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EFFECT OF THERMAL CYCLING AND FILLING TECHNIQUE ON LEAKAGE OF COMPOSITE RESIN RESTORATIONS

EFEITO DA TERMOCICLAGEM E DA TÉCNICA DE INSERÇÃO NA INFILTRAÇÃO DE RESTAURAÇÕES EM RESINA COMPOSTA

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ABSTRACT

The objective of this study was to evaluate *in vitro* the effect on leakage of two incremental filling techniques and two composite resins with different elastic modulus and similar polymerization shrinkage. Eighty Class V cavities (4x4x2mm) were prepared in bovine incisors and were randomly restored with Z-250 (Z) or Durafill VS (D) + Single Bond in axial (a) or oblique (o) increments. The restorations were divided into two groups: Not Aged - N (4-hour-storage in water at 37ºC) and Aged - A (1-week storage in water at 37ºC + 1000 x - 5º-55ºC / 1-min dwell time). The specimens were covered with 2 coats of nail varnish so that only the restoration margins were exposed to silver nitrate 50% (2h) and developed under fluorescent light (8h). After they were sectioned twice in buccal-lingual direction, the four exposed surfaces were digitized (Vidcap) and the silver nitrate penetration was measured (ImageLab) at the incisal and gingival walls. Data were analyzed by a 3-way ANOVA (Resin, Filling Technique and Aging) separately for incisal and gingival walls (α=0.05). Resin and Aging were statistically significant either for the incisal and the gingival walls. The microfill composite resin infiltrated more than the hybrid composite. The thermal cycling caused an overall increase in silver nitrate penetration. The filling technique affected leakage depending on the composite resin and aging regimen.
Uniterms: Composite resins; Elasticity; Dental leakage.

RESUMO

O objetivo deste estudo foi avaliar o efeito de duas técnicas incrementais de inserção na infiltração de restaurações de resinas compostas com módulos de elasticidade distintos e contração de polimerização semelhante. Para isto, foram preparadas 80 cavidades Classe V (4x4x2 mm) em incisivos bovinos que foram restauradas de modo aleatório com Z-250 (Z) ou Durafill VS (D) + Single Bond em incrementos axiais (a) ou oblíquos (o). As restaurações foram divididas em dois grupos: Não Envelhecidas - N (4 h em água destilada a 37º C) e Envelhecidas – E (1 semana de armazenagem em água a 37º C + 1000 x - 5º-55ºC / 1 min de imersão). Os espécimes foram recobertos com duas camadas de esmalte cosmético de modo que apenas as margens das restaurações ficassem expostas ao nitrato de prata (2h) seguido de imersão em revelador (8h) sob luz fluorescente. Posteriormente, eles foram secionados duas vezes no sentido vestíbulo-lingual, as superfícies expostas (4) foram digitalizadas (Vidcap) e a penetração do nitrato de prata medido (ImageLab) nas paredes incisal e gengival. Os dados foram analisados por análise de variância de três fatores (Resina, Técnica de Inserção e Envelhecimento) separadamente para as paredes incisal e gengival. Resina e Envelhecimento foram significativos. A resina composta de micropartículas mostrou maior infiltração que a híbrida. A técnica de inserção influenciou a infiltração marginal dependendo da resina e do emprego ou não de ciclos térmicos.
Unitermos: Resinas compostas; Elasticidade; Infiltração dentária.

INTRODUCTION

Composite resin restorations are subjected to polymerization shrinkage stress that may cause premature failure at the interface[3]. As aging tends to aggravate the restoration's original deficient seal[11], minimizing polymerization shrinkage stress is the first step for a reliable long-term performance of composite resin restorations.

The restoration's C-factor is determinant in the polymerization shrinkage stress level: the higher bonded / unbonded area ratio, the higher the stress build-up[7]. Moreover, a stress relief mechanism by the resin's flow was also reported and considered as the key factor in reducing the adhesive interface breakdown[6]. Based on these findings, the incremental filling technique has been suggested to contribute to the C-factor reduction[1]. However, some authors, using finite element models, have contested this stress reduction capacity and have suggested different stress patterns according to the filling technique applied[21,26].

