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Transdental Photo-activation Technique: Hardness and Marginal Adaptation of Composite Restorations Using Different Light Sources

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Clinical Relevance

The association of transdental and direct photo-activation of composite restorations might improve marginal adaptation, while not being detrimental to composite hardness.

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SUMMARY

This study investigated the influence of different light sources associated with a transdental photo-activation technique on the marginal adaptation and hardness of composite restorations. Cavities (3 mm wide x 3 mm long x 1.5 mm in deep) were prepared on flattened bovine dentin and filled with Z250 composite (3M ESPE). Nine groups (n=10) were defined according to the curing technique (direct; transdental—photo-activation through 1 mm of enamel and 2 mm of dentin; mixed—transdental + direct) and light source (QTH XL2500, 3M ESPE; PAC Apollo 95E, DMD; LED Ultrablue Is, DMC) combination. Marginal

adaptation was evaluated using a dye staining method, and the percentage of stained margins was recorded. Knoop Hardness readings were made across the transversal section of the fillings. Data were submitted to two-way ANOVA and Tukey's test (*p*≤0.05). For margin analysis, although none of the curing conditions provided perfect adaptation, the mixed technique showed lower gap formation. No significant differences were detected between the transdental and other techniques, and no significant differences were detected among the light sources. For hardness, the direct technique showed slightly greater hardness than the mixed technique. Also, the mixed technique yielded greater hardness than the transdental technique. Among the light sources, the LED showed greater hardness than the PAC; whereas, no significant differences between the QTH and other sources were detected. The mixed technique might improve the marginal adaptation of restorations, while not being detrimental to composite hardness.

INTRODUCTION

Resin composites are the material of choice for direct restorative procedures. However, during constrained polymerization, these materials undergo volumetric shrinkage during setting, which may generate stresses within the material and at the tooth-filling interface.[1] This phenomenon could disrupt bonding between the composite and cavity walls or cause cohesive failure of either the restoration or the surrounding tooth structure[1] and may cause marginal failure of the restorations.

Numerous light-curing approaches have been proposed in order to attenuate the resulting shrinkage stress and reduce the formation of marginal gaps.[2-3] These strategies reduced the curing rate, allowing more time for the material to flow during setting.[4] Previous studies[2-3] have shown that marginal integrity might be improved using activation at low irradiance without compromising the final conversion.[5]

An additional approach to reducing the irradiance level is to activate the material through the dental tissues (transdental technique, TDT).[6] This technique, which was introduced based on the common belief that the direction of shrinkage vectors was towards the polymerization light, attempted to change the direction of the vectors towards the bonded walls. However, it was further demonstrated that the shrinkage vectors actually develop toward the bonded walls, irrespective of the light position.[7] Nonetheless, the TDT could be effective in modifying the kinetics of polymerization, as a reduction in light intensity of up to 70% may occur when light passes through the dental structure.[8] This reduction would propitiate the maintenance of bond integrity, working as a modulated photo-curing method.

In addition to curing methods, different light-curing units (LCUs) are available. Light-emitting diodes (LED) and plasma arc (PAC) were introduced as alternatives to traditional quartz-tungsten-halogen (QTH) LCUs. However, little is known about the influence of these different light sources when using the TDT. Therefore, this study investigated the influence of different light sources using direct (DT), mixed (MT) or TDT curing techniques on the marginal adaptation and hardness of composite restorations. The tested hypothesis was that TDT would reduce the formation of gaps without decreasing hardness, regardless of the light source tested.

METHODS AND MATERIALS

The roots of bovine incisors were sectioned 1 mm below the cementum-enamel junction and the teeth were embedded in polystyrene resin. The buccal surface of each tooth was ground using a water-cooled mechanical polisher (APL-4, Arotec, Cotia, SP, Brazil) with 80-, 180-, 320- and 600-grit SiC papers (Norton SA, São Paulo, SP, Brazil) to expose a flat dentin area at least 6 mm in diameter.

