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# Influence of Bulk-fill Restoration on Polymerization Shrinkage Stress and Marginal Gap Formation in Class V Restorations

AMO Correia • MR Andrade • JPM Tribst • ALS Borges • TMF Caneppele

### Clinical Relevance

Restoring Class V cavities with a regular bulk-fill composite presents a more favorable biomechanical behavior than restoring with a regular nano-filled composite.


## SUMMARY

**Purpose: This study evaluated the influence of Class V cavity extension and restorative material on the marginal gap formation, before and after aging, and the theoretical polymerization shrinkage stress distribution in a tooth restoration.**

**Methods and Materials: Class V cavities with the depth of 2 mm, cervical/incisal distance of 4 mm, and margins located in the enamel 1 mm above the cementoenamel junction were prepared in 60 bovine incisors in two mesiodistal dimensions (n=30): 2.9-mm large extension cavities (LE) or 1.4-mm small extension cavities (SE). The cavities' depths were validated using a periodontal probe, while the mesiodistal and cervical/incisal distances were measured using a stereomicroscope. After adhesive application (Clearfil SE Bond), each group was randomly divided into two groups (n=15) according to the restorative material: Filtek Z350 XT (N) or Filtek Bulk Fill Posterior (BF). The marginal gap formation between the tooth structure and the restorative material was evaluated using a stereomicroscope before and after thermocycling for 15,000 cycles (5°C**



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**and 55°C). Data were analyzed using repeated-measures analysis of variance (ANOVA) and Tukey test for multiple comparisons (α=0.05). A three-dimensional geometric model with the same dimensions as the experimental test was created for each cavity, and the restorations were modeled for each restorative material. In the analysis software, the finite element mesh was created with tetrahedral quadratic elements, and the polymerization shrinkage was simulated by thermal analogy. The maximum principal stress was used to express the tensile stress in the adhesive interface through colorimetric graphs.**

**Results: For the marginal gap, the repeated-measures ANOVA revealed a significant effect only for the factors composite resin (*df*=1, *F*=4.09, *p*=0.04) and thermal aging (*df*=1, *F*=44.35, *p*<0.001). For all numerical simulations, higher stress concentration occurred at the enamel margin, and the stress peak decreased in the following sequence: LE-N (17.0 MPa) > SE-N (15.0 MPa) > LE-BF (9.1 MPa) > SE-BF (8.2 MPa).**

**Conclusion: Marginal gaps in the specimens fell between approximately 12 and 17 μm; however, the regular bulk-fill composite showed less gap formation and better stress distribution around the cavity margin than the regular nano-filled composite, regardless of the cavity extension.**

## INTRODUCTION

The complete loss of the restoration is one of the most common causes of failures in noncarious cervical lesion (NCCL) resin restorations, along with marginal gap and marginal staining.[1-4] This loss can be associated with the polymerization shrinkage of the composite resin, still present in low-shrinkage restorative materials, which is responsible for the development of stress at the adhesive interface.[5-7] In addition, the marginal integrity of resin restorations depends on other factors, such as cavity configuration (size, geometry, C-factor, and substrate compliance),[5,8-12] composite resin properties (composition, filler content, resin flow, and elastic modulus [E]),[7,13-15] adhesive systems,[2,16,17] and aspects related to the restorative technique (placement and photopolymerization of the composite).[7,9,18-20]

The size and geometry of a Class V cavity can be one of the key factors,[8,10,12] since for a deeper and larger restoration, higher shrinkage stress and microleakage could be observed,[8] and some geometries may favor the stress concentration at the restoration interface more than others.[10,12,21] In this situation, the incremental filling techniques (horizontal and oblique) have been used to minimize the adverse effects of shrinkage stress and thereby reduce marginal gap formation.[11,19,22] These procedures can still improve the degree of material conversion[23] because they allow the placement of the composite in increments of 2 mm or less. However, the chair time increases and there is the possibility of incorporating voids between the resin layers.[24]

