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Dental Investigations

THREE-DIMENSIONAL ANALYSIS OF CAVITY WALL DEFORMATION AFTER COMPOSITE RESTORATION OF MASTICATORY TEETH

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ABSTRACT
AIM: The aim of the present work was to study the size of cavity wall deformation in eight class I and II defects after composite restoration.
MATERIALS AND METHODS: 1. Creating a geometric model - data on the size of the left maxillary second premolar were obtained from a routine craniofacial scanning of a 20-year-old patient with a 2.5 Dental CT scanner (General Electric), with high resolution and 0.625mm-thin slices. The contour of each of the 33 cross-sections of tooth 25 was delineated using graphics software (CorelDraw 7.0) and transferred to a specialized product for engineering design (SolidWorks Office Premium 2010, SolidWorks Corp. USA). The pulp cavity and periodontal ligament were created in the same manner and were integrated in the premolar body; 2. Generation of a finite element method – the geometric model was exported to specialized software for analysis by the finite element method – COSMOSWorks 2010, which automatically builds a 3D finite elements mesh. Based on the generated model, eight additional models of class I and II cavities with different geometries, adhesive layer and nanofilled composite restorations were constructed. The polymerization shrinkage was modelled by thermal deformation, with a negative temperature difference (cooling), corresponding to the actual volume shrinkage of the composite materials by 2.1%.
RESULTS: In models A and B, the maximum cavity wall displacement was small - 0.014 mm and 0.015 mm, respectively. In models A1, B1, C1 and C, the displacement was at the expense of large deformation of the dental tissues. The maximum cavity wall displacements were 0.020 mm, 0.026 mm, 0.020 mm, 0.035 mm, respectively. The least cavity wall displacement was in models A2 and B2 with 0.008 mm and 0.017 mm, respectively.
CONCLUSIONS: The least displacement resulting from cavity wall deformation is found in patient-friendly class I and II preparations. Preservation of the dental tissues reduces the risk of mechanical pressure on the dentinal lymph and the likelihood of post-operative sensitivity.

Key words: finite element method, cavity deformation, post-operative sensitivity

INTRODUCTION
Composite restoration of occlusal cavities is a routine clinical practice. Although widely used, the composite fillings for these aesthetic restorations show a number of shortcomings. Problems with the marginal integrity and post-operative sensitivity are the most common reasons for their replacement. These can be regarded as factors that determine composite restorations as a long-term temporary solution. The main disadvantage of composite restorations leading to compromised clinical results is their polymerization shrinkage.

The physico-chemical conversion of a monomer to a polymer in the polymerization of composite materials causes a reduction of their volume (shrinkage) by about 2% to 6%.1,2 The knowledge of polymerization kinetics and the application of the finite element method (FEM) made it possible to study the biomechanical relationships in the cavity walls-composite restoration system. They provide

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a means for evaluation of the clinical effects of polymerization shrinkage in different cavity configurations. The conclusions of the analysis indicate the magnitude of cavity wall deformation and generate a risk forecast for marginal disintegration and post-operative sensitivity.

**AIM**

The aim of the present work was to study the magnitude of cavity wall deformation in eight class I and II defects after composite restoration.

**MATERIALS AND METHODS**

For the purpose, a validated 3D FEM computer model of a left maxillary second premolar was generated using class I and II cavities with different geometric configurations, adhesive layer and composite restorations.

**CREATION OF A GEOMETRIC MODEL**

Data of the left maxillary second premolar were obtained from a routine head scan of a 20-year-old patient with a 2,5 Dental CT scanner (General Electric) at high resolution and 0.625 mm-thin slices (Fig. 1). The contour of each of the 33 cross-sections of tooth #25 was delineated using graphics software (CorelDraw 7.0) and transferred to a specialized software product for engineering design (SolidWorks Office Premium 2010, SolidWorks Corp. USA). The 3D body of the premolar, its crown and root, was obtained by parallel positioning, linking and smoothing of the 2D contours. The pulp cavity and periodontal ligament were constructed in the same manner and integrated in the premolar body.

