ORIGINAL ARTICLE

INVESTIGATION OF STRESS-STRAIN STATE OF "RESTORATION & TOOTH" SYSTEM IN WEDGE-SHAPED DEFECTS BY COMPUTED MODELING METHOD

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ABSTRACT

The aim of this research is to study the influence of size and location of wedge-shaped defects of teeth on stress and strain state of restorative material on the basis of biomechanical analysis.

Materials and methods: Biomechanical analysis of the stress-strain state was performed on a jaw bone fragment with canine and premolar inclusion.

Results: Tangential stress increase both in the adhesive layer and in restorative material with depth and width (medial-distal size) of restored wedge-shaped defects of teeth,. The most unfavorable loading on a tooth is a joint action of vertical and horizontal loading in lingual- vestibular or vestibular-lingual direction, depending on localization of the restored wedge-shaped defects of teeth. The formation of retention grooves in wedge-shaped defects of teeth reduces the value of the maximum tangential stress in the adhesive layer of restorative material to 25% and extends the longevity of restorations.

Conclusions: The difference in maximal values of tangential stress increases in adhesive layer of restorative material with or without retention grooves with increasing depth of defect. Thus, it is advisable to form retention grooves in cases of wedge-shaped teeth defects that exceed 1.5 mm. In case of restoration of subgingival wedge-shaped defects of teeth of small height it is recommended to create one retention groove on the gingival or incisal planes of a carious cavity due to significant inconveniences, and sometimes impossibility of formation of traditionally located retention grooves.

KEY WORDS: Computed simulation, wedge-shaped defect

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INTRODUCTION

Historically, first methods of studying the biomechanics of human teeth were based on physical experiments. Among them, photoelastic systems (Caputo et al., 1974), laser holographic interferometry (Burstone and Pryputniewicz, 1980), etc. have become widely used. The rapid development of computer technology has induced appearance both new directions in science and expansion of research in its classical domains. Biomechanics was not an exclusion, which analysis of mathematical models requires a large number of calculations. In dentistry this area has begun to develop more recently due to the complexity of the objects of study and reaching a certain technical limit of electronic computing. Nowadays this limit still does not allow to model the dental apparatus completely. Therefore, modern digital studies are limited to the analysis of the elastic-deformed state of a tooth or its prosthesis under mechanical and temperature loads. Numerical experiments have reached a qualitatively new stage of development with the advent of the finite element method (FE), which is well adapted to the complex geometry of the studied objects. Its first applications in dentistry was focused on solving steady-state problems. Nowaday, the number of publications on the use of FE method in this area covers a wide range of various problems of biomechanics from classical steady-state problems of tooth-jaw system durability to the latest methods of studying its behavior in dynamics and practically eliminates the impossibility of determining exact stress values in the zones of its possible accumulation. [1-6].

THE AIM

The aim of this research is to study the influence of size and location of wedge-shaped defects of teeth on the stress-strain state of filling material on the basis of biomechanical analysis.

MATERIALS AND METHODS

Biomechanical analysis of the stress-strain state was performed on a fragment of a jawbone with the dimensions of height = 22 mm and width 16 mm, Fig. 1.

The proposed model is divided by a rather small finite-element grid of tetrahedral elements (totally 156,646