For these reasons, changes in placement techniques and continual improvements in restorative materials aimed at improving the clinical longevity of resin restorations have been made.[25,26] Recently developed bulk-fill composites exhibit reduced volumetric shrinkage and lower polymerization shrinkage stress, which may be attributed to the incorporation of polymerization modulators and monomers able to relieve stress.[27-30] The use of single increments up to 6-mm thick, depending on the manufacturer, is attributed to increased translucency and inclusion of new photoinitiators, for example, acyl phosphine oxide; Ivocerin (bis[4 methoxybenzoyl]-diethylgermane), and phenyl propanedione. These allow for an increased cure depth because of their significantly more intense absorption of visible light irradiation as compared with conventional photoinitiator systems.[31-33] In addition, the use of this approach prevents voids throughout the composite, simplifies material placement, and reduces clinical time.[29,34] It should also be noted that, to improve the performance of the restoration, advances were made in relation to ultrasonic energy application during the insertion of these materials and including reinforcing fibers.[35-37]

Recent studies reported positive results for these materials in NCCLs.[20,38] One 1-year clinical evaluation showed acceptable clinical performances for the restorations of NCCLs with bulk-fill flowable composites compared with regular nano-filled composites. In a finite element analysis (FEA), the model restored with a bulk-fill composite showed reduced development of interfacial stresses. These investigations have not focused on how the cavity extension influences the stress distribution and marginal gap formation, which may differ depending on the volume and compliance of the cavity walls,[39] justifying further studies.

Table 1: *Technical Information About the Materials Used in the Study*

| Material | Manufacturer | Composition |
|---|---|---|
| Clearfil SE Bond | Kuraray America Inc, New York, NY, USA | Primer: 10-MDP, HEMA, DMA, catalyst, water |
| | | Bond: 10-MDP, HEMA, DMA, Bis-GMA, filler, catalyst |
| Filtek Z350 XT | 3M, St Paul, MN, USA | Filler: 78.5 wt% (59.5 vol%) silica, zirconia, aggregated zirconia/silica |
| | | Matrix: Bis-GMA, UDMA, TEGDMA, dimethacrylate |
| Filtek Bulk Fill Posterior | 3M, St Paul, MN, USA | Filler: 76.5 wt% (58.4 vol%) silica, zirconia, ytterbium trifluoride, aggregated zirconia/silica |
| | | Matrix: AUDMA, AFM, UDMA, DDDMA, EDMAB |

*Abbreviations: 10-MDP, 10-methacryloyloxydecyl dihydrogen phosphate; AFM, addition-fragmentation monomer; AUDMA, aromatic urethane dimethacrylate; Bis-GMA, bisphenol-glycidyl methacrylate; DDDMA, 1, 12-dodecanediol dimethacrylate; DMA, dimethacrylate; EDMAB, ethyl 4-dimethyl aminobenzoate; HEMA, 2-hydroxyethyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.*

The purpose of this study was to evaluate the influence of cavity extension and restorative material on 1) the marginal gap formation, before and after aging, and 2) the stress distribution by FEA in a tooth/restoration. FEA was used to ratify the results obtained experimentally for the marginal gap of resin composite restorations placed in simulated NCCLs.

## METHODS AND MATERIALS

### Tooth Preparation

Sixty undamaged and fresh bovine incisors were collected and stored in 0.1% thymol solution under refrigeration at 4°C until they were used in this laboratory study. The incisal portion was removed to 10 mm above the cementoenamel junction (CEJ), and the root portion was removed to 4 mm below the CEJ, both using a diamond disc coupled to a low-speed hand piece. The teeth were positioned with the enamel surface facing down and embedded in acrylic resin (Jet-Clássico, São Paulo, SP, Brazil). The enamel surface of each tooth was flattened by grinding using 600-grit silicon carbide paper (Extec Corp, Enfield, CT, USA) in a polishing device (Pantec Polipan 2, São Paulo, SP, Brazil) under water irrigation for 30 seconds. This procedure created a flat enamel surface for cavity preparation.