Cavity Preparations

The mesial and distal faces of each tooth were sectioned in order to standardize a width of 7 mm for all specimens. Cavities (3 mm wide x 3 mm long x 1.5 mm deep) were prepared on the central area of the flattened surfaces, defining a thickness of 2 mm for the proximal dentin walls. The preparations were made using air/water-cooled #1094 cylindrical diamond burs (KG Sorensen, Barueri, SP, Brazil). The internal walls of each cavity were perpendicular to the top and bottom surfaces, with round angles as defined by the bur shape, presenting a C-factor of 3. Additionally, a 1 mm thick enamel slice was obtained by removing the dentin portion of the buccal surface of a bovine incisor. Wet-polishing the enamel slice was carried out with 200- and 400-grit SiC papers, and this slice was used for the TDT.

Restorative Procedures

The specimens were randomly assigned to nine groups (n=10), as described in Table 1. Filtek Z250 resin composite (3M ESPE, St Paul, MN, USA) shade A2 and the Single Bond adhesive system (3M ESPE) were used according to the manufacturer's instructions. The composite was inserted into the cavity in a single increment. After light-activation, the specimens were stored in distilled water at 37°C for 24 hours and wet-polished with 600- and 1200-grit SiC papers. Figure 1 shows positioning of the enamel slice during the TDT. For this technique, light-curing was performed through the 1 mm thick enamel slice and the 2 mm thick proximal

Table 1: *Description of the Light Sources and Curing Techniques*

Light Source*	Curing Technique**	Photo-Activation Protocol	Radiant Exposure
QTH	Direct	20 second top	12 J/cm²
	Transdental	20 second mesial + 20 second distal	1.2 J/cm²
	Mixed	20 second mesial + 20 second distal + 20 second top	13.2 J/cm²
LED	Direct	20 second top	10 J/cm²
	Transdental	20 second mesial + 20 second distal	1.6 J/cm²
	Mixed	20 second mesial + 20 second distal + 20 second top	11.6 J/cm²
PAC	Direct	9 second top	12 J/cmv
	Transdental	9 second mesial + 9 second distal	1 J/cm²
	Mixed	9 second mesial + 9 second distal + 9 second top	13 J/cm²

**QTH–XL2500 (3M ESPE), with irradiance of 600 mW/cm²; LED–Ultrablue Is (DMC, São Carlos, SP, Brazil), with irradiance of 500 mW/cm²; PAC–Apollo 95E (DMD, Westlake, CA, USA), with irradiance of 1340 mW/cm². Measurements were made using a handheld radiometer.*

***Transdental technique—photo-activation through 1 mm of enamel slice and 2 mm of mesial/distal dentin wall. The irradiance actually reaching the composite was 30mW/cm² for QTH, 40mW/cm² for LED, and 55mW/cm² for PAC.*

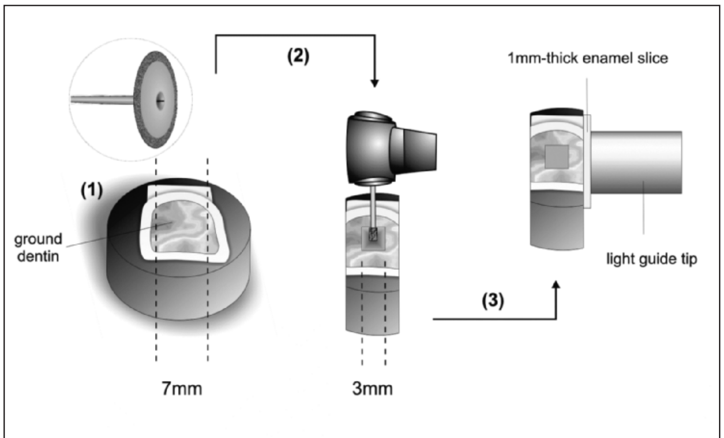

Figure 1. *Experimental design of the study. Bovine incisors were embedded in polystyrene resin and a flat ground surface in dentin was obtained. Both proximal faces were sectioned using a diamond saw to obtain 2 mm-thick dentin walls. 1) Standardized cavities were prepared on the central area of the flattened surfaces. 2) After insertion of the composite, different curing techniques and light sources were tested. 3) A 1 mm-thick enamel slice was positioned between the light guide tip and the proximal dentin wall for the transdental technique.*

dentin walls. A handheld radiometer (Demetron, Danbury, CT, USA) was used to measure irradiance of the LCUs and the irradiance transmitted through a 2 mm thick dentin specimen covered with the enamel slice. These values were used to calculate the radiant exposure for each curing technique-light source combination (Table 1).