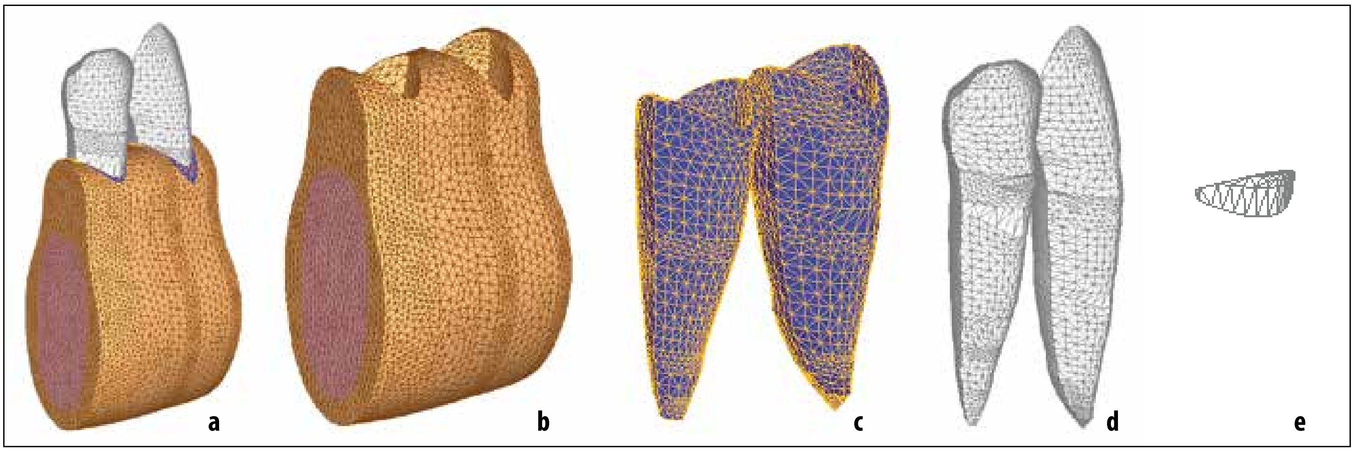

Fig.1. 3D finite element model of the mandible fragment at the first premolar and canine zone.

Table I. Dimensions used medial incisor modeling

Morphometric tooth parameters	The size of the canine, mm	Dimensions of the first premolar, mm
Tooth height	26	23,5
Root height	15,0	14,5
Crown height	11,0	9,0
Vestibular-lingual size of the crown	7,5	7,5
Vestibular-lingual size of the neck	6,5	6,0
Medial-distal size of the crown	6,5	7,5
Medial-distal size of the neck	4,5	4,5

Table II. Physico-mechanical characteristics of the structural components of the finite element model of the mandibular fragment

Material	Elasticity modulus of E, MPa	Poisson's ratio
"Charisma F" light curing composite	$1 \cdot 10^4$	0,3
Tooth crown enamel	$8{,}41 \cdot 10^4$	0,3
Dentine	$1{,}47 \cdot 10^4$	0,3
Cortical layer of bone	$1{,}81 \cdot 10^4$	0,3
Bone spongious substance	$4{,}9 \cdot 10^2$	0,3
Periodontium	10	0,45

