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ORIGINAL ARTICLE

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Influence of composite resin volume and C-factor on the polymerization shrinkage stress

Influência do volume da resina composta e fator-C na tensão da contração de polimerização

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ABSTRACT

Objective: Composite polymerization shrinkage stress is an inherent process of chemical and light composite resin activation. Consequently, this fact has been associated to potential clinical problems. The aim of the present *in vitro* study was to evaluate the volume and C-factor influence on chemical and light-curing composite resin polymerization shrinkage stress, using a non-rigid method that thereby provides lower stress values, causing a minimal deflection in load cell. **Materials and Methods**: The contraction forces of the Z-250 and Concise composite resins during polymerization were recorded in an UTM in two experiments. In the first experiment, the Z-250 composite was inserted beetwen two rectangular steel plates (6.0 x 2.0 mm), varyng the resin volumes and C-factors, in a single increment, polymerized for 20 s and the forces generated were recorded for 120 s. In the second experiment, a pair of rectangular steel plates (3x2mm) and two square steel plates (2x2mm), with varied heights (2; 3 mm, respectively), were used to determine the C-factor (0.6; 0.3) influence. **Results:** The polymerized Z-250 results showed that the volume variations, independent of the C-factor, had a direct influence on the shrinkage stress, different from the Concise, which was influenced by the C-factor. **Conclusion:** The present study showed that a higher volume of composite resins determines an increase in the shrinkage stress of light-curing composites.

KEYWORDS

C-factor. Composite resin. Polymerization. Shrinkage stress.

RESUMO

Objetivo: Contração de polimerização é um processo inerente das resinas compostas de ativação química e fotoativada. Consequentemente, esse fato tem sido associado a potenciais problemas clínicos. O objetivo do presente estudo in vitro foi avaliar a influência do volume e do fator-C na tensão da contração de polimerização em resinas química e fotoativada, utilizando um método não rígido que, dessa forma, fornece valores baixos de tensão, causando mínima deflexão na célula de carga. **Material e Métodos**: As forças de contração das resinas compostas Z-250 e Concise durante a polimerização foram registradas em uma UTM, dividida em dois experimentos. No primeiro experimento, a resina Z-250 foi inserida entre duas placas retangulares (6,0 x 2,0 mm), variando o volume de resina composta e fator-C, em incremento único, polimerizada por 20 s e as tensões geradas foram registradas durante 120 s. No segundo estudo, um par de placas retangulares de aço (3x2 mm) e duas placas de aço quadradas (2x2 mm), variando a altura (2 e 3 mm, respectivamente), foram usadas para determinar a influência do fator-C (0,6 e 0,3). **Resultados**: Os resultados da resina fotopolimerizável Z-250 mostraram que as variações do volume, independente do fator-C teve uma influência direta sobre a tensão de polimerização, diferente da Concise, a qual foi influenciada pelo fator-C. **Conclusão**: Esse estudo mostrou que um volume maior de resina composta determina um aumento na tensão de contração de polimerização.

PALAVRAS-CHAVE

Resina composta. Polimerização. Fator-C. Tensão de contração.

INTRODUCTION

Composite polymerization shrinkage stress is an inherent process of chemical and light composite resin activation as a consequence of monomer approximation during the polymeric chain formation [1]. This fact has been associated to potential clinical problems responsible for marginal failure, recurrent caries and dental fracture [2-4]. The polymerization shrinkage stress behavior and the flow capacity of the material are dependent on its physical and chemical characteristics and the cavity design. Feilzer et al.[1], in 1987 observed that the shrinkage stress in some chemically activated resins is the ratio of the adhesion area to the free area (called cavity configuration factor or C-factor) [1,5] that is considered important to reduce shrinkage stress. The quantity of free area is directly proportional to the flow (or plastic deformation) of the material, relieving in part, the stresses generated by the volumetric contraction. The C-factor may modify or influence the development of shrinkage and the stress tends to be higher in cavities with a higher C-factor [6,7].

The volume of the material is also a factor that influences the shrinkage stress [8-10]. A higher volume may increase the stress due to the greater amount of monomers forming polymeric chains [11]. Volume is considered especially important for light-curing restorative composite resins [8], in which the pre-gel phase is shorter and may not allow stress relief even with a lower C-factor [12].

