grau de conversão e da dureza superficial de topo e principalmente de fundo. Atmadja & Bryant (1990) e Prati *et al.* (1999) recomendaram o aumento de tempo de fotoativação em cavidade profundas. Assim, no capítulo 2, testou-se três tempos de fotoativação utilizando-se três tipos de aparelhos. Quando o tempo de fotoativação foi três vezes maior do que o tempo recomendado por cada fabricante dos aparelhos de fotoativação, aumentou-se significativamente o valor da dureza da superfície de fundo das amostras. Apenas para um tipo de aparelho, o tempo duas vezes maior do que o recomendado apresentou aumento significativo da dureza da superfície de fundo. O aumento do tempo significa aumento da energia de luz que chega na superfície de fundo do compósito, e este aumento compensou em parte a energia dispersada devido a distância de fotoativação.

A energia de luz é tanto dependente do tempo quanto da intensidade. Nos capítulos 2 e 4, três aparelhos de fotoativação foram testados, com energia de luz e intensidades diferentes: dois aparelhos com energia de luz halógena (QTH) e um aparelho com energia emitida por diodo (LED - 360 mW/cm^2 / 40s). Um dos aparelhos QTH utilizados era com intensidade convencional (550 mW/cm^2 / 20s), e o outro com alta intensidade (1160 mW/cm^2 / 10s). O tempo de fotoativação foi o mesmo recomendado pelos fabricantes dos aparelhos, sendo que no capítulo 2, também se testou o tempo duas e três vezes maior que o recomendado. O aparelho convencional normalmente apresentou as maiores médias de dureza na superfície de fundo, com diferenças estatísticas para o

aparelho de alta intensidade. Embora o total de energia seja quase o mesmo para ambos os aparelhos QTH, o de alta intensidade mostrou-se menos eficaz na polimerização da superfície de fundo do compósito, e isto pode ser atribuído ao seu curto tempo de fotoativação (10s), pois quando a fotoativação é realizada com a ponta do aparelho distante do compósito, há uma dispersão de energia, e desta forma, as intensidades de luz dos aparelhos que atingem a superfície do compósito ficam reduzidas. Assim as intensidades podem ter sido aproximadas, diminuindo a diferença entre elas, e, portanto, a única diferença entre os aparelhos foi o tempo de fotoativação.

O outro aparelho testado foi o LED. Este tipo de aparelho emite luz com espectro reduzido, variando entre 440 e 480 nm. (Holfmann *et al.*, 2003). Assim, esta energia luminosa é altamente eficaz para a molécula de canforoquinona, que tem maior excitação com luz de comprimento de onda de 467 nm (Kurachi *et al.*, 2001). Desta forma, mesmo com intensidade inferior, o aparelho LED apresentou resultados similares ao QTH quanto a dureza na superfície de fundo.

5 – CONCLUSÃO GERAL

Sob as condições experimentais deste estudo e com base nos resultados obtidos, analisados e discutidos, pôde-se concluir que:

1) a dureza da superfície de topo foi pouco afetada pelos fatores estudados, não sendo um parâmetro adequado na comprovação da eficácia de polimerização do compósito, entretanto a dureza da superfície de fundo foi consideravelmente afetada pelos fatores: distância entre a ponta do aparelho de fotoativação e a superfície do compósito, intensidade do aparelho de fotoativação, especificidade de luz emitida pelo aparelho de fotoativação, tempo de fotoativação, cor, opacidade e espessura do compósito;

2) a distância entre a ponta do aparelho de fotoativação e a superfície de topo do compósito foi um fator de interferência na polimerização, pois quanto maior esta distância, menor foi a dureza da superfície de fundo do compósito;

3) o compósito teve a capacidade de reduzir a penetração da energia luminosa, e conseqüentemente reduzir significativamente a dureza da superfície de fundo, independentemente dos fatores estudados;

4) quando a distância entre a ponta do aparelho de fotoativação e a superfície do compósito foi superior a 4mm, o tempo de polimerização triplicado; cores claras e utilizar fontes de luz com intensidade convencional apresentaram maiores valores de dureza

5) quando a distância entre a ponta do aparelho de fotoativação e a superfície do compósito foi igual ou superior a 2mm, incrementos de até 1mm de espessura apresentaram maiores valores de dureza, e quando a distância foi igual a 8mm, a espessura do incremento de 0,5mm apresentou maiores valores de dureza.

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