RESEARCH ARTICLE

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3D Study on displacement distributions in dental tissues due to extreme occlusal stress on class I and II direct restorations by finite elements analysis

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ABSTRACT
In recent decades, significantly increase the application of finite elements analysis in dentistry. The design of experiments is continuously optimized by computer visualization of virtual prototypes and virtual tests and evaluations.
The purpose of this study was to investigate the distribution of displacement in integrated 3D models of conventional and adhesive cavities restored with different generations composite and amalgam fillings.
A three-dimensional computer model of the upper premolar is used. Based on this 3D model we built eight additional models with different sizes and geometry class I and II cavities. For each of these eight models restorations of two types of composite material and two generations of dental amalgam are simulated. On each of the generated 32 models axial and oblique load with different magnitudes of force is applied.
In minimal invasive box-type class I and II cavity designs displacements resulting from the deformation is concentrated in a limited range around a filling. Maximum displacement is relatively weak. In extended box-type class I and II cavities large deformation of the dental tissues is observed.

Key words: dentistry, finite element method, distribution of displacement

Introduction

In recent decades, significantly increase the application of finite elements analysis in dentistry (Ausiello et al., 2001; Kalachev, 2003; Vladimirov, 2006). This analysis is used for: Evaluation of the distribution of occlusal stress in dental restorations (Tantbirojn et al., 2004); Investigation of partial prosthetic restorations (Lin et al., 2005); Follow up the clinical behavior of different systems dental pins (Lanza et al., 2005; Nakamura et al., 2006); Study stress on dental implants (Kitagawa et al., 2005).

In modern dental scientific studies, experimental and numerical approaches such as finite element method undoubtedly represent the most comprehensive in vitro methods for investigation in restorative dentistry (Magne, 2007). The design of experiments is continuously optimized by computer visualization of virtual prototypes and virtual tests and evaluations.

The aim of this study is to investigate the distribution of displacement in integrated 3D models of conventional and adhesive cavities restored with different generations composite and amalgam fillings.

Materials and Methods

Three-dimensional computer model of the upper premolar is applied to test the study hypothesis. Establishing and determining the validity of the 3D model of the upper premolar by FEM was carried out at the Department of Operative Dentistry and endodontics FDM-Plovdiv (Manchorova, 2009). The mechanical characteristics of the modeled tissues are presented in Table1.

Table 1. *Mechanical properties of the modeled tissue.*

Type of tissue	Module of linear deformation E (GPa)	Poisson coefficient (μ)	Coefficient of linear thermal expansion (α)
Enemal	48	0.28	1.15×10^{-5}
Dentin	19	0.31	1.01×10^{-5}
Pulp	0.00207	0.45	1.01×10^{-5}
Periodontal ligamentum	0.0069	0.45	1.01×10^{-5}

Table 2. *Mechanical properties of materials modeled.*

Type area	Module of linear deformation E (GPa)	Poisson coefficient (μ)	Coefficient of linear thermal expansion (α)
Adhesive layer	4.85	0.30	3.94×10^{-5}
RBCM 1	19	0.32	3.94×10^{-5}
RBCM 2	6.7	0.22	3.94×10^{-5}
GICs	10	0.30	35×10^{-6}
DA 1	20	0.34	25×10^{-6}
DA 2	58	0.34	25×10^{-6}

Based on this 3D model of the upper premolar eight additional models with different sizes and geometry of class I and II cavities are built. For each of these eight models restorations of two types of resin based composite material (RBCM) and two generations of dental amalgam (DA) are simulated. For the objective of the study adhesive layer with the same type of finite elements and a width of 30μm is patterned. In the models mechanical characteristics of the adhesive layer (Optibond FL), two types RBCM (RBCM1-Filtek P-60; RBDM 2-Gradia Direct Posterior), conventional GICs (Fuji IX), two generations DA (DA1- conventional; DA2- modern higher content of Cu and without γ2 phase) are included (Table 2).

Polymerization shrinkage is modeled by thermal deformation of a negative temperature difference (cooling) corresponding to the actual volumetric shrinkage of the composite material: RBCM 1, Filtek P-60 = 1.7 vol% RBCM 2, Gradia Direct Posterior = 1.8 vol%.

On each of the created 32 models axial and oblique load of different magnitudes of masticatory force is simulated (Table 3). Total of 192 simulations are studied using software SOLIDWORKS S 2016.