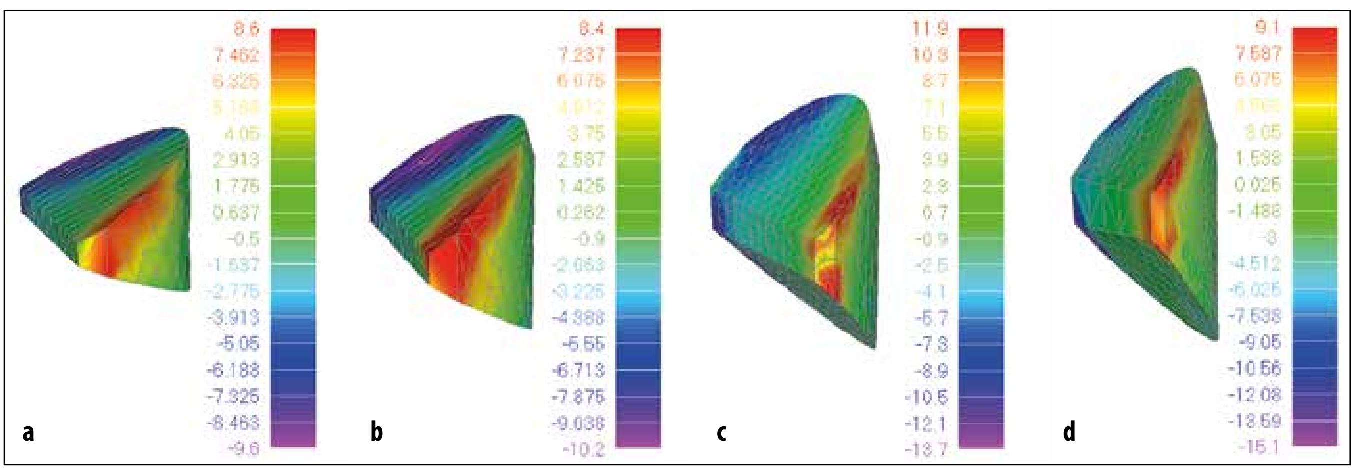

Fig. 2. Fields of distribution of tangential stresses in adhesive layers of restorations depending on the magnitude of the angles of the wedge in the restored cavity on the oral side of the first premolar: a) 30° magnitude; b) 45° magnitude; c) 60° magnitude; d) 70° magnitude.

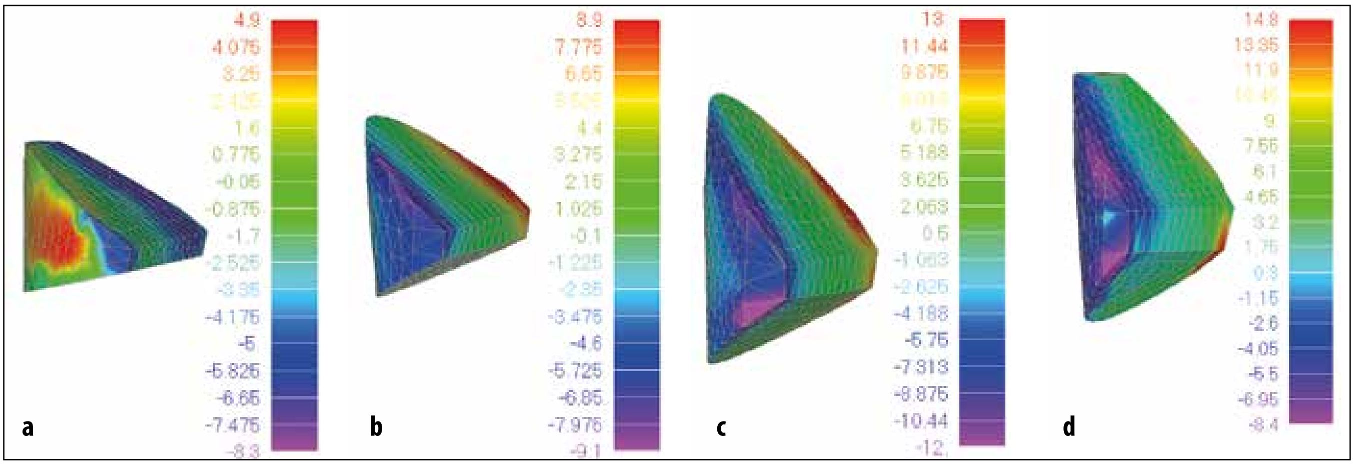

Fig. 3. Fields of distribution of tangential stresses in the adhesive layer of restorations depending on the magnitude of the angles of the wedge of the restored cavity of the vestibular surface of the first premolar: a) 30° magnitude; b) 45° magnitude; c) 60° magnitude; d) 70° magnitude.

