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Shrinkage stress of resin composites: effect of material composition - sistematic review

Tensão de contração de resinas compostas: efeito da composição do material - revisão sistemática

John Alexis DOMINGUEZ[1], **Bruna Fortes BITTENCOURT**[1], **Paulo Vitor FARAGO**[2], **Luis Antonio PINHEIRO**[3], **Osnara Maria Mongruel GOMES**[1]

1 – Department of Restorative Dentistry – School of Dentistry – State University of Ponta Grossa – Ponta Grossa – Brazil.

2 – Postgraduate Program in Pharmaceutical Science – Department of Pharmaceutical Sciences – State University of Ponta Grossa – Ponta Grossa – Brazil.

3 – Department of Materials Engineering – State University of Ponta Grossa – Ponta Grossa – Brazil.

ABSTRACT

The longevity of resin depends on its binding between the margin of restorations and the polymer, and one factor that influences this aspect is the shrinkage stress. Thus, the working group presentsthe following systematic review thatverifies the influence of composite resin composition on shrinkage stress. The following electronic databases were searched: MEDLINE (via Ovid and PubMed - 2004 to January 2014), with the keywords: shrinkage stress, degree of conversion, resin composite. For shrinkage stress,, the best results were found when the BISGMA monomer was used and for the inorganic composition, an inverse relationship was observed: the increased inorganic filler content decreases shrinkage stress.

KEYWORDS

Shrinkage stress; Degree of conversion; Resin composite.

RESUMO

A longevidade de resina depende da sua ligação entre a margem de restaurações e o polímero, e um fator que influencia a este aspecto, é a tensão de contração. Assim, o grupo de trabalho faz a seguinte análise sistemática para verificar a influência da composição das resinas composta na tensão de contração. As seguintes bases de dados eletrônicas foram pesquisadas: MEDLINE (via PubMed e Ovídio - de 2004 a janeiro de 2014), com as palavras-chave: estresse de contração, grau de conversão, resina composta. Para tensão de contração, os melhores resultados foram encontrados quando o monômero BISGMA foi utilizada e para a composição inorgânica, uma relação inversa foi observada: o aumento do teor de carga inorgânica diminui estresse de contração.

PALAVRAS-CHAVE

Estresse de contração; Grau de conversão; Resina composta.

INTRODUCTION

Polymerization shrinkage and consequent stress generation are the main disadvantages of resin composites [1,2]. This stressis responsible for the composite detachment from the margin, creating a marginal gap, which may result in postoperative sensitivity, enamel cracking, recurrent caries, marginal discoloration and failure of the restoration [3].

Many factors influence the composite contraction stress, including those related to material composition such as organic matrix, initiation system and inorganic filler content. These characteristics may influence the degree of conversion of material, which has a direct relationship with the shrinkage stress generated into dental structures [4,5].

The purpose of the systematic review is to discuss the influence of the resin composite composition and its relationship with shrinkage stress and degree of conversion.

CRITICAL REVIEW

The following electronic databases were searched: MEDLINE (via Ovid and PubMed - 2004 to January 2014), with the keywords: shrinkage stress, degree of conversion, resin composite. The inclusion criteria for this review were: resin composite evaluations: shrinkage stress and / or degree of conversion, its composition and/ or modified. The exclusion criteria were: articles evaluating materials other than resin composite, other languages than English and abstracts. The distribution of revised articles is in Table 1.

Pfeifer et al. [6] evaluated the polymerization rate and volumetric shrinkage as a function of composite formulation and irradiance, in an attempt to verify the contributions of these variables to polymerization stress development. Two composites were mixed: Formulation B consisted of equal parts by weight of 2,2-bis[p-(29-hydroxy-39-methacryloxypropoxy)phenylene] propane (Bis-GMA) and triethylene glycol dimethacrylate (TEGDMA); formulation U had equal parts by weight of Bis-GMA, TEGDMA, and 1,6-bis(methacryloxy-2-ethoxycarbonylamino)-2,4,4-trimethylhexane (UDMA). Lightcuring was performed by two irradiation light cure units (with different irradiances). The authors concluded that when the two composites were compared, differences in reaction rate did not correlate with differences in shrinkage stress and no significant interaction between irradiance and monomer blend was observed in any of the tests, except for maximum rate of stress development.

It is important to recognize and determine the influence of the polymeric material composition. So, this section was divided into two topics: organic matrix and inorganic composition.