**GENERATION OF A FE MODEL**

The geometric model was exported to specialized software for finite element analysis – COSMOSWorks 2010, which automatically builds a 3D finite element mesh. The mechanical characteristics of the modelled tissues were introduced in the same program (Table 1) and the boundary conditions were defined – the active forces and static supporting structures. It was assumed that the tissues constituting the model (enamel, dentin, periodontal ligament) were homogeneous and isotropic, with linear elastic behaviour.

**CONSTRUCTION OF MODELS OF CLASS I AND II CAVITIES WITH DIFFERENT GEOMETRIC CONFIGURATIONS, ADHESIVE LAYER AND COMPOSITE RESTORATIONS.**

Based on the model thus generated, eight additional models of class I and II cavities with different geometries were constructed. They corresponded to clinical situations of moderate and deep caries with restricted and wide preparation without bevels on the occlusal and approximal margins.

The eight configurations we constructed had the following characteristics:

- Three class I cavities (one with restricted design - model A2, and two classically shaped, corresponding to a moderate - model A, and deep - model A1, carious process)

![Figure 1. CT craniofacial image and 2D tooth contour.](image-url)
Three class II MO cavities (one with restricted design - model B2) and two classically shaped, corresponding to a moderate (model B) and deep (model B1) carious process)

- Two class II MOD classically shaped cavities (corresponding to a moderate - model C, and deep - model C1, carious process)

For the purposes of this study we made an adhesive layer model of the same type of finite elements and 30 μm wide. The model included data about Filtek Supreme (3MESPE) nanofilled resin composite. The mechanical characteristics of the modelled areas and materials are shown in Table 1.

### Table 1. Mechanical properties of modelled tissues and materials

<table>
<thead>
<tr>
<th>Type of tissue</th>
<th>Linear deformation modulus E (GPa)</th>
<th>Poisson's coefficient μ</th>
<th>Coefficient of linear thermal expansion α</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>48 (4)</td>
<td>0.28 (4)</td>
<td>1.15 × 10⁻⁵</td>
</tr>
<tr>
<td>Dentin</td>
<td>19 (6)</td>
<td>0.31 (7)</td>
<td>1.01 × 10⁻⁵</td>
</tr>
<tr>
<td>Pulp</td>
<td>0.000207 (7)</td>
<td>0.45 (7)</td>
<td>1.01 × 10⁻⁵</td>
</tr>
<tr>
<td>Periodontal ligament</td>
<td>0.0069 (8)</td>
<td>0.45 (8)</td>
<td>1.01 × 10⁻⁵</td>
</tr>
<tr>
<td>Adhesive layer</td>
<td>4.85 (9)</td>
<td>0.30 (10)</td>
<td>3.94 × 10⁻⁵</td>
</tr>
<tr>
<td>Composite</td>
<td>11 (11, 12)</td>
<td>0.24 (13)</td>
<td>3.94 × 10⁻⁵</td>
</tr>
</tbody>
</table>

To determine the validity of the finite element model thus constructed, simulation was carried out applying axial force of 300N on the restoration of a wide and deep mesial-occlusal-distal cavity with a rigid support on the outer surface of the periodontal ligament (bone deformation on the outer surface of the periodontal ligament was not registered).

The obtained results were compared with the data from scientific publications describing analogous numerical and experimental studies. The consistency of these results with data provided by other

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**Figure 2.** 3D body with integrated dental tissues and MOD restoration.
authors\(^\text{10,14}\) allows the conclusion that the model is realistic and therefore can be used to study polymerization shrinkage stresses and deformations of composite materials (CM) in adhesive restorations.

**CREATION OF A MODEL OF POLYMERIZATION SHRINKAGE OF THE COMPOSITE MATERIAL**

A model of polymerization shrinkage was generated using thermal deformation, with a negative temperature difference (cooling), corresponding to the actual volume shrinkage of the composite material by 2.1\(^\%\).\(^\text{11}\)

The FEM maxillary premolar, pulp cavity, periodontal ligament, adhesive layer and composite restoration were integrated into a single model for each of the eight cavity configurations (Fig. 2).