### Cavity Preparation

The teeth were randomly divided into two groups (n=30): the large extension cavity group (LE) and the small extension cavity group (SE). In each tooth, a Class V cavity was prepared under abundant air-water coolant with a spherical diamond bur corresponding to the cervical/incisal distance (No. 3018 for the LE and No. 1014 for the SE; KG Sorensen, Barueri, SP, Brazil) and adapted to a cutting machine (spindle speed 2000 rpm, frequency 50-60 Hz) to produce standardized cavity preparation dimensions. The cavity margins were located in the enamel, 1 mm above the CEJ. New burs were used after every five cavity preparations. The depth and the mesiodistal distance of the preparations were controlled to keep 2 mm and 4 mm, respectively, independent of the cavity configurations. For LE cavities, the cervical/incisal dimension was 2.9 mm, and for SE cavities, it was 1.4 mm. The cavities' depths were validated using a periodontal probe, while the mesiodistal and cervical/incisal distances were measured using a stereomicroscope (Stemi-2000C, Zeiss, Gottingen, Germany).

### Restorative Procedures

All prepared cavities were bonded using the same two-step self-etch adhesive (Clearfil SE Bond, Kuraray America, New York, NY, USA; Table 1), according to the manufacturer's instructions. One coat of primer was gently scrubbed on the entire lesion surface for 20 seconds, followed by a gentle air stream to evaporate the solvent. Then, the bonding agent was applied and light cured for 10 seconds at 1200 mW/cm$^2$ with a polywave light-emitting diode (LED) device (Bluephase N, Ivoclar Vivadent, São Paulo, SP, Brazil). The irradiance was assessed with a radiometer (L.E.D, Demetron, Kerr Corp, Orange, CA, USA).

Composite filling materials included one nanofilled composite (Filtek Z350 XT, 3M, St Paul, MN, USA) and one bulk-fill composite (Filtek Bulk Fill Posterior, 3M; Table 1). The LE group was divided into two subgroups (n=15): group LE-N, which was filled with Filtek Z350 XT, and group LE-BF, which was filled with Filtek Bulk Fill Posterior. The SE group was also divided into two subgroups using the same composites (n=15): group SE-N and group SE-BF. The experimental design of this study is shown in Figure 1.