Results

In minimal invasive box-type Class I and Class II MO and MOD cavities deformations are concentrated around fillings periphery. The maximum displacement is relatively weak (Figure 1-6).

In classic extended box-type class I and II MO and MOD cavities cusps` displacement is at the expense of large deformation of the dental tissues.

In modified pear-shaped Class II cavity a minimal displacement due to deformation of cavity walls is observed.

Simulations at the maximum power load of models both in axial- 900N, and oblique-600N direction are presented.

Discussion

Displacement of the fillings due to deformation of the models (Figure 6, 7) is almost identical to the materials tested in each of the load forces. In obliquely directed load models deformation is more pronounced compared to the displacement due to axial load.

In model A, A1, A2, B2, C, C1, C2 as a result of axial and oblique load, the deformations of cavity walls are at the expense of the palatal cusp. In model B, B1 as a result of axial and oblique load, the deformations of cavity walls are at the expense of the buccal cusp.

The greatest deformation of cavity walls in deep and wide Class I and II MO cavities, as well as all MOD configurations are detected. These observations confirm the results of other researchers (Tantbirojn et al., 2004; Versluis , 2004).

Deformation of cavity walls and the concentration of stresses depends on the module of linear deformation (E), polymerization shrinkage and coefficient of linear thermal expansion of the filling material. More elastic RBCM (low E) can undergo elastic deformation and transfer the forces of polymerization shrinkage on dental cavity walls and cause more deformation of dental tissues (Apicella et al., 1994; Ausiello et al., 2001). More rigid composites (large E) result in less displacement of dental tissues, but larger stresses in the biomaterials.

Our results are similar to the presented speculations on relation between elastic modulus of restorations and displacement range . Gradia direct posterior is micro hybrid composites with a low modulus of elasticity (6.7 GPa). More flexible RBCM (low E) cause more deformation on thin cavity walls in extensive preparation. Rigid composites (large E) as Filtek P 60 (19GPa) result in less displacement of dental walls, but greater risk of restoration fracture.

Table 3. *Design of simulations.*

Mode 1	Type of cavity	Filling material	Load (N)					
			Axial			Oblique		
			300	600	900	200	400	600
A	Class I shallow and narrow cavity	RBCM 1, adhesive layer RBCM 2, adhesive layer DA 1, GICs DAA 2, GICs						
A1	Class I deep and wide cavity	RBCM 1, adhesive layer RBCM 2, adhesive layer DA 1, GICs DA 2 GICs						
A2	Class I limited, pear-shaped cavity	RBCM 1, adhesive layer RBCM 2, adhesive layer DA 1 GICs DA 2 GICs						
B	Class II shallow and narrow MO cavity	RBCM 1, adhesive layer RBCM 2, adhesive layer DA 1 GICs DA 2 GICs						
B1	Class II deep and wide MO cavity	RBCM 1, adhesive layer RBCM 2, adhesive layer DA 1 GICs DA 2 GICs						
B2	Class II limited, pear-shaped cavity	RBCM 1, adhesive layer RBCM 2, adhesive layer DA 1 GICs DA 2 GICs						
C	Class II shallow and narrow MOD cavity	RBCM 1, adhesive layer RBCM 2, adhesive layer DA 1 GICs DA 2 GICs						
C1	Class II deep and wide MOD cavity	RBCM 1, adhesive layer RBCM 2, adhesive layer DA 1 GICs DA 2 GICs						