The polymerization technique is equally important to relieve shrinkage stress resulting from the polymerization shrinkage stress when a sufficient free area is available. When a low light intensity is used, there is an increasing of the period that the resin remains with a low elasticity modulus (pre-gel phase), allowing molecular accommodation and relieving shrinkage [13]. It has been shown that when a composite is cured with initial low-intensity light followed by high-intensity light, there is a decrease in the curing stress [14]. However, the common method used by professionals in the dental office is the continuous uniform polymerization technique (conventional technique). Thus, it would be important to use the conventional technique (light-curing) and test the volume and C-factor influence in the polymerization shrinkage stress.

Some authors observed [1] that the volume of the material has no influence in the shrinkage when the C-factor remained constant, but it is important to consider that this study was performed using chemically activated resins, where the pre-gel phase is much longer than light-curing composite resins. Chemically activated resins present a low modulus elastic limit which permits permanent deformation through the sliding of the forming polymeric chains [13]. On the other hand, light-curing resins have faster polymerization than chemical resins and as a consequence, it is less flowable, generating greater shrinkage stress, which is decisive for the success of the adhesive process [14-16].

Although the shrinkage stress presents clinical significance in relation to the polymerization technique, its polymerization shrinkage constitutes a major problem for composite resins and they cannot be measured directly. Thus, there are indirect methods to measure the stresses transmitted by these forces. A frequently used method incorporates a modified testing machine associated with a load cell using a compliance system measure with or without feedback (between the plates). The methodology without repositioning the steel plates (high compliance) is a non-rigid method that thereby provides lower stress values, causing a minimal deflection in load cell [8,16]. However, this methodology was not used to test light-curing composite resin. Most studies [1,3,8,17,18] were performed with chemically activated composite resins and there is preference for the use of light-curing composite resins in anterior and posterior teeth. Furthermore, most studies use a high sample volume and cylindrical shaped plates, which has no relation to the clinical practice for the use of composite resins [2,7,13,17-19].

As a result, doubts still persist on the real importance of the shrinkage stress due to the volume and C-factor over the shrinkage stress of light-curing composite resins that have a shorter period to relieve the stresses than the chemical one. Thus, the aim of the present *in vitro* study was to compare the influence of the volume and C-factor of restorative materials in the shrinkage stress of chemically and physically activated composite resins, using the methodology without repositioning between the plates (high compliance), closer simulating the clinical practice conditions.

The null hypothesis tested was that the volume and C-factor will not have any influence on the shrinkage stress values of the composite resins analyzed.

MATERIALS AND METHODS

Experimental design

The present *in vitro* study was performed involving 2 factors: volume and C-factor. Two commercial composite resins (Z-250 and Concise, 3M/ESPE, St. Paul, MN, USA) (Chart 1) were used as the test materials to demonstrate the influence of the volume and C-factor on the shrinkage stress of composite resins using an Universal Testing Machine (UTM) (Emic DL 500, São José dos Pinhais, PR, BRA), without a feedback system (high compliance), as previously described in the literature [16]. The study was divided into two experiments. During the tests, the upper plate was linked to a movable arm through a 10 kg cell load (Figure 1), and the lower plate was linked to a fixed plate of the UTM that was not allowed to move (Figure 1), causing a minimal deflection in load cell, which was transmitted to the testing machine. As a consequence of the material polymerization shrinkage stress force, the load cell underwent a deformation that was transformed in force (N). Thus, a specific method for the Tesc Program (Emic, São José dos Pinhais, PR, BRA) was developed in order to keep the upper and lower plates fixed during the test, permitting the forces generated during the polymerization to be recorded by the program. A force/time graph was obtained for each sample. The values of the 120 and 600 s periods were recorded for the Z-250 and Concise, respectively.

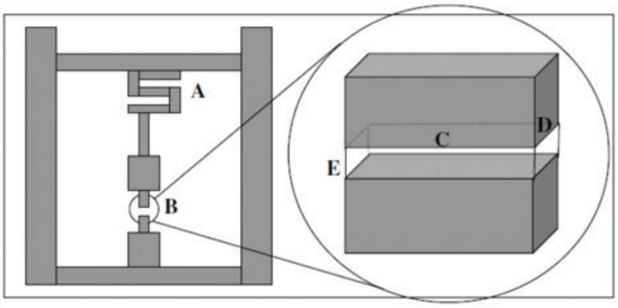

Figure 1 - Equipment scheme used during the test. A. Cell load (10Kg); B. Metal plates fixed on the equipment; C. Metallic plates length (6.0 mm); D. Metallic plates width (2.0 mm); E. Adjustable space between metal plates to insert composite resin.