**RESULTS**

The deformation of the dental tissues resulting from polymerization shrinkage can be assessed by the displacements of the cavity walls.

In models A and B (Figs 3, 4), the deformation caused displacements were largely concentrated in the outer surface of the restorations (occlusally and approximately). The maximum cavity wall displacement was small, 0.014 mm and 0.015 mm, respectively.

In models A1, B1, C and C1 (Figs 3, 4, 5), the displacement was at the expense of a large deformation of the dental tissues. The respective maximum displacements of the cavity walls were 0.020 mm, 0.026 mm, 0.020 mm, 0.035 mm. For models A1 and C1, the buccal and lingual tubercles deformed towards the axial line of the tooth, while in B1 and C the cavity wall deformation was at the expense of the palatal tubercle.

The least displacement resulting from cavity wall deformation was established in the patient-friendly class I and II preparations with minimal removal of tooth tissues (A2 and B2). The maximum displacement of the cavity walls was 0.008 mm and 0.017 mm, respectively.

**DISCUSSION**

The present results are consistent with the findings on cavity wall deformations by Tantbirojn, D. et al.\(^\text{15}\), who applied the method of photoelastic models of molars. The displacements found in this study are also similar to the results obtained by Versluis, A. et al.\(^\text{13}\) using the finite element method.

The greatest deformation of cavity walls was observed in deep and wide class I and II MO cavities, and in all MOD configurations. These observations confirm the results of other researchers.\(^\text{13,15}\) The bending of the weakened cavity walls provokes mechanical irritation. The dentinal fluid flow is activated and pain perception arises according to Branström’s hydrodynamic theory.

The results from the present study show the presumed etiopathogenesis of post-restorative sensitivity: stresses caused by the polymerization of the composite material seek to break the bond with the dental tissues. In large class I and II restorations the stress distribution in the adhesive layer is more favourable. The adhesion forces exceed the polymerization shrinkage forces. The stresses are relieved by being transferred onto and concentrated in the

![Figure 3](image-url) Displacements in dental tissues during polymerization in models A, A1 and A2. The initial position of the tooth (grey) and the displacement after simulation (colour scale) are represented in different colours.
cavity walls. This leads to cavity wall deformation and post-operative sensitivity. Larger cavities are at a greater risk of sensitivity.

Class I and II cavity configurations with restricted, pear-like design, which are maximally gentle to the dental tissues on the one hand create the best conditions for the emergence of a strong bond resistant to the forces of polymerization shrinkage. On the other hand, preservation of the enamel and dentin counteracts the deformation forces and ensures low displacement of the cavity walls. The risk of dentinal mechanical pressure on the dentinal lymph is minimal, and it is unlikely for post-operative sensitivity to occur.

These findings are confirmed by the results in the clinical trial of post-operative sensitivity in class I and II restorations with one step self-etch adhesive and three-step bonding system. The largest number of cases of post-operative sensitivity was found with Scotchbond MP, whose bond with the hard dental tissues (HDT) is probably stronger than the polymerization shrinkage forces. In large cavity configurations, the arising stresses deform the cavity walls, creating mechanical pressure on the liquid in the dentinal canals and triggering pain. The weaker bond of the self-etch adhesive Adper Prompt L-Pop with the HDT is ruptured by the polymerization shrinkage forces. In the analysis

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**Figure 4** Displacements in dental tissues during polymerization in models B, B1 and B2. The initial position of the tooth (grey) and the displacement after simulation (colour scale) are represented in different colours.