Marginal Adaptation Analysis

After air-drying the samples, a drop of 1% acid red propylene glycol solution (Caries Detector, Kuraray, Osaka, Japan) was placed on the margins for 20 seconds. The samples were rinsed with water, air-dried and digital images were obtained. The length of time for staining along the margins was measured using Image Tool 2.0 software (UTHSC, San Antonio, TX, USA). Marginal adaptation (%) was calculated as the ratio of the stained margin by the total length of the margin. Data were submitted to two-way ANOVA and Tukey's test ($p \leq 0.05$).

Hardness Evaluation

Each specimen was cut in half through the center of the restoration. The cervical portion was wet-polished with 400-, 600- and 1200-git SiC papers. Knoop indentations were made across the section of the composite with an indenter (HMV-2, Shimadzu, Tokyo, Japan), using a 50g load for 15 seconds. Three readings were performed at 0.5 mm deep and three at 1 mm deep. The Knoop Hardness number (KHN) for each specimen was recorded as the average of the six indentations. The data were submitted to two-way ANOVA and Tukey's test ($p \leq 0.05$).

RESULTS

Table 2 presents the results of the marginal adaptation analysis. Significant differences among the light-curing techniques were detected ($p=0.009$); whereas, the factor light source ($p=0.774$) and the interaction between the technique and light source ($p=0.692$) were not significant. No curing technique-light source combination provided a perfect marginal adaptation. However,

Table 2: *Average Percentage (Standard Deviation) of Marginal Gap Formation*

Curing Technique	Light Source			
	LED	QTH	PAC	Total
Direct	13.3 (5.9)	19.8 (6.4)	17.5 (5.3)	16.8 **a**
Transdental	12.3 (3.0)	9.7 (2.6)	6.2 (1.5)	9.4 **ab**
Mixed	6.3 (2.8)	8.2 (1.8)	7.7 (2. 2)	7.4 **b**
Total	10.6 **A**	12.5 **A**	10.5 **A**	

Same capital letter in the row indicates no significant difference for light source, and same small letter in the column indicates no significant difference for curing technique (p>0.05).

Table 3: *Knoop Hardness Means (Standard Deviation)*

Curing Technique	Light Source			
	LED	QTH	PAC	Total
Direct	95.3 (1.1)	96.2 (1.4)	87.4 (1.9)	93.0 **a**
Transdental	88.6 (1.6)	87.1 (2.1)	86.5 (1.9)	87.4 **b**
Mixed	63.2 (1.3)	56.5 (3.0)	58.3 (3.3)	59.3 **c**
Total	82.4 **A**	79.9 **AB**	77.4 **B**	

Same capital letters indicate no significant differences for light source, and same small letters indicate no significant differences for curing technique (p>0.05).

MT yielded a decrease in gap formation compared with DT ($p<0.05$), regardless of the light source. No significant difference was detected between TDT and the other techniques.

Table 3 shows the results of the hardness analysis. Significant differences were detected among the curing techniques ($p<0.001$) and light sources ($p=0.033$) but not for the interaction between them ($p=0.152$). DT showed greater hardness than both TDT ($p<0.01$) and MT ($p<0.05$). Also, MT yielded greater hardness than TDT ($p<0.05$). For the light source, LED showed greater hardness compared with the PAC ($p<0.05$), but there was no significant difference between QTH and other light sources.