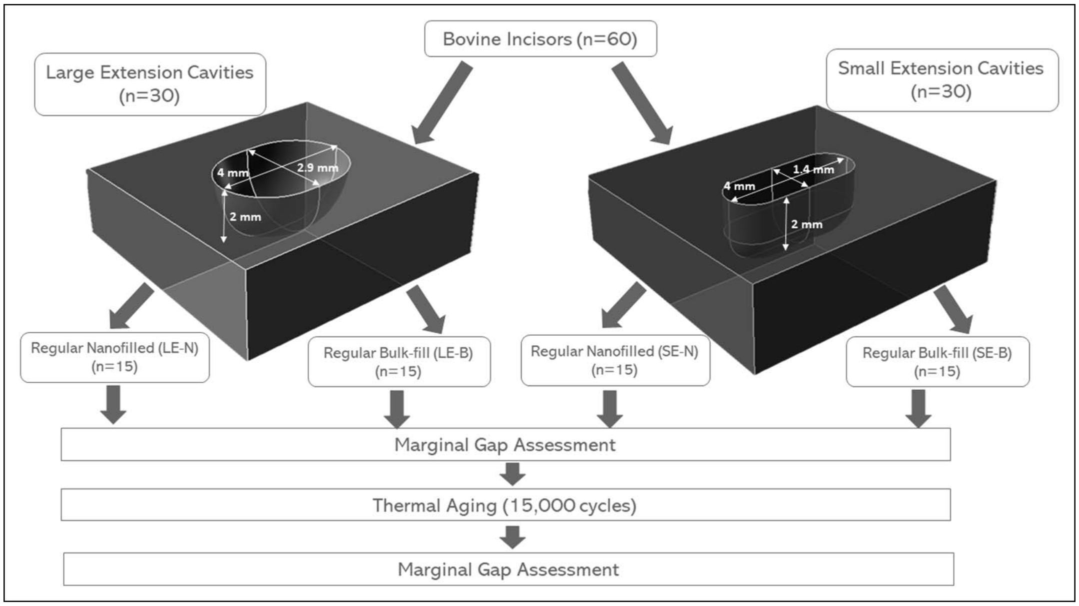



Figure 1. *Experimental design of the study.*

To ensure a smooth surface, the cavities were filled either in bulk placement (LE-BF, SE-N, and SE-BF) or with two oblique increments of 2 mm (LE-N) and covered with a transparent polyester strip until the end of the polymerization. For all groups, light-curing was performed for 40 seconds with the Bluephase N (Ivoclar Vivadent). The light tip was placed perpendicularly over the polyester strip at a 0-mm distance. The specimens were stored in ultrapure water at 37°C for at least 48 hours to ensure complete material polymerization.

The specimens' surfaces were ground flat and polished using a polishing device (Pantec Polipan 2, São Paulo, SP, Brazil) with 1200-, 2400-, and 4000-grit silicon carbide paper (Extec Corp) under continuous water cooling. All specimens were ultrasonically cleaned in ultrapure water (Type II, Adamo, Piracicaba, São Paulo, SP, Brazil) for 10 minutes. After cleaning, they were immersed in ultrapure water at 37°C until their next use.

## Marginal Gap Assessment

The marginal gap between the tooth structure and the restorative material was assessed along the margin of the restoration at a magnification of 50× using a stereomicroscope (Discovery V20, Zeiss) with a bilateral LED light and corresponding digital camera. Immediately before the marginal gap assessment, each specimen was dried with absorbent paper. In each specimen, digital images of the three largest gaps were taken (16-bit resolution). AxioVision Software (Zeiss) was used to measure the width of each gap. A mean of these three values was calculated, and then an average marginal gap formation was obtained for each group (yielding a total of 15 data points per group). During the marginal gap assessment, the operator was blinded to the type of the resin used on each specimen.

## Thermal Aging

All specimens were submitted to thermocycling for 15,000 cycles in water baths between temperatures of 5°C and 55°C, with the dwell time set at 15 seconds (Thermocycler Machine, Erios, Sao Paulo, SP, Brazil). The marginal gap assessment was then performed. One operator prepared all of the specimens and conducted all of the laboratory procedures (MRA).

## Residual Stress Calculation: FEA

A three-dimensional geometric model of a bovine tooth square section was modeled with 0.5 mm enamel (elastic modulus [E]=50 GPa and Poisson ratio [$\nu$]=0.30)[40] and 9.5 mm dentin (E=14.7 GPa and $\nu$=0.31)[40] using computer-aided design Rhinoceros software (version 4.0SR8; McNeel North America, Seattle, WA, USA). Two models were replicated following the same dimensions of the experimental test, resulting in two different cavity geometries. The restorations were modeled in the tooth bonding surfaces. Then, each model was duplicated, totaling four models, in which two received restorations with

Table 2: *Mean (SD) Marginal Gap Measurement (μm) Before and After Thermal Aging*

| Restorative Material | Before | | After | |
|---|---|---|---|---|
| | Large Extension Cavity | Small Extension Cavity | Large Extension Cavity | Small Extension Cavity |
| Nanofilled composite | 13.01 (4.16) | 14.47 (4.44) | 14.65 (4.11) | 15.42 (4.62) |
| Bulk-fill composite | 10.33 (2.82) | 10.44 (2.36) | 12.07 (2.38) | 11.47 (2.74) |

a nano-filled composite (Filtek Z350 XT, 3M; E=13.45 GPz, $v$=0.17, and linear shrinkage=0.00033),[20] and the other two received restorations with a bulk-fill composite (Filtek Bulk Fill, 3M; E=13.46 GPa, $v$=0.18, and linear shrinkage=0.00025).[20]

