

Analysis of stresses during the polymerization shrinkage of self-curing resin cement in indirect restorations: A finite-element study

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ABSTRACT

Background: Adhesive cementation is essential for the longevity of indirect esthetic restorations. However, polymerization shrinkage of resin cement generates stress, which may cause failures in the tooth–restoration interface. So, understanding of the biomechanics of resin cement is important for predicting the clinical behavior of an esthetic indirect restoration.

Aims: To analyze the stresses generated during polymerization shrinkage of self-curing resin cement in ceramic and in indirect resin (IR) restorations, using the finite-element method (FEM).

Settings and Design: Numerical study using the finite-element analysis.

Materials and Methods: A three-dimensional (3D) model of a second molar restored with ceramic or IR onlay restoration was designed. The polymerization shrinkage of self-curing resin cement was simulated in FEM software using an analogy between the thermal stress and the resulting contraction of the resin cement. The localization and values of tensile stresses in the dental structure, cement, and adhesive layer were identified.

Results: The location and value of the tensile stresses were similar for the two restorative materials. High tensile stresses were identified in the axiopulpal wall and angles of the tooth preparation, with the major stresses found in the cement located in the axiopulpal wall.

Conclusions: The high stresses values and their concentration in the angles of the prepared tooth emphasize the importance of round angles and the use of cements with lower rates of shrinkage.

Key words: Adhesion, biomechanics, dental cement, finite-element method, polymerization shrinkage

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The adhesive cementation is essential for the longevity and predictability of indirect esthetic restorations. However, the polymerization shrinkage inherent to the polymeric resin materials generates contraction stress, which may cause failures in the bonding process at the tooth–restoration interface.^[1–3] Such failures may lead to microleakage, secondary decays, and cracks in the restorative material, reducing the success of these restorations.^[4]

Polymerization shrinkage is dependent upon both C-factor and resin volume, resin diluent concentration, speed of monomer conversion, viscoelastic behavior, flow capacity and Young's modulus of the resin, and factors related to the operator.^[5–8] Thus, the control or minimization of contraction stress of resin-based cements is critical.

As polymerization shrinkage behavior may affect the longevity of a restoration, proper understanding of the biomechanics at the tooth–restoration interface is essential for restorative planning, determination of the shape of the dental preparation, choice of restorative material and cementation technique. Therefore, the aim of this study was to analyze the tensile stresses generated in the tooth structure, cement, and adhesive layer during the polymerization shrinkage of chemically cured resin cement, using the finite-element method. It was hoped to gain a better understanding of the biomechanical behavior of the tooth–restoration interface, which is necessary to optimize clinical restorative techniques.

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MATERIALS AND METHODS

A lower second molar was modelled from an anatomical atlas with six defined structures: Enamel, dentin, pulp, adhesive layer (e.g. All-Bond 2™, Bisco Inc., Schaumburg, IL, USA), self-curing resin cement (e.g. C&B™, Bisco Inc., Schaumburg, IL, USA), and ceramic (e.g. Vitadur™ Alpha, Vita Zahnfabrik, Bad Säckingen Germany) or indirect resin (IR) (e.g. Sinfony™, 3M Espe, St. Paul, MN, USA) onlay restorations [Figure 1]. The mechanical properties of the materials were based on previous literature [Table 1].^[9] The geometric model was then simplified into an axisymmetric model for analysis of the stress that occurred during the polymerization shrinkage of the cement [Figure 2]. All modelled materials were assumed to be homogeneous, isotropic, and with linear elastic properties.

In this study, it was determined for the resin cement a 1% volumetric shrinkage and a layer thickness of 200 μm . ANSYS® 11.0 software (ANSYS Inc, Canonsburg, PA, USA) was used to simulate the initial strain caused by the resin cement polymerization shrinkage and, for this, an analogy between the thermal stress and the resulting contraction of the cement was used. The total strain caused by shrinkage was obtained by multiplying the coefficient of linear shrinkage, taken as the expected strain due to resin cement shrinkage, by a temperature decrease of 1°C.^[10] The coefficient of thermal expansion was correlated to a temperature variation, so that the linear shrinkage of the resin cement could be applied to the model in a simple way, which can be predicted by the software. For example, if the temperature variation is equal to -1°C, then the coefficient of thermal expansion must be equal to the linear shrinkage of the resin cement. After determining the shrinkage coefficient, the maximum tensile stress points were located and measured in the dentine, cement, and adhesive in both ceramic and IR onlay restorations.

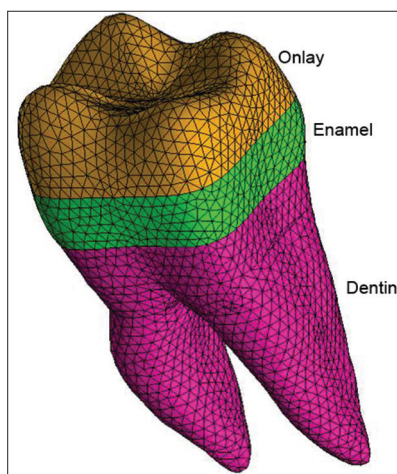


Figure 1: Three-dimensional model of a second molar restored with onlay restoration, with tetrahedral elements of 10 knots, 78079 elements, and 107792 nodes. The materials were considered isotropic, homogeneous, and linearly elastic

RESULTS

The maximum values of tensile stresses are listed in Table 2. Stresses were higher in cement than in both dentin and adhesive, and were similar between ceramic and IR restorations. The maximum stress values were consistently located in the axiopulpal wall [Figures 3 and 4].