The composite resin's shrinkage, elastic modulus and polymerization rate of various composite resins and adhesive systems have also been investigated. In general, high filler content materials as hybrid composites have exhibited low shrinkage and high elastic modulus, a positive and a negative feature, respectively, regarding polymerization shrinkage stress. In contrast, a microfilled composite have showed low shrinkage and low rigidity, a combination that might be potentially less damaging to the interface[15]. Although the relative contribution of each parameter remains unknown, they affect the amount of polymerization shrinkage stress developed.

Once the adhesive interface has survived the polymerization shrinkage stress, the long-term performance of the composite resin restorations is an extra source of concern, as other factors such as thermal changes are likely to challenge the adhesive interface. Thermal cycling is a commonly adopted in vitro aging procedure and, despite the variety of regimens described in a review of 130 studies, it generally increases marginal leakage[11] and was also reported to increase the gap width at the interface[20].

Another issue of major concern is water sorption, which has been considered to cause the degradation of resin-dentin bonding[13]. Water sorption was also reported to decrease the marginal gap width, especially in microfilled composites[20], and allow relaxation of polymerization shrinkage shear stress[8]. However, some caution must be taken in considering this potentially positive effect as the composite resin's selection depends on other features such as its mechanical properties, which could be compromised.

It is expected, for two composite resins with similar polymerization shrinkage, that the one with higher elastic modulus would generate more stress build-up at the interface with equivalent bond quality. It is still unknown whether this relationship remains with a variable adhesion substrate such as the dentin and the consequences after thermal aging as time dependent thermal stress σ (t) is also significantly dependent on the elasticity modulus (E)[23].

The objective of this study was to evaluate in vitro the effect of two incremental filling techniques using composite resins of different elastic modulus and similar polymerization shrinkage on leakage of Class V restorations. The effect of thermal cycling was also assessed.

MATERIAL AND METHODS

Z-250 (Z, 3M ESPE, St Paul, MN, USA) and Durafill VS (D, Heraeus Kulzer GmbH, Wehrheim, Germany) were selected because of their different elastic moduli (18.5 GPa[18] and 6.48 GPa, respectively[15]) and similar polymerization shrinkage (p=0.9987 - not shown) measured by the method described by Watts and Cash[24] (1.92 ± 0.07%).

A 1%-chloramine solution was used as a disinfectant medium for the 80 bovine incisors used in this study. A standardized class V (4x4x2mm) cavity was prepared in the buccal surface of each tooth. The cavities were pumiced, acid etched (15s) and the adhesive (Single Bond - 3M ESPE, St Paul, MN, USA) was applied according to the manufacturer's instructions. The teeth were restored in axial or oblique increments as represented in Figure 1 using a light-curing unit (Variable Intensity Polymerizer, Bisco, Schaumburg, IL, USA) at a constant intensity of 600mW/cm^2 (80s).

The restorations were finished with Sof-Lex Pop-On disks (3M ESPE, St. Paul, MN, USA) and randomly divided into two groups: Not Aged (4-hour-storage in water at 37^{o}C) and Aged (1-week storage in water at 37^{o}C + 1000 thermal cycles with baths of 5^o and 55^{o}C with 1-min dwell time).

After the respective storage period, the specimens had their apical foramina blocked by sticky wax and cyanoacrylate (SuperBonder, Henckel Loctite, SP, Brazil) and covered with two coats of nail varnish except for 1mm beyond the restoration's exposed margins. This procedure was followed by immersion in a 50% $AgNO_3$ solution in a dark vial for 2h, washing in tap water and exposing to a developing solution under fluorescent light for 8h[17].

Then, they were sectioned twice in buccal-lingual direction and the exposed surfaces (4) were observed at 40x magnification in a light microscope and the respective

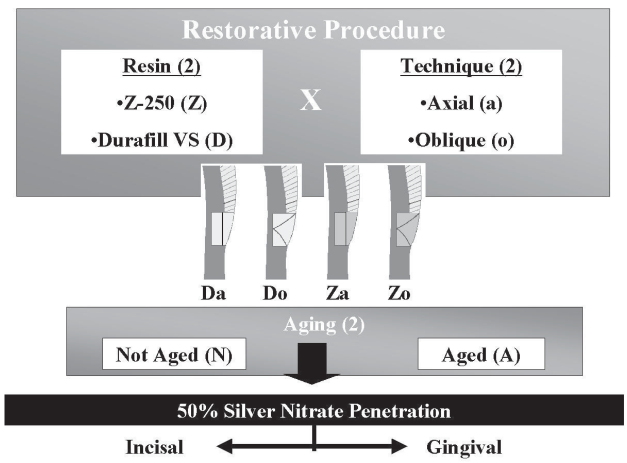

FIGURE 1- Expermental design

images were digitized (Vidcap 32) so that the silver nitrate penetration (mm) could be measured with ImageLab software at the incisal and gingival walls of the cavities. Data were analyzed by a 3-way ANOVA at a confidence level of 95%. The factors considered were: Resin (2 levels), Filling Technique (2 levels) and Aging (2 levels) separately for the incisal and gingival wall data.