**Figure 5** Displacements in dental tissues during polymerization in models C and C1. The initial position of the tooth (grey) and the displacement after simulation (colour scale) are represented in different colours.
of the stresses generated between the cavity walls and the adhesive layer, areas prevail where they exceed the bond strength. The residual stresses are transmitted to the cavity walls in a lesser degree. Clinical observations also show fewer cases of postoperative sensitivity in composite restorations with one-step adhesive. The weak bond with the cavity walls in these systems, however, gives rise to crack formation and micro-leakage, whose effects are established in the long run. Other evidence is provided by the deteriorated marginal indicators in clinical evaluation after a 36-month observation in this group of restorations.17

Cavity wall deformation and stress concentration in the cavity walls also depend on the modulus of elasticity (E), polymerization shrinkage and the thermal expansion coefficient of the restorative material. Under functional loading after polymerization, the softer composite material (low E) can undergo elastic deformation and compensate for the polymerization shrinkage forces by transmitting stresses to the dental cavity walls and cause their yet greater deformation.10,18 The harder composites (high E) lead to a slighter displacement of the dental tissues, but higher stresses in the restoration.

Filtek Supreme is a nanocomposite with a low modulus of elasticity (11 GPa). Due to its elasticity, in large restorations (models A1, B1, C1) the post-polymerization shrinkage stresses concentrate largely in the HDT and deform the cavity walls. This is also favoured by the low stresses in the adhesive layer.

CONCLUSIONS

We found the least displacement resulting from cavity wall deformation in class I and II patient-friendly preparations. Preservation of dental tissues reduces the risk of mechanical pressure on the dentinal lymph and the likelihood of post-operative sensitivity. Deep and wide class I and II MO cavities and in all MOD configurations had the greatest cavity wall deformation and the highest risk of post-operative sensitivity.

Composite materials with a low modulus of elasticity cause large deformation in the weakened cavity walls in extensive cavity preparations and a risk of occurrence of postoperative sensitivity.

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3D АНАЛИЗ ДЕФОРМАЦИИ КАВИТЕТНЫХ СТЕНОК ПОСЛЕ ОБТУРИРОВАНИЯ ЖЕВАТЕЛЬНЫХ ЗУБОВ КОМПОЗИТНЫМ МАТЕРИАЛОМ

Н. Манчорова-Велева

РЕЗЮМЕ

Цель: Целью настоящего исследования является изучение величины деформаций кавитетных стенок при восьми типах I и II класса дефектах после обтурирования композитным материалом.

Материал и методы: 1. Создание геометрической модели – данные о размерах верхнего второго премоляра пациента получены в результате рутинного исследования лицевого черепа 20-летнего пациента компьютерным томографом 2.5 Dental (General Electric) высокой резолюции и узкого слайса – 0.625 мм. Из 33 поперечных срезов 25 контурированы с помощью графического программного обеспечения (CorelDraw 7.0) и трансферированы до специализированного продукта для инженерного дизайна (Solid Works Office Premium 2010 SolidWorks Corp. USA). Аналогичным способом созданы пульпарная полость и периодONTALный лигамент и интегрированы в единую модель.

2. Генерирование модели из конечных элементов (МКЭ) – геометрическая модель экспортирована в специализированный программный продукт МКЭ - Cosmos Works 2010, который автоматически создает 3D сеть из конечных элементов. На основе этой модели создано 8 дополнительных моделей с различными по геометрии I и II класса кавитетами, адгезивным слоем и обтурациями из нанофильтрованного композита. Полимеризационное сжатие моделировано температурной деформацией с отрицательной температурной разницей (охлаждение), соответствующей действительному объемному сжатию композитного материала – 2.1%.

Результаты: При моделях А и Б максимальное смещение кавитетных стенок незначительно, соответственно 0.014 мм и 0.015 мм. При моделях А1, Б1, С1 и С1 смещение происходит за счет большой деформации зубных тканей. Максимальное смещение кавитетных стенок соответственно 0.020 мм, 0.026 мм, 0.020мм, 0.035 мм. Наименьшее смещение кавитетных стенок наблюдается при моделях А2 и Б2, соответственно 0.008 мм и 0.017 мм.

Выводы: При I и II класса щадящих препарациях установлено наименьшее смещение в результате деформации кавитетных стенок. Сохранение зубных тканей уменьшает риск возникновения механического давления на дентинную лимфу и вероятность появления постоперативной чувствительности.