DISCUSSION

The combination of various materials with complex geometries and different mechanical properties makes the analysis of stress distribution in a restored tooth complicated. Thus, the construction of numerical models for biomechanical analysis is an important tool for predicting clinical behavior.^[11]

Analysis of polymerization shrinkage of cement showed that the process generates high tensile stresses in the cement layer of both types of onlay restorations, with the maximum stress occurring at the axiopulpal angle of the tooth preparation. It is noteworthy that the threshold cement shrinkage rate was 1%, although higher rates are found in literature.^[2,11] Although the tensile stress in the adhesive was lower, it

Table 1: Mechanical properties of the materials^[8]

Materials	Young's modulus (GPa)	Poisson's ratio
Enamel	84.1	0.33
Dentin	14.7	0.31
Ceramic	74	0.19
IR	25	0.30
Resin cement	6	0.36
Adhesive	1	0.30

Table 2: Tensile stresses: Maximum values

Stress (MPa)	Dentin	Cement	Adhesive
Ceramic	11.4	45.0	10.6
IR	9.0	41.5	9.6

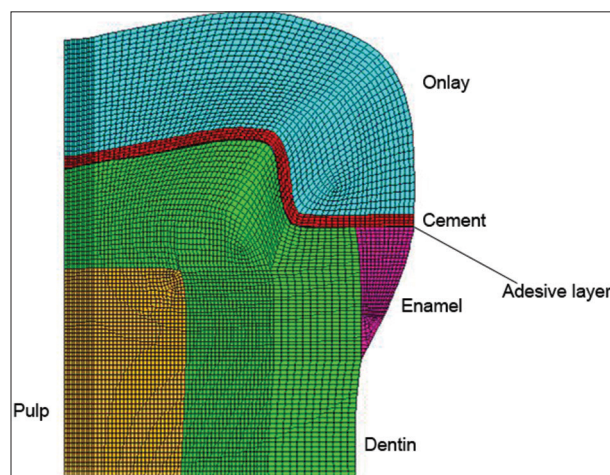


Figure 2: Model with axisymmetric solid elements of eight nodes with three degrees of freedom per node, totalling 22970 nodes and 7553 elements

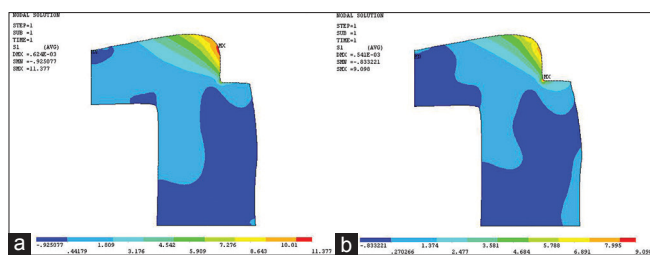


Figure 3: Tensile stress in tooth preparation: (a) Model with ceramic onlay; (b) model with IR onlay

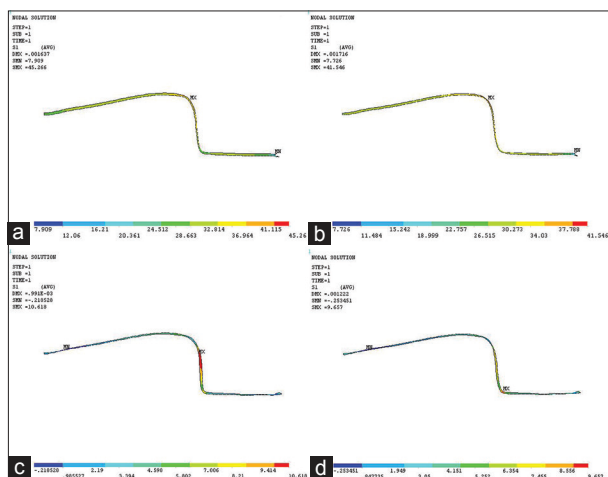


Figure 4: Tensile stress in the cement: (a) Ceramic onlay; (b) IR onlay. Tensile stress in the adhesive: (c) Ceramic onlay; (d) IR onlay

should be remembered that it bonds chemically to the cement, thereby functioning as a single cohesive material. Therefore, this level of stress present in the cement layer could lead to the rupture of the adhesive from the dentin or generate high residual tensile stress, which could damage the tooth–restoration structure. Additional stress is subsequently imposed by mechanical loading during chewing and thermal stresses during ingestion of cold and hot liquids. Because this additional load is cyclical, it can lead to fatigue failure at the interface of the adhesive and eventually cause microleakage.

As contraction stresses may be deleterious to the restoration, control of polymerization shrinkage is important in restoration planning. When using light-cured direct composite resins, polymerization shrinkage can be minimized by an incremental technique,^[1,10] by the control of light intensity or time,^[12] or even by using the recently developed silorane-based resins.^[13] However, this is not possible when using self-cured resin-based cements.

Therefore, the importance of rounding the angles of the tooth preparation should be emphasized. Sharp angles concentrate stresses, and the maximum stresses in both models were found in the axiopulpal angle and wall. Resin cements with lower rates of volumetric shrinkage are also desirable. Additionally, as volumetric shrinkage is not the only parameter to be considered to predict resin behavior regarding stress development, other factors such as the viscoelastic characteristic and the flow capacity of a resin should be considered when using adhesive cementation.^[2,8]

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