RESULTS

Incisal Wall

The factors, Resin and Aging, were significant ($p<0.05$): Durafill VS infiltrated more than Z-250 - the mean silver nitrate penetrations were 0.27±0.12mm and 0.19±0.12mm, respectively. The thermal cycles increased leakage. No significant difference was detected between the axial and the oblique filling techniques ($p>0.05$).

The Resin x Technique interaction was significant ($p<0.05$) and the Da group infiltrated more than all the other combinations (Table 1). The Resin x Aging interaction was also significant ($p<0.05$); the ZN group presented the lowest silver nitrate penetration and the DA group the highest. Intermediate values were exhibited by the groups DN and ZA, which were not statistically significant different ($p>0.05$).

Gingival Wall

Similar results were found at the gingival wall considering only the main factors Resin and Aging, which were significant ($p<0.05$): the mean silver nitrate penetration was 0.68±0.28mm and 0.55±0.19mm for Durafill VS and Z-250 respectively. Silver nitrate penetration increased from a mean value of 0.49±0.13mm to 0.74±0.27mm with thermal cycles. The filling technique was not significant ($p>0.05$).

The second order interaction was significant ($p<0.05$). Za and Do groups were not affected by thermal cycles as no differences were observed between Not Aged and Aged groups. In contrast, Zo and Da groups were significantly affected by the thermal cycles ($p<0.05$).

TABLE 1- Silver Nitrate Leakage at the Incisal and Gilgival wall

LEAKAGE (mm)			
INCISAL		GINGIVAL	
Resin x Aging	*Mean ± SD*	*Resin x Technique x Aging*	*Mean ± SD*
DN	0.28±0.11[b]	ZaN	0.51±0.11 [e,f]
DA	0.27±0.13[b]	ZaA	0.55±0.08 [e,f]
ZN	0.13±0.09[a]	ZoN	0.38±0.12 [e]
ZA	0.25±0.12[b]	ZoA	0.77±0.18 [f,g]
Resin x Technique	*Mean ± SD*	DaN	0.50±0.14 [e,f]
Da	0.35±0.12[d]	DaA	0.96±0.39 [g]
Do	0.20±0.04[c]	DoN	0.57±0.06 [e,f]
Za	0.16±0.06[c]	DoA	0.67±0.16 [f]
Zo	0.22±0.15[c]	(*) Same symbols indicate no statistically significant difference (p>0.05)	

DISCUSSION

The excellent bond to enamel has been shown to survive long water storage and protect the resin-dentin bond against degradation[4]. The comparatively weaker bond to dentin has been reported to result in more severe leakage at the gingival than at the incisal wall of the restorations[5,9,14].

The present study supports these previous observations, as the mean incisal values of silver nitrate penetration were approximately one third of those found at the gingival wall. Thermal cycling was also reported to be an effective aging process[11] and was included to determine whether the adhesive interface's rupture occurs immediately after the restoration, which could be related to polymerization shrinkage stresses, or as a result of the aging process.

Resin and Aging affected leakage at the incisal and gingival walls. For both substrates, Durafill VS showed higher silver nitrate infiltration than Z-250. These results were not expected in the Not Aged group, because the higher elastic modulus of Z-250 should have produced more stress buildup at the interface than Durafill VS. A possible explanation might be related to composition differences between the composite resins that could have favored chemical compatibility between the resin and adhesive system from the same manufacturer (Z-250 and Single Bond, both manufactured by 3M).

Incompatibility between simplified-step adhesives and chemically-cured or dual-cured composites was reported in some studies[12,19], but cannot be considered as a general rule[10,16]. Furthermore, incompatibility was suggested to be influenced not only by the chemical composition of the adhesive, but also by that of the composite[12]. A partial incompatibility might be a possible explanation for the higher leakage of Durafill VS, although it was demonstrated that it does not affect light cured composites' bond strength even after thermal cycling[2].