Organic Matrix

The organic matrix of composite resins is responsible for texture, viscosity and influences the properties assessed. Most current polymers used for dental restorative materials are composed by high-molecular weight monomers, Bis-GMA or urethane dimethacrylate (UDMA) [7]. These monomers are highly viscous liquids, and diluents are added to the composites to facilitate clinical use. Current diluents are generally lower molecular weight dimethacrylate monomers, e.g. triethyleneglycol dimethacrylate (TEGDMA). Many Bis-GMA-based composites contain signficant amount of TEGDMA, approximately 20–50 wt% [8].

Lai et al. [9] evaluated visible lightcured dental composites based on the high molecular weight siloxane monomer 1,3-bis[(p- acryloxymethyl) phenethyl] tetramethyldisiloxane (BAPD).Experimental resins were made with BAPD at various concentrations and the two controls contained 8.25 wt% of Bis-GMA and TEGDMA at various concentrations. In vitro hardness, diametral tensile strength, degree of conversion, water sorption and polymerization shrinkage were evaluated, concluding that when there is the same filler concentration, Bis-GMA-based composites have more shrinkage than BAPD-based composites due to the presence of the lower molecular weight diluent. Because of the absence of a diluent monomer, the polymerization shrinkage of the siloxane composites could be lower than that of bis-GMA-based composites, even if degree of conversion is higher. Fong et al. [10] evaluated new experimental composite resins with polyhedral oligomeric silsesquioxane methacrylate monomer (POSS-MA). This monomer was used to partially or completely replacement of the commonly used monomer Bis-GMA.The replacement of Bis-GMA by POOS-MA (10% or less) showed increased flexural strength values, but with no difference in degree of conversion. Palin et al. [11] evaluated other oxirane and silorane monomers compared with commercial composites. The evaluating parameters were: microleakage, cuspal deflection and degree of conversion. A significant decrease in cuspal deflection was observed when oxirane and silorane monomers were used; and the authors suggest that it may decrease the magnitude of polymerization shrinkage stress at the tooth/ restoration interface. Hussain et al. [12] evaluated various formulations of metacrylated beta-cyclodextrins (MCDs) compared with Bis-GMA, and MCDs with different diluents (HEMA, UMMA, 2-PEMA, BMA).The analyzed properties were flexural strength, volumetric shrinkage and degree of conversion. The authors foundthat the properties of the experimental monomer depended on the kind of diluent used, and the best properties, in terms of flexural strength and volumetric shrinkage were comparable with Bis-GMA formulation controls. He et al. [13] evaluated a new monomer 5,50-bis[4-(20-hydroxy-30-methacryloyloxy-propoxy)-phenyl] hexahydro -4,7-methan-oindan (5,50-BHMPHM) with molecular weight of 640 and large molecular volume. The monomer was designed and synthesized, and diluent TEGDMA was used. Also, a formulation of Bis-GMA–TEGDMA was used for comparison purposes. The results illustrated that double bond conversion, polymerization shrinkage and diffusion coefficient were lower for the experimental resin. Also, water sorption was higher than the control formulation.

Gonçalves et al. [14] evaluated three concentrations of Bis-GMA (33, 50 and 66%) with two diluents (TEGDMA and Bis-EMA). The higher concentration of Bis-GMA, the lower polymerization shrinkage stress and volumetric contraction were found. Gonçalves et al. [15] evaluated the influence of Bis-GMA/TEGDMA and UDMA/TEGDMA ratios in polymerization stress of experimental composites and variables related to its development, such as degree of conversion, volumetric shrinkage, elastic modulus, kinetics and viscosity of the blends. The findings of this study showed that UDMA with lower TEGDMA content demonstrated reduced viscosity and kinetics properties, which led to elevated conversion and relatively lower polymerization stress compared to Bis-GMA/TEGDMA blends. Amirouche-Korichi et al. [16] mixed (0 and 80%) opaque fillers (La_2O_3, BaO, $BaSO_4$, SrO and ZrO_2) and three Bis-GMA/TEGDMA ratios (25/75, 50/50, 75/25). The results indicated that when Bis-GMA content increased, without filler content (0%), degree of conversion and shrinkage stress also decreased. The same result was obtained with all experimental opaque fillers studied. Podgórki [17] synthesized 1,4 butylene and 1,6 hexylene glycol with glicidyl-methacrylate, and a photoinitiator, thus obtained 2,2 – dimethoxy – 2 - phenyloacetophen. The results showed that the new dimethacrylate demonstrated lower shrinkage stress, higher degree of conversion and similar water absorption compared to Bis-GMA.