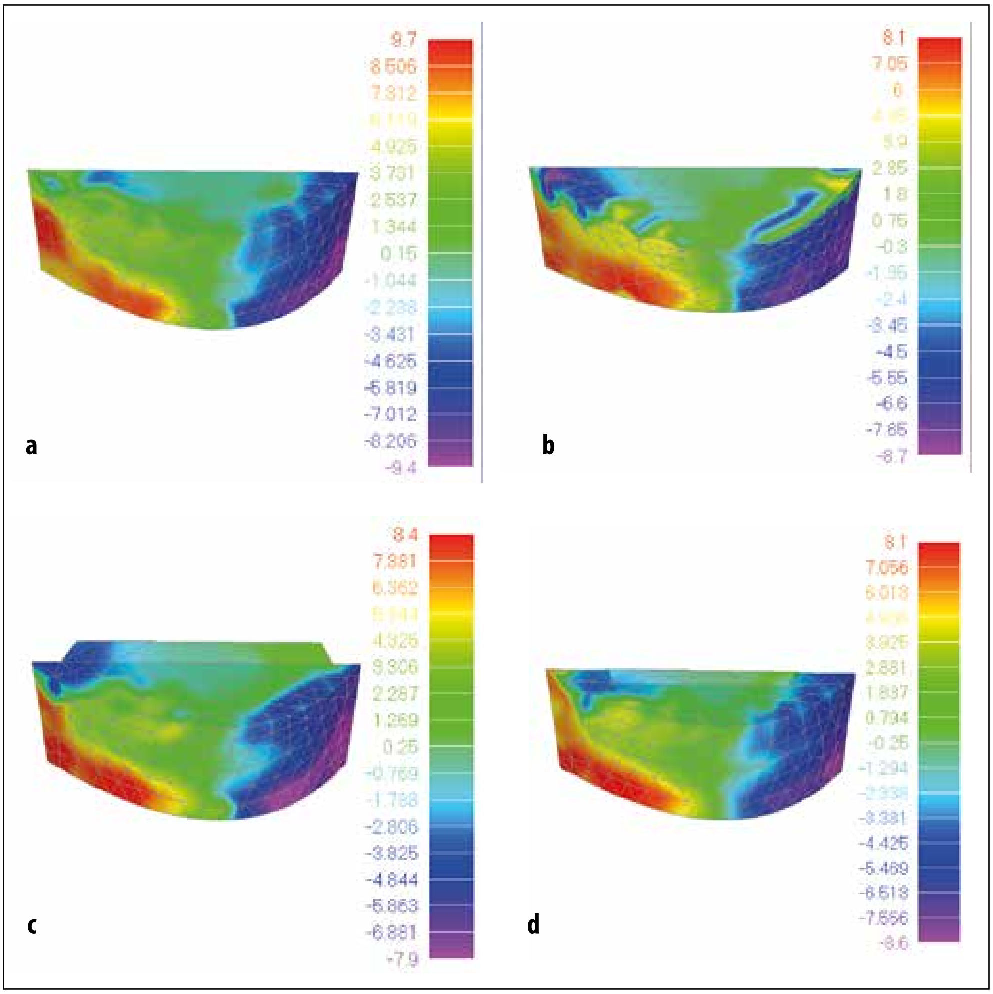

Fig. 4. Fields of distribution of tangential stress in the adhesive layer of restorative material depending on the shape and depth of the restoration at the cavity depth of l = 1.25 mm localized on the oral surface of first premolars:
a) restored prismatic cavity;
b) restored cavity of a trapezoidal cross-section;
c) restored prismatic cavity with retention grooves on the cavity floor;
d) restored prismatic cavity with retention grooves on the cavity walls.

3D-elements and 224,234 nodal points were used for reconstruction).

Mathematical modeling was performed with the usage of FEMAP 10.2.0 modeling package and finite element analysis, designed for implementation in Windows bases PCs.

The program, which is used for reconstruction and analyzis of models on the basis of the finite element procedure, serves for determination of displacement of each node of the finite element along three coordinate axes, normal and tangential stresses, as well as equivalent Huber-Mises stress.

As the main criteria for assessing the stress-strain state of the restorative material it is advisable to take the maximum values of tangential stresses at the adhesion boundary, which shift the filling material relative to the boundary of the restored cavity and thus determine the strength of the adhesive layer and durability [7,8,9].