Determination of the volume

To determine the volume of the composite resin increment inserted between the steel plates, the length of the plate or the resin increment was multiplied by its thickness and height. As a result, a constant volume of the evaluated groups was determined.

Determination of C-factor

C-factor was determined by the relation between the adhered surfaces (rigid contraction) and free surfaces (free contraction) of the restorative material. According to Feilzer et al. [1], the adhered surface should be determined by the summation of the steel plate areas that are in contact with the composite resin and the free surface by summation of the side areas of the resin increments that are in free contact with the steel plates.

Influence of volume and C-factor in the intensity of the forces generated during the polymerization shrinkage of a light-activated composite resin

In this first experiment, the contraction forces of the Z-250 during polymerization were recorded, varying the C-factor and composite resin volume in a total of 6 groups (n=10) (Chart 2). Two rectangular stainless steel plates (6.0 x 2.0 mm) were connected parallel to the UTM (Figure 1), varying the distance between plates, the volume and C-factor (Chart 2). The steel surface was treated with aluminum oxide jets to ensure the bonding of the composite to the steel face. The Z-250 composite resin was inserted into the space between the steel plates and light-cured for 20s, per group, with a halogen light source (Spectrum, Dentsply-Caulk, Milford, DE, USA) performing 500 mW/cm^2, E=10 J/cm^2, verified by a curing radiometer (Model 100; DemetronReseach Corp., Dancury, CT, USA).

Influence of C-factor variation in the intensity of the forces generated during the polymerization shrinkage of physically and chemically activated composite resins

In this second experiment, the shrinkage stress of the Z-250 and Concise were evaluated, varying C-factors but with constant volume of the specimens, in a total of 4 groups (n=10) (Chart 3). A pair of rectangular steel plates (3.0 mm length x 2.0 mm width) and two square steel plates (2.0 mm length x 2.0 mm width) were employed to determine the C-factor influence (Figure 2). The adjustments in distance were made between the plates (2.0 mm and 3.0 mm high, respectively) to achieve a standardized volume of 12 mm^3 for groups G7 to G10, with different C-Factors (0.6 and 0.33, respectively) (Chart 3).

The chemically activated composite resin (Concise) (G9 and G10) was mixed for 30s and inserted between the steel plates for 90s. After 120s, the assay began for a total time of 600s, necessary for the polymerization reaction of the chemical resin. The Z-250 composite resin (G7 and G8) was inserted between the plates in a single increment and polymerized, as described previously.

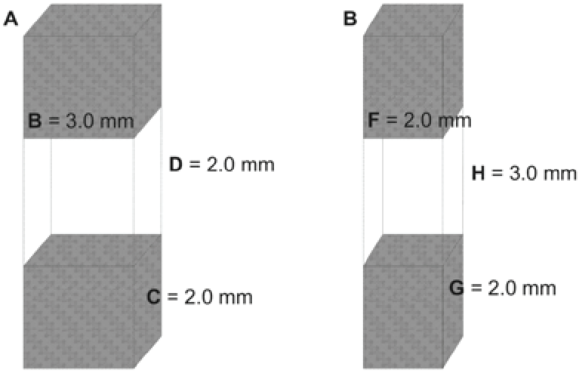

Figure 2 - Metallic plate schemes that were used with constant volume (12mm^3). A. Rectangular metallic plate (3.0 x 2.0 mm, 0.6 C-factor); B. Metallic plate length (3.0 mm); C. Metallic plate width (2.0 mm); D. Height between metallic plates (2.0 mm); E. Square metallic plate (2.0 x 2.0mm, 0.33 C-factor); G. Metallic plate width (2.0 mm); H. Height between metallic plates (3.0 mm).

Chart 1 - Composition of composite resins evaluated in the study

Composite resins	Organic Matrix	Inorganic Fillers	Polymerization	Type of Particle	Color	Series
Z-250 (3M/ESPE)	Bis-GMA TEGDMA	Zirconium/silica	Physical	Microhybrid (0.6 µm)	A2	4 AC
Concise (3M/ESPE)	Bis-GMA TEGDMA	Silica	Chemical	Macroparticles (1-40 µm)	Universal	DT1

* Information provided by manufacturer.