The initiator system is also included in the composite resin matrix. The most commonly light-initiator used in dental resins is camphorquinone, while the reducing agent, the tertiary amine, may vary. Furuse et al. [18] evaluated experimental blends constituted by Bis-GMA, TEGDMA (3:1and 0.25 wt%), camphorquinone and amine (1 wt %). The evaluated amines were: 1-DMAEMA (2-dimethylaminoethyl methacrylate), 2-CEMA (N,N-cyanoethylmethylaniline), 3-DMPT (NN-dimethyl p-toluidine), 4-DEPT (N,N-diethanol p-toluidine) and 5-DABE (N,N-dimethyl-p-aminobenzoic acid ethylester) with four exposure times (20, 30, 40, and 40+7 s) and storage periods (0,1,24 and 168 h).It was concluded that increasing curing time and the storage time increases the degree of conversion, regardless of the tertiary amine. The resin containing DMAEMA showed higher degree of conversion, shrinkage stress and microhardness values.

Inorganic Composition

The composition, size and quantity of the inorganic matrix influence the physical properties of composite resins. The properties of resin-based materials are directly related to the filler content. Ataiet al. [19] studied an experimental resin composed by Bis-GMA (65 wt%), TEGDMA (35 wt%), camphorquinone

(0.5wt%), DMAEMA and barium aluminum silicate glass filler indifferent percentages (31, 40, 45, 51, 53.7 and 57 wt %). The evaluated properties were polymerization kinetics, and three storage temperatures (23,35 and 45 °C). It was concluded that increased shrinkage stress is proportional to storage temperature. Chen et al. [20] developed a new low-shrinkage nanocomposite, using an epoxy resin 3,4-epoxycyclohexylmethyl-(3,4-epoxy) cyclohexane carboxylate (ERL4221) matrix with 55% wt of 70–100 nm nanosilica fillers, which had their surfaces modified with γ-glycidoxypropyl trimethoxysilane (GPS). Composite properties such as hardness, thermal expansion coefficient and thermal stability were enhanced by the interaction between the fillers and the organic matrix, which was strengthened by the GPS. Fleming et al. [21], evaluated degree of conversion, shrinkage stress associated with cuspal movement and microleakage of two commercial composite resin with different filler sizes (microhybrid and macro fillers). The light cure unit was also varied: a light emitting diode (LED) and halogen lamp. The LED decreased cuspal movement compared with halogen lamp, but increased microleakage was observed with LED, regardless of the filler size.

Garoushi et al. [22] studied five experimental nanofilled composites, varying their inorganic filler content (0,10,20,30,40 and 50%) and glass fiber reinforcement in the polymeric matrix, in two temperatures (26 and 37 °C) to evaluate shrinkage stress. The authors found an inverse relationship between fillerand shrinkage stress. The temperature has no effect on degree of conversion. Turssi et al. [23] evaluated the filler size (100 to 1500 nm) and shape (spherical or irregular), without varying the filler content (56.7 % by volume), in degree of conversion and wear behavior. The findings suggested that the smaller particles, either spherical or irregular, may enhanced the wear resistance without compromised degree of conversion of the experimental composites.

Other effects

Different light curing units, time and speed also influence the composite contraction stress. Pteifer et al. [24] evaluated two commercial resin composites divided into 6 experimental groups, according to initial pulse irradiance (100 mW/cm^2 x 5 s or 500 mW/cm^2 x 1 s) and delay-time between pulses (0, 1 or 3 min). In all groups, a second irradiation of 500 mW/cm^2 x 39 s was applied, so that the total radiant exposure (energy dose) was approximately 20 J/cm^2.The conclusion was that pulse-delay curing, associated with a 3-min delay between irradiances, resulted in lower shrinkage stress without compromising degree of conversion. Cunha et al. [25] evaluate the effect of three different photoactivation methods (continuous light, soft start, and intermittent light) on the polymerization shrinkage stress of a composite using different resin liners, concluding that intermittent light was always associated with statistically lower stress values when compared with continuous light and the use of a flowable composite liner reduced the stress values when compared with the use of one adhesive coat.