Thermal stress (σ) was reported to be directly proportional to the elastic modulus (E) and to the thermal expansion coefficient (α). In a restoration, the resultant interfacial stress under thermal variation (σ) is expected to be high if the product of these two properties (E x α) leads to a severe mismatch between the tooth and the composite [23]. Therefore, it is possible that a partial incompatibility remained undetected in previous studies because such mismatch's effect on stress did not exceed the bond strength.

Durafill VS higher leakage is unlikely to be related to this mismatch: a 13GPa[23] elastic modulus was attributed for dentin and 18.5GPa [18] and 6.48GPa [15] for Z-250 and Durafill VS, respectively. Moreover, Z-250's α is expected to be approximately half that of Durafill VS' as it was previously reported for Z-100 (22.5±1.4 x $10^{-6}/^{o}C$) and Silux Plus (41.6±1.5 x $10^{-6}/^{o}C$)[22], composite resins of similar type [25]. As a result, Z-250's thermal stress (σ) would be expected to be about 1.5 higher than Durafill VS' if their bond strength were similar. Therefore, a reduction in Durafill VS' bond strength related to a decreased chemical compatibility with the adhesive might have caused its higher leakage.

Although Technique was not significant either for the incisal or for the gingival wall, the filling technique adversely affected leakage depending on the composite resin and aging, as indicated by the significant interactions. The most severe leakage was observed for Da group while Z-250 restorations were not affected by the filling technique (Table 1). Likewise, the second order interaction at the gingival wall was significant ($p<0.05$) and thermal cycles adversely affected only the Zo and Da groups.

In previous finite elements studies, the oblique technique was considered to lead to the highest tensile stress build-up to the adhesive interface, while the bulk filling, to the lowest. The gingival-occlusal filling technique (similar to the axial technique in this study) reached an intermediate tensile stress level [21,26]. Therefore, the influence of the filling technique observed in the second order interaction in this study can be related to differences in the tensile stress build-up suggested by finite element models and the possible partial adhesive-resin incompatibility.

For Z-250, the oblique filling technique resulted in lower silver nitrate infiltration when the Not Aged group was considered. However, the high stress level generated during the cure of the composite could have led to more residual stress that caused the interface's rupture after the thermal cycles. For Durafill VS, the oblique technique caused premature failure for the Not Aged without further infiltration detected for the aged groups.

In contrast, for Durafill VS, the axial technique with relatively lower tensile stress might have favored the interface's survival, minimizing the possible partial incompatibility effect in the Not Aged group. However, because the coefficient of thermal expansion of this resin is relatively high[22], a significant increase in leakage was detected after the thermal cycles.

An additional group with a period of storage in water similar to that of the Aged group without thermal cycles would be helpful to determine the isolated effect of water or temperature on leakage. However, this was beyond the scope of this study, which focused the polymerization shrinkage effect (Not Aged group – 4h) and the thermal cycling effect (Aged group – 1 week), both dependent on the elastic modulus (E) and the corresponding dimensional changes involved.

As a variety of composite resins and adhesive systems are currently available, no general theoretical models can be used in the selection of a restorative procedure. Further studies are needed to clarify the relative contribution of the factors that rule the amount of polymerization shrinkage stress generated such as the elastic modulus, polymerization rate and shrinkage.

In this study, the microfill composite resin infiltrated more than the hybrid composite independently of its lower elastic modulus and similar polymerization shrinkage. Thus, another factor, such as incompatibility with the adhesive, might have produced its bond strength reduction. The filling technique was observed to adversely affect leakage depending on the composite resin and the aging regimen applied. As aging was found to increase leakage significantly, even at the enamel interface, future studies should investigate the basis for the development of more durable composite resin restorations.

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REFERENCES

1- Carvalho RM, Pereira JC, Yoshiyama M, Pashley DH. A review of polymerization contraction: the influence of stress development versus stress relief. Oper Dent 1996;21(1):17-24.

2- Chan DC, Reinhardt JW, Boyer DB. Composite resin compatibility and bond longevity of a dentin bonding agent. J Dent Res 1985;64(12):1402-4.