The models were imported in STEP (Standard for the Exchange of Product Model Data) format into the analysis software (ANSYS 17.2, ANSYS Inc, Houston, TX, USA). The mesh was created with tetrahedral quadratic elements. The mechanical properties to characterize each structure/material were based on the literature. All materials were considered homogenous, elastic, and isotropic. In all models, the tooth-restoration interfaces were considered ideal. Polymerization shrinkage was simulated by thermal analogy.[10] The temperature was reduced by 1°C, and the linear shrinkage value (postgel shrinkage) was entered as the coefficient of linear thermal expansion. For the models restored with two increments, the stress was generated in two steps (one for each portion of the composite).

The maximum principal stress was used to express the tensile stress in the adhesive interface through colorimetric graphs. For each model, the stress peak was recorded in MPa for a qualitative comparison between the groups.

### Statistical Analysis

The Kolmogorov-Smirnov test checked the normality of the data. Repeated-measures analysis of variance (ANOVA) was used to compare the marginal gap results among the four groups, followed by the Tukey test for multiple comparisons ($\alpha$=0.05). The null hypotheses tested were 1) there is no significant difference in marginal gap formation among the restorations for the LE and SE cavity groups and 2) there is no significant difference in marginal gap formation between the bulk-fill and nano-filled composites, before and after aging.

## RESULTS

### Marginal Gap

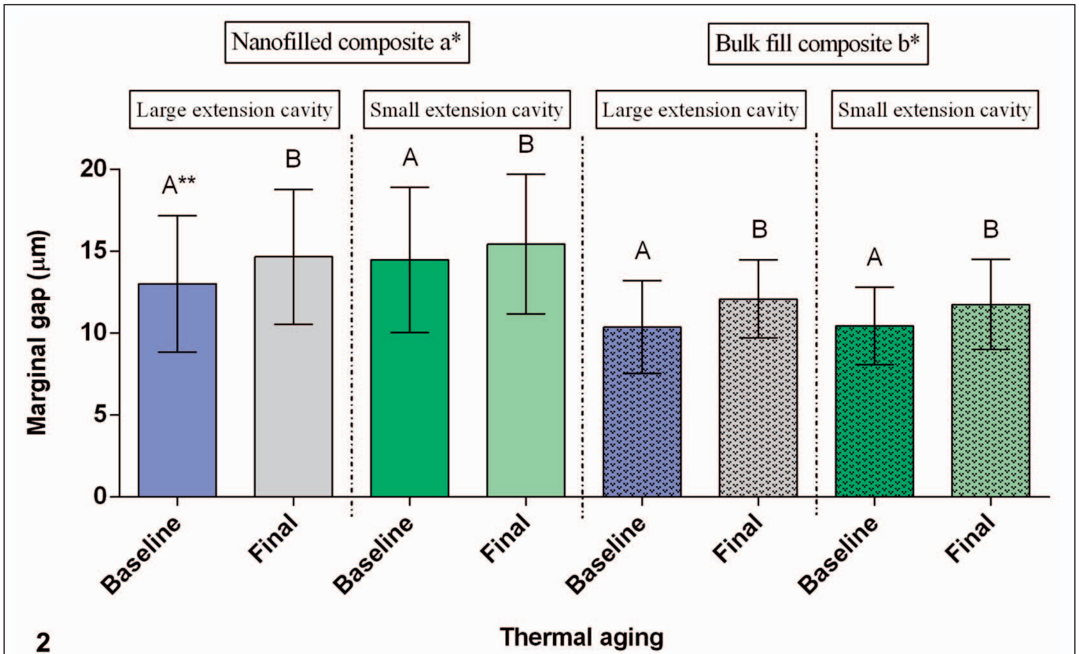
Means and standard deviations of marginal gap measurements are presented in Table 2. The repeated-measures ANOVA revealed a significant effect only for the composite resin ($df$=1, $F$=4.09, $p$=0.04) and thermal aging ($df$=1, $F$=44.35, $p$<0.001) factors. There was no significant effect for the cavity extension factor ($df$=1, $F$=0.63, $p$=0.42) or for the interactions among the factors. Tukey test showed a lower marginal gap for the bulk-fill composite (Filtek Bulk Fill Posterior) compared with the nano-filled composite (Filtek Z350 XT). For all groups, gap formation increased significantly after thermocycling (Figure 2).