Table III. Maximal values of tangential stress in adhesive layer of restorations depending on the magnitude of wedge angles of the restored cavity with a constant depth l = 1.0 mm and the mesiodistal size of the restorations b = 3 mm

Localization of cavities	Maximal values of tangential stresses τ, MPa, at different wedge angles			
	30°	45°	60°	70°
Vestibular surface of the first premolar	9,60	10,12	13,65	15,02
Oral surface of the first premolar	8,33	9,09	12,94	14,79

The main dimensions used for modeling of a premolar profile correspond to the recommended morphometric parameters for teeth modeling [10] are represented in table I. The width of the periodontal gap along the height of the teeth varies between 0.15 – 0.25 mm. Physico-mechanical characteristics of the individual structural components of the finite element model of the mandibular fragment are represented in table II, according to the values [11,12].

For simulation of functional loads on the studied teeth with wedge-shaped defects for the mathematical model vertical Fz and horizontal Fx (in the medial-distal direction) and Fy (in the vestibular-lingual direction) components of the load were applied at the level of teeth crown apexes. Despite the fact that the absolute values of the load do not significantly affect the solution of the problem the calculated value of the vertical load is assumed to be equal to 100 N because for comparison of maximal values of tangential stress occurring in the adhesive layers of the filling material at different sizes and shapes of restored defects any reference value of the load can be used. The horizontal components of the loads, according to [13], are 10% of the vertical component and are equal to 10 N.

The study of the stress-strain state in adhesive layers of the filling material was performed for different geometric shapes of renewable defects in order to ensure more reliable adhesion and maximal durability of restorations.

The wedge-shaped shape with different wedge angles is considered as the first of the studied geometric shapes of the restored cavities. Accepted values of the wedge angles were 30°, 45°, 60° and 70° while maintaining a constant depth of the cavity equal to l = 1.0 mm.

The studies were performed for cases of localization of cavities on both oral and vestibular surfaces of the teeth.

RESULTS AND DISCUSSION

Results of research for the most unfavorable case of functional load are shown in Fig. 2, Fig. 3 and in table III.

Analyzing the obtained results for both cases of localizations of cavities we discovered the tendency of maximal values of tangential stresses increasement in adhesive layer of restorative material with enlargement of wedge angles size. The difference between the maximum values of tangential stresses in adhesive layer of the filling material at different angles of the wedge of the restored cavity reached 45-50%.

The difference in maximal values of tangential stress in adhesive layer of restorative material within same loads, depths and mesiodistal size of the restorations located both from oral and vestibular surfaces of the first premolar was 10-15% on average. This difference was conditioned with morphometric parameters of the coronal part of the premolar, thought the tendency of localization and distribution of tangential stresses in adhesive layer of the restorative material remains same in both variants of cavities localization.

Also, it should be mentioned that the direction of the horizontal component of the functional load in the most unfavorable combination with the vertical load is preconditioned to the oral or vestibular location of the restorations.

The horizontal component of the functional load in the most unfavorable case of combination with the vertical load is always directed from the opposite side of the localization of restoration towards the restored cavity (i.e. when the restorations are located in the most compressed fibers of the restored tooth).

According to the obtained tendencies of maximal values change of tangential stress in adhesive layer of restorative material it would be more expedient to formate prismatic cavities which cause smaller absolute values of tangential stress in adhesive layer of restorative material in comparison with wedge-shaped looking cavities.

The following three-dimensional FE-models were designed to study the stress-strain state in the adhesive layer of the restorative material used in cavities with trapezoidal cross-section and prismatic cavities with different retention grooves on the cavity walls. All studied restorations were localized on the oral surface of the first premolar.

While preparing cavities with a trapezoidal cross-section, the deviation of gingival and incisal cavity walls from was 10 ° to the horizontal plane.

For matching of obtained results the size of the restored cavities were taken equal for all considered shapes: height of reparations h = 1.1 mm, mesio-distal size b = 3 mm when changing of cavity depth within l = 0.75 – 1, 5 mm.

The results of studies of the stress-strain state in the adhesive layer of restorative material of differently shaped cavities located on the oral surface of first premolars for the most unfavorable case of functional load with the cavity depth of l = 1.25 mm are shown in Fig. 4.