Chart 2 - Groups division according to the height between plates for the Z-250 composite resin volume and C-Factor

Groups	Composite resins	Metal plates (mm)	Heigh between plates (mm)	Volume (mm^3)	C-Factor
1	Z-250	6.0x2.0	0.5	6.0	3.0
2	Z-250	6.0x2.0	1.0	12.0	1.5
3	Z-250	6.0x2.0	1.5	18.0	1.0
4	Z-250	6.0x2.0	2.0	24.0	0.75
5	Z-250	6.0x2.0	2.5	30.0	0.6
6	Z-250	6.0x2.0	3.0	36.0	0.5

Chart 3 - Groups division according to the composite resins and C-Factor variation with constant volume (12 mm^3)

Groups	Composite resins	Metal plates (mm)	Heigh between plates (mm)	Volume (mm^3)	C-Factor
7	Z-250	3.0x2.0	2.0	12.0	0.6
8	Z-250	2.0x2.0	3.0	12.0	0.33
9	Concise	3.0x2.0	2.0	12.0	0.6
10	Concise	2.0x2.0	3.0	12.0	0.33

Statistical analyses

Statistical analysis was performed using the SPSS 17.0 software after confirming the validity of the assumption of normality by means of the group results. All the data were accomplished by two-way analysis of variance (ANOVA) to verify the influence of volume and C-factor in the first experiment and one-way ANOVA to verify the influence of C-factor in the second experiment, followed by the Tukey´s test for all groups. For all analyses, 5% was considered the level of significance.

RESULTS

Influence of volume and C-factor variation on the shrinkage stress of a light-curing composite resin

Table 1 shows the results of the forces generated during polymerization shrinkage of the Z-250 composite resin according to the volume and C-factor variation. ANOVA and Tukey´s test showed significant differences between all groups ($p<0.05$).

Analyzing the graph of Figure 3 [force (N)/time (s) graph], a similar standard was observed in the development of the forces generated during polymerization shrinkage for the six groups analyzed.

At the start of the test and beginning of the polymerization, independent of the volume and C-factor, shrinkage stress quickly began to generate during the polymerization (20s). At the conclusion of the composite resin photo activation, the composite resin continued to generate forces at lower intensities until the end of the test (120s) (Figure 3).

When the results in Table 1 and Figure 3 were analyzed, a direct influence on the volume variation used for the Z-250 was observed in the forces generated during polymerization shrinkage. However, the C-factor was not determinant in relation to the results observed when the Z-250 with conventional polymerization was used.

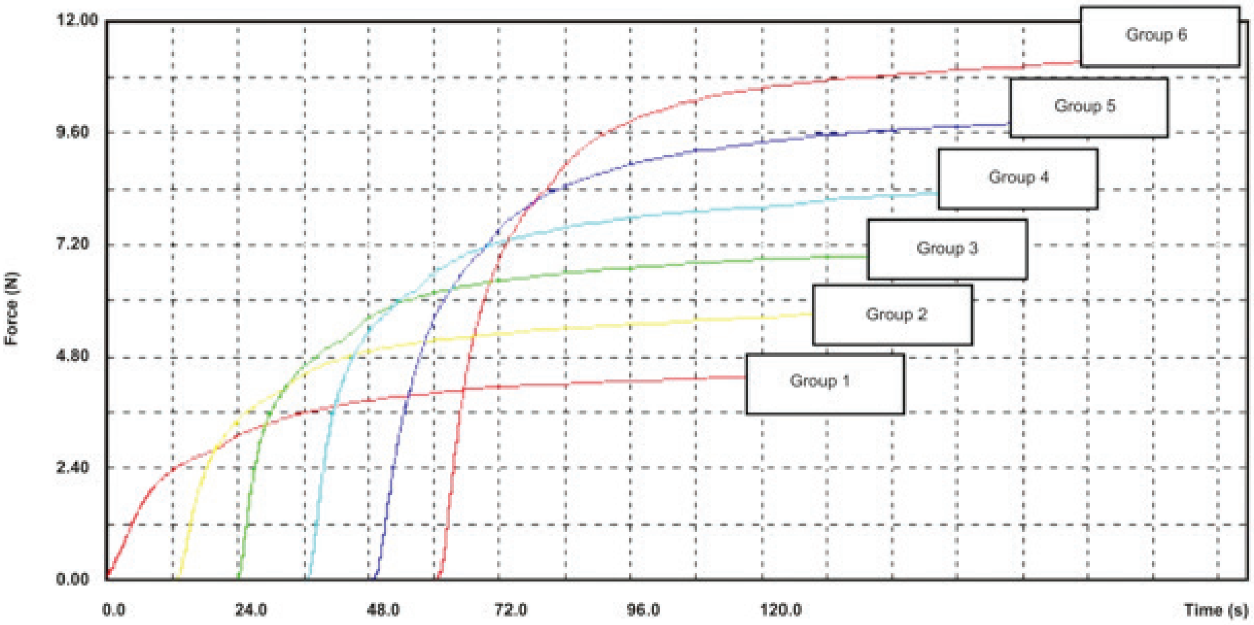

Figure 3 - Curve of the forces (N) generated during the physically activated composite resin (Z-250) polymerization shrinkage in relation to time (s), according to the volume and C-factor variations.