### Finite Element Analysis

The polymerization shrinkage stress results for all groups are shown as colorimetric graphs in Figure 3. Different colorimetric fringes represent different stress magnitudes, visible in the horizontal scale of Figure 3. Hot colors mean higher stress values, while cold colors indicate lower stress values. Positive values indicate areas that were subjected to tensile stress. In general, the composite resin factor affected the stress distribution in the tooth, while the restoration with regular nano-filled composite resulted in a higher stress concentration. For all models, a higher stress concentration occurred at the enamel margin around the cavity, with a lower magnitude in the dentin surface inside the cavity. Regardless of the restorative material, the smaller cavities presented a lower stress concentration. The models' stress peak decreased in the following sequence: LE-N (17.0 MPa) > SE-N (15.0 MPa) > LE-BF (9.1 MPa) > SE-BF (8.2 MPa).

## DISCUSSION

The resin restoration of NCCLs often fails because of marginal leakage and restoration loss.[1-4] This phenomenon is the result of a localized bond failure between the restorative material and the tooth substrate,[41] and it depends on the complex interactions among multiple factors.[5,8-10,13,14,18,19] For this reason, laboratory studies with a clinically relevant aspect are still conducted. Such models allow isolating the variable of interest, specimen standardization, lower cost and sample size, and time savings, and they are an alternative to testing an unviable laboratory setup *in vivo*.[6,19,34] Thus, the polymeriza-



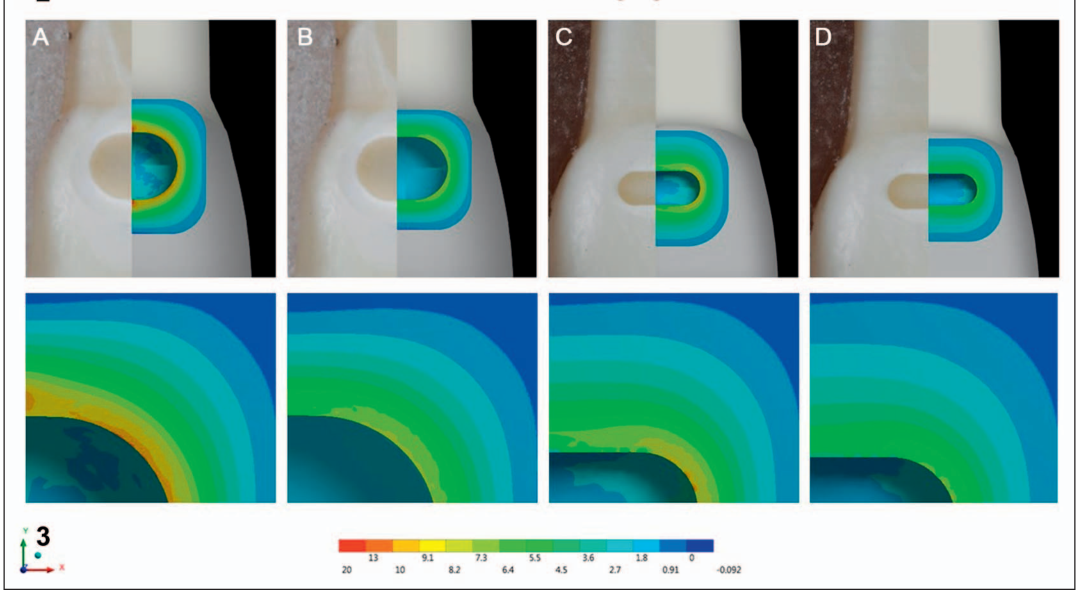




Figure 2. *Mean marginal gap measurement, with respective standard deviations, by group for each period investigated. *Different letters mean significant differences between the resin composites. **Different letters indicate significant differences before and after thermal aging* ($p<0.05$)*. There was no significant difference between large and small extension cavities* ($p=0.42$)*.*