The maximal values of tangential stresses in the adhesive layer of restorative material of differently shaped cavities in case of changing the cavity depth within l = 0.75 – 1.5 mm, are represented in the table IV.

Analysis of obtained results revealed some tendencies of localization and distribution of tangential stress in the restorative material. Maximal values of tangential stress

Table IV. Maximal values of tangential stress in adhesive layer of restorations depending on the shape of restoration and its depth in case of heights of restorations h = 1.1 mm and the mesio-distal size of b = 3 mm

Shape of restoration	The maximum values of tangential stress in case of the following cavity depth, mm			
	0,75	1,0	1,25	1,5
Restorations of prismatic cross-sections	8,39	8,74	9,71	10,76
Restorations of a trapezoidal cross-section	8,11	8,02	8,68	9,48
Restorations of prismatic shape with retention grooves at the bottom of the cavity	–	7,56	8,36	9,18
Restorations of prismatic shape with retention grooves distanced from the bottom of the cavity	–	–	8,56	8,92

in the adhesive layer of restorative material increase regardless of the studied forms of restorations with the increasement of carious cavity depths. This is due to the increase of the volume of restorative material that replaces tooth dentin and also the increasement in the share of the total internal force received by the restorative material which modulus of elasticity differs from the modulus of elasticity of tooth dentin.

Maximal and approaching to maximum values of tangential stress with the combined action of vertical and horizontal components of functional loads in the studied forms of restorations are located in lower adhesive layers of restorative material of mesial and distal surfaces as well as the bottom of carious cavities near the enamel-dentin junction. That is caused by the difference in the elasticity modulus of tooth enamel, dentin and restorative material.

Maximal values of tangential stress of gingival and incisal planes of the restored cavities, which significantly affect the duration of restorations, are much less significant than maximal values that appear in the adhesive layers of restorative material on mesial and distal walls and cavities bottoms.

The localization of maximal tangential stress which was equal to 2,99 –3,85 MPa was observed near mesio-axial-gingival and distal-axial-gingival angles of the restored wedge-shaped defects during the combined action of vertical and horizontal functional load on the gingival and incisal planes of teeth. As can be seen from the results of the research when performing restorations of trapezoidal shape in frontal cross sections, the reduction of maximum values of tangential stress is reduced by 5-15% comparing to restorations of prismatic shape, while the reduction of maximal values of tangential stress on gingival and incisal planes decreases by 20%. The maximum values of tangential stress in case of restorations with retention grooves are 15-20% reduced comparing to stress that occurs in prismatic restorations. The difference between the values of tangential stress on gingival and incisal planes of both types of preparation reaches 20-25%.

It should also stated that the stress-strain state of the adhesive layer of restorative material in wedge-shaped defects of teeth is significantly affected by enamel thickness, without changing the trends of tangential stress in the adhesive layer of the restorative material.

CONCLUSIONS

Thus, the following conclusions can be drawn according to the results of the research,

- the tangential stress increases both in the adhesive layer and in the restorative material with increasing depth and width (mesio-distal size) of wedge-shaped defects of teeth;
- the most affective situation for a tooth is a joint action of vertical and horizontal loading aimed on lingual-vestibular or vestibular-lingual direction, depending on localization of a wedge-shaped defect;
- formation of retention grooves during preparation of wedge-shaped defects of teeth reduces the values of the maximal tangential stress in adhesive layer of restorative material up to 25%, thus prolongs the longevity of restorations;
- the difference in the maximum value of tangential stress in the adhesive layer of filling material for restoration of wedge-shaped defects of teeth with or without retention grooves increases due to the increase of cavity depth, thus retention groove formation should be recommended in case of wedge-shaped defects deeper than 1,5mm.
- in case of restoration of small wedge-shaped defects of teeth of, it is recommended to form one of these retention fists on gum or different area of carious cavity due to significant inconveniences, and impossibility to formate traditionall retention grooves.

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Conflict of interest:
The Author declare no conflict of interest.

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