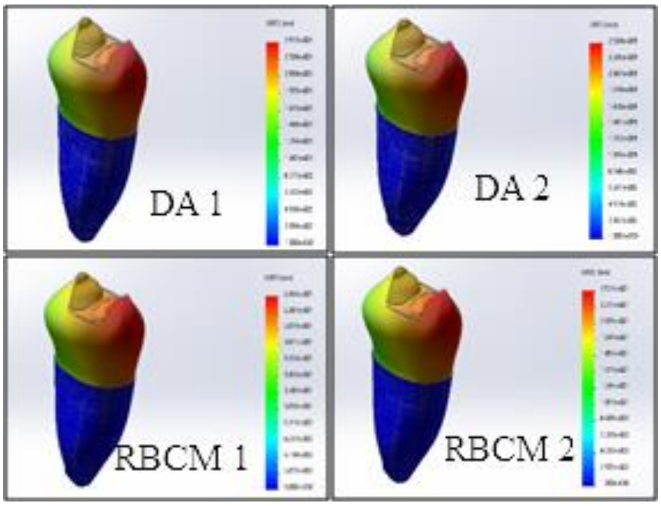


Figure 1. *Distribution of deformations in the model A in axial load.*

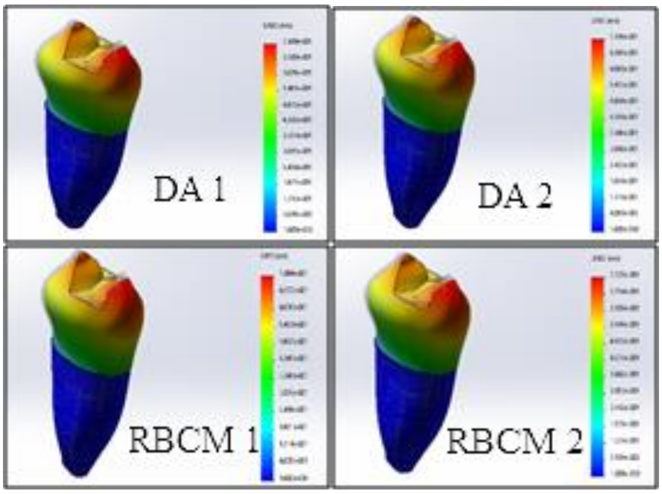


Figure 2. *Distribution of deformations in model A in oblique load.*

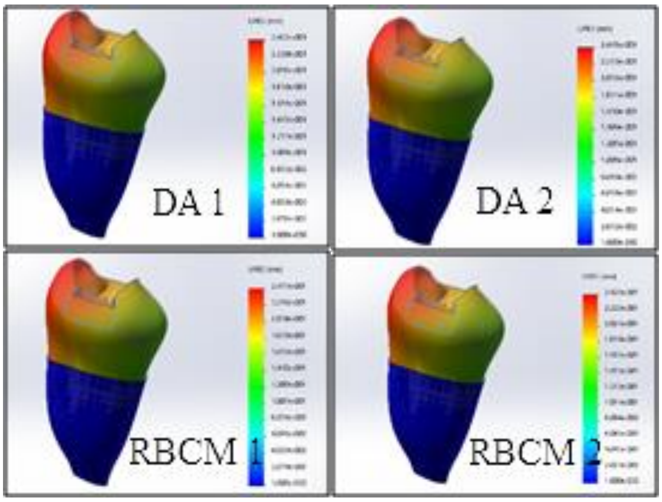


Figure 3. *Distribution of deformations in model B in axial load.*

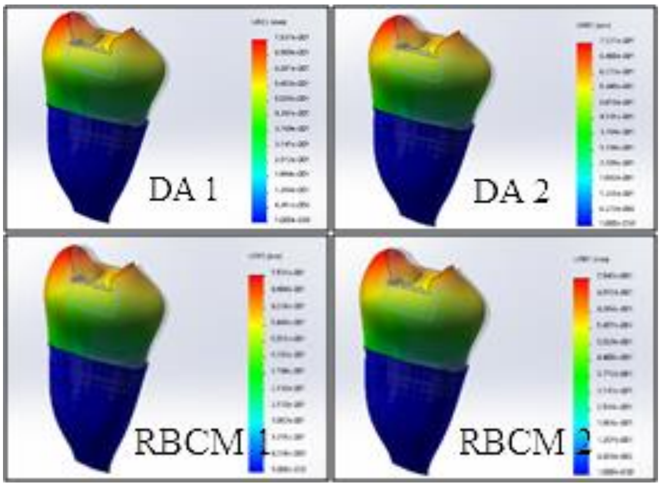


Figure 4. *Distribution of deformations in model B in oblique load.*

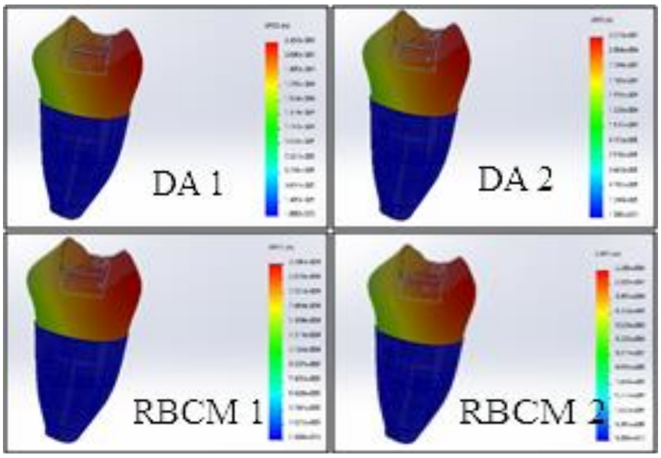


Figure 5. *Distribution of deformations in model C in axial load.*

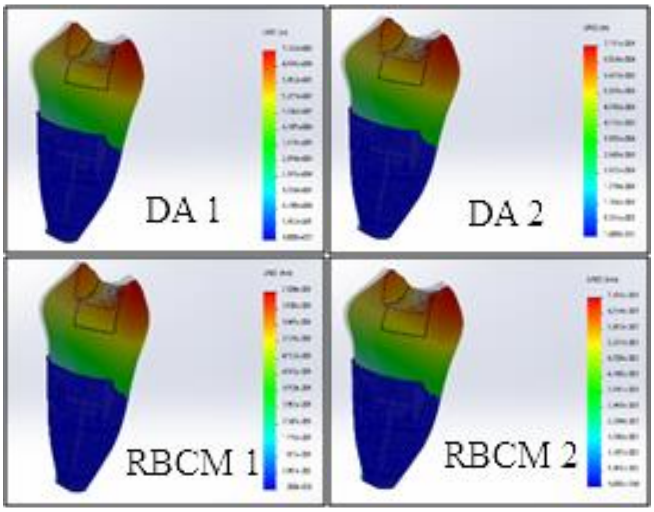