3- Davidson CL, Feilzer AJ. Polymerization shrinkage and polymerization shrinkage stress in polymer-based restoratives. J Dent 1997;25(6):435-40.

4- De Munck J, Van Meerbeek B, Yoshida Y, Inoue S, Vargas M, Suzuki K, et al. Four-year water degradation of total-etch adhesives bonded to dentin. J Dent Res 2003;82(2):136-40.

5- Eakle W, SIto RK. Effect of insertion technique on microleakage in mesio-occlusodistal composite resin restorations. Quintessence Int 1990;21(5):369-74.

6- Feilzer AJ, De Gee AJ, Davidson CL. Quantitative determination of stress reduction by flow in composite restorations. Dent Mater 1990; 6(3):167-71.

7- Feilzer AJ, De Gee AJ, Davidson CL. Setting stress in composite resin in relation to configuration of the restoration. J Dent Res 1987; 66(11):1636-9.

8- Feilzer AJ, de Gee AJ, Davidson CL. Relaxation of polymerization contraction shear stress by hygroscopic expansion. J Dent Res 1990; 69(1):36-9.

9- Fisbein S, Holan G, Grajower R, Fuks A. The effect of vlc scotchbond and an incremental filling technique on leakage around class II composite restorations. ASDC J Dent Child 1988;55(1):29-33.

10- Franco EB, Lopes LG, D'Alpino P H, Pereira JC, Mondelli RF, Navarro MF. Evaluation of compatibility between different types of adhesives and dual-cured resin cement. J Adhes Dent 2002;4(4):271-5.

11- Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. J Dent 1999;27(2):89-99.

12- Giachetti L, Scaminaci Russo D, Landi D. [Bonding compatibility between adhesive systems and composite resins]. Minerva Stomatol 2003;52(4):157-67.

13- Hashimoto M, Ohno H, Sano H, Kaga M, Oguchi H. Degradation patterns of different adhesives and bonding procedures. J Biomed Mater Res 2003;66B(1):324-30.

14- Koenigsberg S, Fuks A, Grajower R. The effect of three filling techniques on marginal leakage around class ii composite resin restorations in vitro. Quintessence Int 1989; 20(2):117-21.

15- Labella R, Lambrechts P, Van Meerbeek B, Vanherle G. Polymerization shrinkage and elasticity of flowable composites and filled adhesives. Dent Mater 1999;15(2):128-37.

16- Pfeifer C, Shih D, Braga RR. Compatibility of dental adhesives and dual-cure cements. Am J Dent 2003; 16(4):235-8.

17- Pintado MR, Douglas WH. The comparison of microleakage between two different dentin bonding resin systems. Quintessence Int 1988; 19(12):905-7.

18- Sabbagh J, Vreven J, Leloup G. Dynamic and static moduli of elasticity of resin-based materials. Dent Mater 2002;18(1):64-71.

19- Tay FR, Pashley DH, Yiu CK, Sanares AM, Wei SH. Factors contributing to the incompatibility between simplified-step adhesives and chemically-cured or dual-cured composites. Part I. Single-step self-etching adhesive. J Adhes Dent 2003;5(1):27-40.

20- Torstenson B, Brannstrom M. Contraction gap under composite resin restorations: Effect of hygroscopic expansion and thermal stress. Oper Dent 1988; 13(1):24-31.

21- Versluis A, Douglas WH, Cross M, Sakaguchi RL. Does an incremental filling technique reduce polymerization shrinkage stresses? J Dent Res 1996;75(3):871-8.

22- Versluis A, Douglas WH, Sakaguchi RL. Thermal expansion coefficient of dental composites measured with strain gauges. Dent Mater 1996; 12(5):290-4.

23- Watts DC. Elastic moduli and visco-elastic relaxation. J Dent 1994; 22(3): 154-8.

24- Watts DC, Cash AJ. Determination of polymerization shrinkage kinetics in visible-light-cured materials: Methods development. Dent Mater 1991;7(4):281-7.

25- Willems G, Lambrechts P, Braem M, Celis JP, Vanherle G. A classification of dental composites according to their morphological and mechanical characteristics. Dent Mater 1992; 8(5):310-9.

26- Winkler MM, Katona TR, Paydar NH. Finite element stress analysis of three filling techniques for class v light-cured composite restorations. J Dent Res 1996;75(7):1477-83.