DISCUSSION

It is known that continuous irradiance at high intensity generates high contraction stress[9] and gap formation.[2-3] Indeed, the poorest marginal adaptation was found for DT. This technique also showed the greatest hardness, which is probably related to a higher degree of conversion and shrinkage, which might have also accounted for increasing gap formation. On the other hand, it could be expected that the lower initial irradiance provided by TDT would interfere with gap formation. Nonetheless, only MT provided better marginal adaptation than direct curing. Therefore, the tested hypothesis cannot be confirmed.

The lower gap formation observed for MT could be explained by a reduction in irradiance when light passes through the dental structure. Indeed, previous studies[10-11] reported that photo-activation at reduced irradiance is more efficient than trying to guide the shrinkage vectors in order to preserve marginal integrity, as the direction of vectors is determined by boundary conditions.[1] Therefore, MT seemed to work as a soft-start polymerization. Also, the current results suggest that an increase in exposure time leads to smaller gap formation. However, when activation was carried out through just the dental structure, no improvement in marginal adaptation was detected. The hardness outcomes might explain this phenomenon, as significantly softer polymers were detected for TDT. When compared to the other techniques, the radiant exposure for TDT was noticeably lower, as a function of the significant reduction in irradiance for the light transmitted through enamel and dentin, probably leading to a lower degree of conversion. During polishing procedures, irregularities around the restoration margins could have been produced because of low polymerized material increasing marginal staining. This outcome highlights a proper curing of the composite. which might be essential for the long-term success of the restorations.

In order to assess marginal adaptation, a dye staining method was used.[12] Although depth of penetration or gap width are usually evaluated, the presence of gaps, regardless of their width or depth, might be the first sign of restoration failure.[12] However, due to the limitations of *in vitro* analyzes, it is difficult to predict whether the observation of dye-stained margins could indicate poor clinical performance. Nonetheless, the presence of gaps might lead to interfacial leakage, degradation of the bonding layer or even extrinsic staining. Therefore, it would be advisable to use a curing method capable of improving the adaptation of fillings.

On the other hand, with respect to the light source, no significant differences in gap formation were detected, regardless of the photo-activation technique used. This result is probably related to the similar radiant exposure that controls conversion and shrinkage. Therefore, it seems that, for gap formation, the light source presents less influence than the activation technique. In addition, the LED source showed significantly greater hardness than the PAC. In the current study, a nine second exposure time was used for activation with PAC, instead of the three seconds recommended by its manufacturer, in order to ensure adequate composite cure. Nonetheless, despite the similar radiant exposure, a slight reduction in hardness, compared to the LED source, was observed. This might be related to the fact that the output light spectrum of the LCU also has critical importance for polymerization potential.[13] Therefore, the narrower emission spectrum of LED lights, which is better correlated with the spectral absorbance peak of camphorquinone, could improve their curing ability.

Moreover, a slight reduction in hardness was verified for MT when compared with DT. An attempt to explain this outcome considers that the initial exposure at low-light intensity for TDT might result in the formation of short, low-molecular weight polymer chains, with less cross-linking[4] interfering with the mechanical properties of the composite.[13] Nevertheless, considering the magnitude of the difference verified between DT and MT, and also between the LED and PAC sources, it is difficult to predict whether this could have significant influence on the clinical practice.

In summary, the current results show that a photocuring technique that combines initial activation through the dental structure and final exposure from the top surface of the restoration might reduce the formation of gaps, while not being detrimental to composite hardness, irrespective of the light source. Thereby, this technique could be encouraged in clinical practice. Nonetheless, it is important to highlight the fact that high-intensity lights should be used, as irradiance through the dental structure would be markedly reduced.

CONCLUSIONS

- The association between transdental and direct curing techniques could reduce the formation of marginal gaps, regardless of the light source, while not being detrimental to composite hardness;
- The transdental photo-activation technique might produce no significant beneficial effect on the marginal adaptation of composite restorations, while significantly interfering with material hardness;
- The different light sources (QTH, LED and PAC) showed no influence on the marginal adaptation of composite restorations, while the LED unit yielded greater hardness than PAC.

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