Table 1 - Volume, C-factor and contraction forces (N) (Mean ± Standard deviation, n=10) according to the groups

Groups	Volume (mm^3)	C-Factor	Contraction Forces (N)
1	6.0	3.0	4.4±0.2^{a}
2	12.0	1.5	5.7±0.2^{b}
3	18.0	1.0	7.0±0.1^{c}
4	24.0	0.75	8.3±0.3^{d}
5	30.0	0.6	9.8±0.3^{e}
6	36.0	0.5	11.1±0.3^{f}

Influence of C-factor variation on the shrinkage stress of physically and chemically activated composite resins

Table 2 shows the results of the forces generated during polymerization shrinkage of the physically activated Z-250 composite resin, and the chemically activated Concise composite resin, with a constant volume (12 mm^3) and C-factor varying from 0.6 and 0.33 of the increments of the composite resins inserted between the steel plates.

Two-way ANOVA (composite resins and C-factor) verified significant differences ($p<0.05$) among the studied groups, with positive interaction between the two factors analyzed. When groups were analyzed with the Tukey´s test (Table 2), there were no statistical differences ($p>0.05$) between groups 7 and 8 of the physically activated composite resin (Z-250). In relation to the chemically activated composite resin (Concise), there were statistically significant differences between groups G9 and G10. Groups G7 and G8 presented significant differences in comparison to groups G9 and G10.

The graph of Figure 4 shows the curves obtained [force (N)/time (s) graph] of the four groups analyzed. Different behaviors in the development of the forces generated during polymerization shrinkage can be observed according to the activation mode of the composite resins. For the physically activated composite resin (G7 and G8), a similar behavior independent of the C-factor was observed.

The curves of the stress of the chemically activated composite resin (G9 and G10) were directly influenced by the variation of C-factor (Figure 4). The G9 group with a 0.6 C-factor

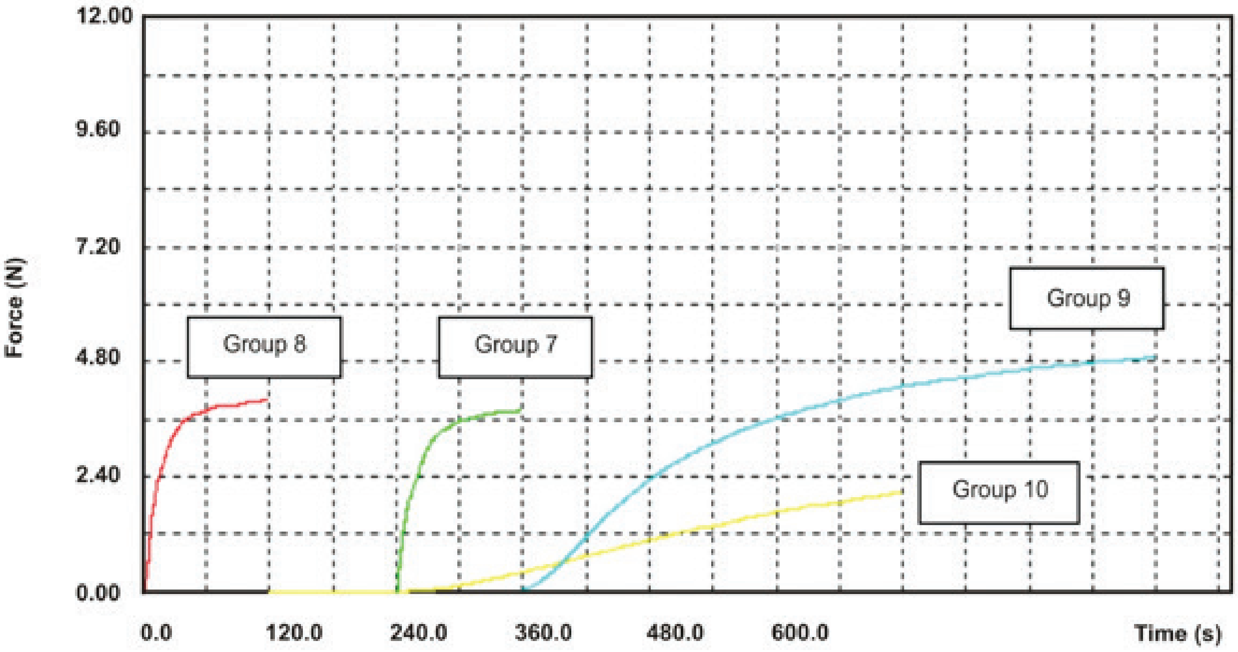

Figure 4 - Curve of the forces (N) generated during the polymerization shrinkage of Z-250 and Concise composite resins in relation to time (s) and variations in C-factor with constant volume (12 mm³).