Figure 3. *Polymerization shrinkage stress at the virtual tooth preparation according to the* in vitro *experimental design. (A): Large extension cavity restored with regular nano-filled composite (LE-N). (B): Large extension cavity restored with regular bulk-fill composite (LE-BF). (C): Small extension cavity restored with regular nano-filled composite (SE-N). (D): Small extension cavity restored with regular bulk-fill composite (SE-BF).*

tion shrinkage stresses promoted by the resin composites were assessed by marginal gap formation and biomechanical behavior. The thermocycling creates contraction/expansion stresses and accelerated chemical degradation,[42] simulating the clinical condition to which the restorations are exposed.[6] In this study, the thermal aging influenced the formation of the gaps at the adhesive interface, independent of the restorative material. It is interesting to note that the thermocycling protocol used in this study provoked an effect that mimicked long-term bonding effectiveness. Indeed, it has been suggested that 10,000 cycles give a close estimate of 1 year of clinical function.[42]

Two critical factors for the marginal gap formation were considered in this study: cavity extension and the restorative material. Thus, care was taken about tooth selection, cavity standardization, and restorative protocol. Teeth with structural defects were excluded because they influence the bonding.[19] The extensions of 2.9 mm and 1.4 mm were chosen based on a previous study of the prevalence of NCCLs,[43] in which the occlusogingival width of evaluated NCCLs ranged from 1 to 4 mm in most of the lesions (91%). In the present study, the purpose was to evaluate the influence of the cavity extension and, consequently, the volume of restorative material on the marginal gap formation and the theoretical polymerization shrinkage stress distribution in a tooth/restoration. Thus, two different sizes (large 2.9 mm and small 1.4 mm) within that previously reported range were determined. The use of a cutting machine allowed the adapted spherical bur to be moved precisely, and consequently, constant dimensions were obtained for each group. Clearfil SE Bond, a two-step self-etch adhesive, was chosen because it showed a good bonding performance in NCCLs, even without additional mechanical retention.[44] This adhesive system was used according to the manufacturer's instructions for a more effective bond. The teeth treated with Clearfil SE Bond were restored using the bulk-filled protocol for the LE-BF, SE-N, and SE-BF groups and the two oblique increments protocol for the LE-N group.

The gap marginal formation was similar between the restorations in the LE group and the SE group (Figure 2). It was previously suggested that restorations with the same substrate and depth, but with an increased diameter, would result in a higher volume and, consequently, an increase in the interfacial stress.[39] High stresses may contribute to the marginal gap formation.[8] In this study, a larger marginal gap was expected in the LE group because of the higher volume of restorative material, since this group presented an 11.6% greater magnitude of tensile stress peak calculated at the restoration margin compared with the SE group. Despite this, the influence of the volume for marginal gap formation may have been less pronounced compared with other variables of the cavity (geometry, C-factor, and substrate compliance) and composite resin properties (composition, filler content, resin flow, and E) because both cavities presented similar behavior during laboratory tests. However, the hypothesis cannot be ruled out that the areas with higher marginal stress concentration, mainly under loading, are more prone to interfacial damage.