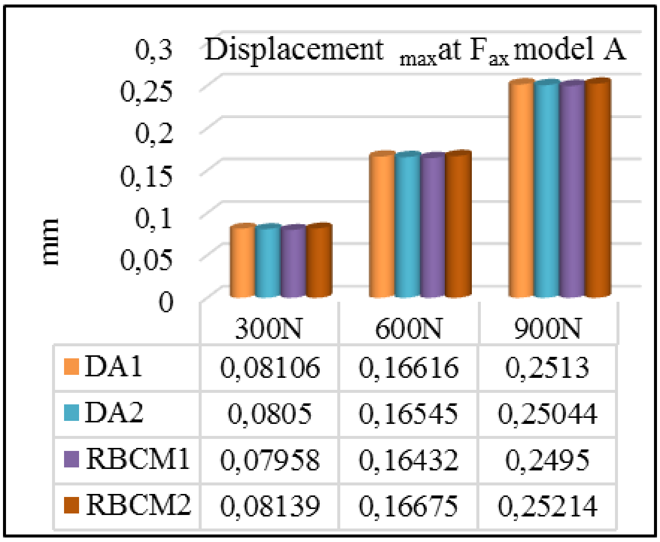
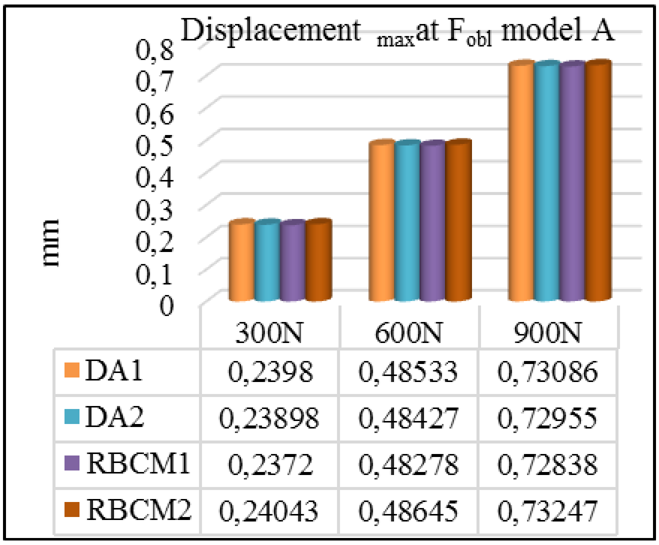


Figure 6. *Distribution of deformations in model C in oblique load.*



	300N	600N	900N
DA1	0,08106	0,16616	0,2513
DA2	0,0805	0,16545	0,25044
RBCM1	0,07958	0,16432	0,2495
RBCM2	0,08139	0,16675	0,25214

Figure 7. *Maximum deformations at axial load model A.*



	300N	600N	900N
DA1	0,2398	0,48533	0,73086
DA2	0,23898	0,48427	0,72955
RBCM1	0,2372	0,48278	0,72838
RBCM2	0,24043	0,48645	0,73247

Figure 8. *Maximum deformations at oblique load model.*

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