showed the largest shrinkage force values (4.926 N) while the G10 group, with a 0.33 C-factor, showed lower values (2.197 N). Differences in the curves obtained for these groups are very clear, which shows a direct influence of the C-factor in the relaxation of the stress generated during the polymerization shrinkage stress of the chemically activated composite resin analyzed.

Table 2 - Groups of composite resins according to C-factor variations and the forces (N) generated during polymerization shrinkage (Mean ± Standard deviation, n=10), with constant volume (12 mm³).

Groups	Composite Resins	C-factor	Contraction Forces (N)
7	Z-250	0.6	3.9±0.1^b
8	Z-250	0.33	4.0±0.1^b
9	Concise	0.6	4.9±0.3^c
10	Concise	0.33	2.2±0.3^a

DISCUSSION

Polymerization shrinkage stresses are able to break adhesive links between composite resins and teeth, causing cracks, plaque accumulation and even restorative loss [20]. Due to the increased use of composite resin materials in clinical practice, the shrinkage stress of these materials have been investigated.

Since the shrinkage stress of the composite resins cannot be directly measured in the oral cavities, indirect methods have been developed. The use of UTMs associated with cell loads permitted the stress transmitted by the polymerization shrinkage stress of the composite resins to another specimen to be numerically determined, obtaining the curves of their behavior during polymerization (polymerization kinetics). The most used method to investigate the shrinkage stress was originally described by Feilzer et al. [1], where the force values are based on the cell load deformation. Variations of equipment, shape and pretreatment of the plates were proposed to provide more reliable results, although there is still no consensus in the current literature [6,10].

The C-factor has been the subject of a lot of controversy mainly when its listed as being the main cause of adhesive restoration failure [21].

In reality, the C-factor should not be analyzed alone, but associated with other factors such as the characteristic of each substrate (enamel and dentin), adhesive system technique, type of restorative material, restorative technique related to the material insertion, polymerization as well as the finishing and polishing procedure and the treatment of the cavosurface angle.

Erroneous interpretation or failure affects the reliable information related to the real behavior of the composite resins during their polymerization shrinkage stress and still causes doubt and confusion in the scientific community mainly related to the assay system used which presents low or high "compliance". Some characteristics related to polymerization shrinkage of the composite resins observed in the current literature use cylindrical plates for adhesion, varying the diameter, height, volume and C-factor of the material increments. The current literature conducted the wrong interpretation of the composite resins behavior during their polymerization shrinkage. The problem is related to the different type of polymerization of the composite resins (chemical or physical), rather than the system used or non-repositionating of the plates.

Independently of the assay system used, with or without repositionating, the control of the volume and C-factor variables to determine the polymerization shrinkage of the physical or chemically activated composite resins used in the present study provide realistic information regarding the behavior of these materials during the polymerization process.

The present study used a methodology without repositionating the steel plates (high compliance), considering a non-rigid method that thereby provides lower stress values. The results suggest that the methodology used was able to capture the curves and the magnitude of the shrinkage stress of the composite resins analyzed, as seen in the graphs of Figures 3 and 4. The accuracy of the lock systems of the machine, the cell load and the steel plates used provide a system with minimal deviation. Previous investigations using the same methodology for other variables also showed the accuracy of this method [16], and this methodology can be used to test new light-cured composite resins launched onto the market. Although there is a preference in clinical practice for the use of light-curing composite resins, most articles [1,3,8,17,18] in the literature used chemically activated composite resins and glass plates (volume, diameter of the glass plates, etc.). According to Feilzer et al. [1], the C-factor has a fundamental influence on the relaxation of the tensions to determine some polymerization behaviors that were inadvertently transferred to the light-curing composite resins. Thus, the present study used both chemically activated (Concise) and light-curing (Z-250) composite resins.