A commercial composite was subjected to different curing protocols (continuous at high irradiance, continuous at low irradiance, and pulse-delay) and radiant exposures (6, 12, and 24 J/cm^2).The findings suggest that when low irradiances or pulse-delay methods are used, the lower degree of conversion and higher water absorption were observed [26].

Takahashi et al. [27] evaluated 8 composite resins (1 nanofilled, 5 nanohybrid, 1 flow, 1 hybrid and 1 microfilled) to evaluate marginal adaptation in dentin and adhesive resins. Only two nanohybrid resins demonstrated perfect marginal adaptation when bonded to dentin; in the other hand, all non-bonded adaptation values were greater.

Pre-heating resin composite with appropriate devices has been advocated as a method to reduce viscosity, improving marginal adaptation and monomer conversion and to shorten curing times [28]. Lohbauer et al. [29] pre heated a commercial composite between 10-68 °C.Increased degree of conversion and shrinkage stress were observed. Korashi [30] evaluated three pre-heating temperatures (37, 54 and 68 °C) with a high-intensity light emitting diode (LED) curing unit. The authors found that preheating the resin composite prior to curing increased its degree of conversion, but also increased its post-gel shrinkage stress, and the soft-start mode decreased the post-gel shrinkage stress without influence the degree of conversion.

DISCUSSION

The basic composition of a resin composite is a monomer, a diluent, an initiator, a coinitiator, as organic matrix, and fillers, as inorganic matrix. All components have influence on the polymerization behavior before, during and after the curing process.

The most widely used monomer is Bis-GMA (bisphenyl-glycidyl dimethacrylate). Lower percentages of this monomerreduced degree of conversion [12]. Likewise, higher concentrations of Bis-GMA may also negatively influence degree of conversion; it may be explained by the high viscosity conferred by the hydroxyl groups, and by stiffness due to the phenyl rings, since both reduce the mobility of the reactive species [19,32]. The high viscosity of Bis-GMA is compensated by TEGDMA addition, which increases the reactivity of Bis-GMA/TEGDMA mixtures and accelerates the initial conversion more rapidly, achieving the point where both chain propagation and termination become diffusion-controlled [33].

Between the co-monomers is the TEGDMA and BisEMA; the last more viscous, decreases the mobility of the monomers, promoting lower degree of conversion. Otherwise, the presence of TEGDMA facilitated the interaction among the reacting molecules, allowing the formation of a more densely packed network, and better polymerization behavior of Bis-GMA based-materials [32].

The concentration of tertiary amine has no influence on polymerization rate [34], but DMAEMA is the amine that showed the best mechanical properties in the composite resins [18].

Many studies have developed new monomers [10,12,13] to substitute or modify Bis-GMA [14]. Good results in polymerization shrinkage stress were obtained with oxiranes-siloranes systems [11]; however, these results did not guarantee increased longevity of the restoration. Under the same conditions, increased microleakage was visualized with the oxiranes-siloranes systems, compared to commercial blends.

The reduced polymerization shrinkage would lead to minimization of the deleterious effects of shrinkage on the clinical performance of composite materials, buthydrophilic dimethacrylates with higher water uptake are not suitable for the use as dental monomers [35,36].

The polymerization shrinkage depends on the light intensity: increasing the light intensity, microleakage also increases [22]. After light curing, the composite resin presented volumetric shrinkage in less than two minutes [37].Studies evaluating volumetric shrinkage without adhesive application demonstrate the resins prior to adhesive application exhibit better marginal adaptation [38-40]. Increasing the inorganic content improves shrinkage stress values and volumetric shrinkage without disturbing the degree of conversion [29,30].

CONCLUSION

1. For shrinkage stress, the best results were found when the BISGMA monomer was used;

2. The optimal diluent monomer for BISGMA is TEGDMA;

3. The best shrinkage stress results were obtained when the lowest BISGMA concentrations were used;

4. For the inorganic composition, an inverse relationship was observed: the increased inorganic filler content decreases shrinkage stress;

5. Shrinkage stress reduction and increased degree of conversion have no relationship with good quality marginal adaptation.

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John Alexis Dominguez
(Corresponding address)
Alameda Nabuco de Araujo 422, Barrio Uvaranas
CEP 84031-510 - Ponta Grossa, Parana - Brasil.
e-mail: johnalexis.dominguez@gmail.com

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