Contrary to the results in the cavity extension, the restorative material employed had a significant influence on the marginal gap formation, before and after aging. Indeed, the composite resin properties (composition, filler content, resin flow, and E) affected polymerization shrinkage and, consequently, the marginal gap formation.[5,14,29,34] It is known that polymerization shrinkage has an inverse correlation with filler content and E,[5,14,15] meaning that the higher the filler content and E, the lower the polymerization shrinkage. Among the composites studied, Filtek Bulk Fill Posterior showed the lowest marginal gap formation and shrinkage stress, despite its having a relatively lower filler content (wt%) and similar E compared with Filtek Z350 XT. Filtek Bulk Fill Posterior is formulated with two novel methacrylate monomers (aromatic urethane dimethacrylate [AUDMA] and addition-fragmentation monomer [AFM]) designed to reduce volumetric shrinkage and shrinkage stress. The action mechanism of AUDMA, a monomer of high molecular weight, consists in reducing the number of reactive sites, thereby moderating the volumetric shrinkage and the stiffness of the developing and final polymer matrix, which is responsible for polymerization stress development. The presence of AFM has the potential to reduce polymerization shrinkage stress without prejudice to physical properties of the polymer.[45] According to the manufacturer, when the polymerization occurs, AFM first reacts into the developing polymer, leading to the formation of crosslinks between polymeric chains, like any methacrylate. A third reactive site of this monomer cleaves through a fragmentation process, in which a mechanism for the relaxation of the polymeric network is reached, allowing stress relief.

Regardless of the restorative material, when we observe the figures of the stress maps (Figure 3), it is shown that the region of highest stress concentration occurred in the enamel margin around the cavity compared with the dentin wall inside the cavity. This is in agreement with the results of Peutzfeldt and others[6] showing that the gaps are more visible in enamel than in dentin. However, the same study concluded that for a Class II cavity, the incremental technique with a regular composite is less susceptible to gap marginal formation than the single increment technique with a bulk-fill composite. It is noteworthy that the cavity of the present study presented enamel along its margin, different from the cavity of Peutzfeldt and others,[6] which contained margins in the dentin also. These findings are also supported by the observations of Alqudaihi and others,[19] in which a regular composite incrementally placed in a Class I cavity showed less gap formation and better internal adaptation than the bulk-fill composite.

Clinically, the presence of a marginal gap can facilitate bacterial infiltration with subsequent degradation of the adhesive interface and dental structure, development of secondary caries, pulpal irritation, hypersensitivity, marginal staining, and durability of resin restorations.[1-4,19,29,46] Nevertheless, secondary caries lesions seem to be related to individual factors, and their development is linked to a gap larger than 7-13 μm.[47] For Maske and others,[47,48] the secondary caries lesions develop in gap size between 13 and 30 μm, while the threshold gap size for the secondary caries wall lesion would be about 30 μm independent of caries activity level of the patient. The gap measurement values of the four groups investigated in the present study (Figure 2) are in agreement with previously reported studies. This means that the gap generated can have a significant impact on the development of secondary caries. This outcome might be related to shrinkage stress, poor adhesion of the restorative material, and personal factors.[7,19,47]

The results of the present study are in agreement with other previous theoretical findings, which conclude that the use of a bulk-fill composite may reduce the undesirable effects of polymerization shrinkage.[6,19,20,32,46] However, these results should be carefully interpreted, since the cavities' margins were located only in the enamel, which is unfortunately not representative of NCCLs found clinically. Several factors, such as the adhesive system, the substrate type (enamel or dentin), the aging protocol, the photopolymerization protocol, and the loading of the restorations during masticatory function also have to be considered, since the cavity and restorative material are not the only factors that influence the clinical performance of a restoration.[6,11,18,19] It should be emphasized that bovine teeth were used in this study. Despite the similarity between chemical and physical properties of the bovine substrate (composition, density, and microhardness, for example) and human enamel,[49,50] and bovine teeth are the first choice to replace human teeth, it is important to consider the differences in the values of marginal gap and stress concentration that can be found if human teeth are used. Furthermore, another limiting factor is the finite element model with an isotropic composite resin, without bubbles or defects in the material, perfectly bonded in all cavities and with a linear behavior.

## CONCLUSION

For the present study, the first null hypothesis was not rejected since the cavity extension did not influence the gap formation. However, the second null hypothesis was rejected because the bulk-fill composite showed less gap formation before and after aging and better stress distribution around the cavity margin than the nano-filled composite, regardless of the cavity's geometry. Based on this, and taking into account the study's limitations, further studies remain necessary to investigate questions that have not yet been answered, as well as the clinical behavior of a bulk-fill composite in Class V restorations.

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### Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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