The polymerization reaction velocity of the light-curing composite resins is faster than those chemically activated. This fact can be clearly observed in the curves [force (N)/time (s)] obtained for the Z-250 (Figures 3 and 4), when compared with the curves obtained for the Concise (Figure 4). In the beginning of the test and photoactivation, the forces for the Z-250 were generated faster than for the Concise, with an abrupt rise of the curve in the initial period. The polymerization kinetics presented by the Z-250 shows the minor possibility of this type of composite resin to relax the shrinkage stress due to its flow. This occurs because of the extremely short duration of its pre-gel phase [22].

Material flow is a time-dependent property and is therefore influenced by the polymerization speed as well. Slower polymerization reactions result in a longer time to reach the gel-point, thus reaching lower "rigid contraction" [11]. For light-curing composite resins, a conventional technique provides a fast polymerization reaction and a rapid increase of the elasticity modulus [2]. Until the gel point, the shrinkage stress can be compensated by the molecular rearrangement of the polymers. After the rigidity of the resin, a reduction in the flow of this polymer occurs, increasing the shrinkage stress. In the present study, the Z-250 showed similar behavior according to other studies [2,23-25]. These light-curing composite resins generated and stored polymerization shrinkage even after completing photo activation. However, the speed of the stress decreased considerably. The results shows that the polymerization kinetics of the chemically activated composite resin is different from the light-curing composite resin (Table 2) and the C-factor influenced the two types of composite resins differently.

Furthermore, it is worth noting that a smaller volume of composite resins was used in the present investigation, simulating the clinical practice condition of this material (incremental technique). The incremental technique could be useful for a precise adaptation of the material in the cavity, and permit correct depth of polymerization and good adhesion to the cavity. It is possible to obtain the polymerization of the entire resin increment in only one procedure. When the Z-250 was used, the importance of using increments with a small volume during the restoration procedure using light-curing composite resins was observed, as well as its disposition on the cavity. Most studies show high values of stress [1,2,7,23,24], mainly attributed to the high volume of the material in the samples.

Based on the methodology used in the present study, it is suggested that the influence of the volume and C-factor on the contraction forces of the composite resins should be studied separately or without association in order to evaluate the material´s behavior, simulating a clinical situation. It is worth highlighting that light-curing composite resins did not follow the C-factor theory presented in the present study. Thus, the stress was not influenced by the free area of the specimens when a parallel plate system was used, but it was influenced by its volume. Its occurrence in its pre-gel phase is shorter than in conventional polymerization, with no time for the relaxation of forces. Thus, the stress are generated immediately. A low light intensity increases the period that the composite resin remains with a low elasticity modulus (pre-gel phase), allowing molecular accommodation and relieving contraction stress [27]. As a result, the pulse delay technique reduces the polymerization stress [22], when compared to the single pulse technique, following the C-factor theory.

When the volume used was constant (12.0 mm^3), but varying the C-factor to 0.6 and 0.33, the assay system was capable of showing the influence of this factor on the stress generated during the chemical polymerization of the Concise resin, different from the Z-250 resin, which was not influenced by this variable (Table 2 and Figure 4).

The Concise composite resin presented an opposite behavior compared to the Z-250 composite resin, since it was directly influenced by the C-factor. In Group 9, it was observed that the contraction force was 4.9 N, while Group 10 showed 2.2N, presenting a lower intensity of contraction forces and higher tension dissipation during the initial period of the assay. Thus, when the composite resins present a slow polymerization reaction, the free surfaces are capable of dissipating the stress generated by the polymerization shrinkage of the composite resins, confirming the C-factor theory proposed by Feilzer et al. [1].

Within the limitations of the present *in vitro* study, it provides valuable information and suggests that a higher volume determines an increase in the shrinkage stress of light-curing composite resins. When composite resins with lower rates of force generation, as a function of time are combined with a low C-factor, stress relief and consequently lower shrinkage stress values can be obtained.

REFERENCES

1. Feilzer AJ, De Gee AJ, Davidson CL. Setting stress in composite resin in relation to configuration of the restoration. J Dent Res. 1987 Nov;66(11):1636-9.
2. Davidson CL, Feilzer AJ. Polymerization shrinkage and polymerization shrinkage stress in polymer-based restoratives. J Dent. 1997 Nov;25(6):435-40.
3. Ferracane JL. Developing a more complete understanding of stresses produced in dental composites during polymerization. Dent Mater. 2005 Jan;21(1):36-42.

4. Ishikiriama SK, Mondelli RF, Kano SC, Ishikiriama A, Mondelli J. Role of additional retention on marginal adaptation and sealing of large resin composite Class II restorations. Oper Dent. 2007 Nov-Dec;32(6):564-70.

5. Boaro LC, Brandt WC, Meira JB, Rodrigues FP, Palin WM, Braga RR. Experimental and FE displacement and polymerization stress of bonded restorations as a function of the C-Factor, volume and substrate stiffness. J Dent. 2014 Feb;42(2):140-8. doi: 10.1016/j.jdent.2013.11.016.

6. Braga RR, Ferracane JL. Contraction stress related to degree of conversion and reaction kinetics. J Dent Res. 2002 Feb;81(2):114-8.

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

8. Boaro LC, Meira JB, Ballester RY, Braga RR. Influence of specimen dimensions and their derivatives (C-factor and volume) on polymerization stress determined in a high compliance testing system. Dent Mater. 2013 Oct;29(10):1034-9. doi: 10.1016/j.dental.2013.07.011.

9. Ozcan M, Mese A. Adhesion of conventional and simplified resin-based luting cements to superficial and deep dentin. Clin Oral Investig. 2012 Aug;16(4):1081-8. doi: 10.1007/s00784-011-0594-z.

10. Watts DC, Satterthwaite JD. Axial shrinkage-stress depends upon both C-factor and composite mass. Dent Mater. 2008 Jan;24(1):1-8.

11. Braga RR, Ballester RY, Ferracane JL. Factors involved in the development of polymerization shrinkage stress in resin-composites: a systematic review. Dent Mater. 2005 Oct;21(10):962-70.

12. Feilzer AJ, de Gee AJ, Davidson CL. Setting stresses in composites for two different curing modes. Dent Mater. 1993 Jan;9(1):2-5.

13. Calheiros FC, Braga RR, Kawano Y, Ballester RY. Relationship between contraction stress and degree of conversion in restorative composites. Dent Mater. 2004 Dec;20(10):939-46.

14. Yoshikawa T, Nakaoki Y, Takada T, Burrow MF, Tagami J. The effects of light curing method and irradiation time on marginal sealing and cavity wall adaptation of resin composite restorations. Am J Dent. 2003 Sep;16 Spec No:63A-67A.

15. Kinomoto Y, Torii M, Takeshige F, Ebisu S. Comparison of polymerization contraction stresses between self- and light-curing composites. J Dent. 1999 Jul;27(5):383-9.

16. Castaneda-Espinosa JC, Pereira RA, Cavalcanti AP, Mondelli RF. Transmission of composite polymerization contraction force through a flowable composite and a resin-modified glass ionomer cement. J Appl Oral Sci. 2007 Dec;15(6):495-500.

17. Alster D, Feilzer AJ, de Gee AJ, Davidson CL. Polymerization contraction stress in thin resin composite layers as a function of layer thickness. Dent Mater. 1997 May;13(3):146-50.

18. Davidson CL, de Gee AJ, Feilzer A. The competition between the composite dentin bond strength and the polymerization contraction stress. J Dent Res. 1984 Dec;63(12):1396-9.

19. Miguel A, de la Macorra JC. A predictive formula of the contraction stress in restorative and luting materials attending to free and adhered surfaces, volume and deformation. Dent Mater. 2001 May;17(3):241-6.

20. Ilie N, Kunzelmann KH, Hickel R. Evaluation of micro-tensile bond strengths of composite materials in comparison to their polymerization shrinkage. Dent Mater. 2006 Jul;22(7):593-601.

21. Nikolaenko SA, Lohbauer U, Roggendorf M, Petschelt A, Dasch W, Frankenberger R. Influence of c-factor and layering technique on microtensile bond strength to dentin. Dent Mater. 2004 Jul;20(6):579-85.

22. Sakaguchi RL, Wiltbank BD, Murchison CF. Contraction force rate of polymer composites is linearly correlated with irradiance. Dent Mater. 2004 May;20(4):402-7.

23. Bouschlicher MR, Vargas MA, Boyer DB. Effect of composite type, light intensity, configuration factor and laser polymerization on polymerization contraction forces. Am J Dent. 1997 Apr;10(2):88-96.

24. Chen HY, Manhart J, Hickel R, Kunzelmann KH. Polymerization contraction stress in light-cured packable composite resins. Dent Mater. 2001 May;17(3):253-9.

25. Yap AU, Soh MS, Siow KS. Effectiveness of composite cure with pulse activation and soft-start polymerization. Oper Dent. 2002 Jan-Feb;27(1):44-9.

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