http://dx.doi.org/10.35630/2199-885X/2020/10/4.34

BIOMECHANICAL ASSESSMENT OF THE STRESS-STRAIN STATUS OF SPLINTING STRUCTURES AND TEETH PERIODONTIUM IN CASE OF CHRONIC PERIODONTITIS

Received 29 September 2020; Received in revised form 02 November 2020; Accepted 09 November 2020

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ABSTRACT — The authors have proposed an all-cast pin splint, whose technological feature is the ceramic lining of the over-the-bar part, which acts as a covering aesthetic structure, provides better distribution of the functional load and binds firmly mobile teeth affected by chronic moderate localized periodontitis.

The paper offers a view at the outcomes of a comparative analysis of the stress-strain state of periodontal tissues, teeth, and cortical bone in chronic moderate localized periodontitis at the anterior group of teeth in the lower jaw, when they are splinted with a specially designed splint and a conventional metal-ceramic monolithic splint by finite element modeling. The developed 3D mathematical model included, as the initial data, the features of the periodontium, of dental tissue and of cortical bone. There was an examination carried out focusing on the distribution of stresses, which occur when using the designed splint under the impact of multidirectional loads of 130 N, acting strictly down relative to the tooth longitudinal axis (vertically), and a load at an angle of 45°. The proposed method of splinting reduces the maximum stress in the periodontium at a vertical load by 26.9%, while at a side load of 45° it reduced the stress by 34.7%, if compared to a traditional monolithic metal-ceramic splint.

KEYWORDS — periodontium, periodontitis, splinting, metal-ceramic crown, stress-strain state.

INTRODUCTION

There are numerous methods available for splinting mobile teeth in case of chronic localized periodontitis of varying degrees of severity [1–4], while there is no doubt that the top place among the methods employed to treat the pathology in question belongs to long-term splinting performed as a block of solid crowns or solid splints covered with ceramics [5]. The success of the orthopedic treatment will ultimately depend on the manufacturing technology and the splinting structure design.

Only the finite element method (FEM) is good for identifying the stress-strain state of objects featuring complex geometric shape [6]. Calculations based on FEM are in high demand, since they allow eliminating flaws at the design stage, reducing the time of refinement and the number of experiments (http://www.ansys.com/solutions/solutions-by industry/healthcare).

This work was performed using the ANSYS Academic Research Release 18.2 software package (academic license for scientific research; owner: S.P. Korolev Samara National Research University) which includes the ANSYS SpaceClaim geometric modeling module, and the ANSYS Mechanical module for solving strength problems. The consultation was offered by P.V. Bondarchuk, a CADFEM-CIS expert (Samara, Russia).

Aim of the study was to conduct a biomechanical evaluation of the efficacy of the proposed solid-cast ceramics-coated splint by the finite-element method on designed 3D mathematical model under multidirectional loads.

MATERIALS AND METHODS

A CAD (automated drawing) model of the lower jaw was designed based on tomographic examination and its processing in the computer-aided design (NX) system. The model was modified through creating a crescent-shaped periodontal lesion zone at the front teeth area, while the lower jaw canines were modeled intact (Fig. 1a). The jaw model is divided into two volumes: the cortical and spongy bone. The model has holes for the teeth as shown in the step section (Fig. 1b).

The central incisor, the lateral incisor and the canine teeth were created following a 3D computer model. The study does not take into account the holes of missing teeth due to the lack of their effect on the model deformation. The periodontal layer is of the same thickness (0.25 mm [7]).

We have designed two types of splint models that connected the teeth of the original model. The study is

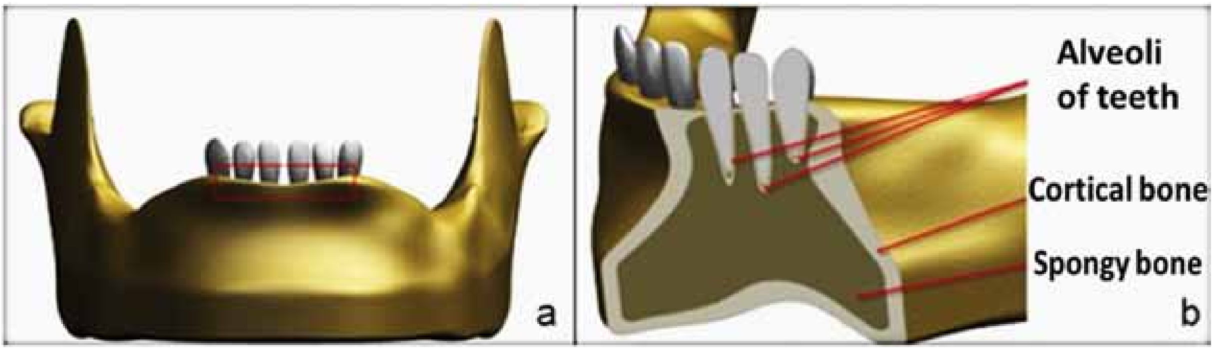

Fig. 1. Patient's lower jaw model: a — bone defect in the front teeth area; b — step section of the model

focused on the conventional cermet monolithic splint (Group 1) and a splint of the new design (Group 2).

The newly designed splint (RF patent #175754) was installed on the dentition as shown in Fig. 2a. Fig. 2b offers a more detailed view of the design, showing the splint and the prepared teeth. The splinting technique implies manufacturing a metal frame, constructed as a cast beam with pins, whereas for the pulpless teeth with parallel canals, the length of the root pins was ⅔ the length of the root canals, and for teeth with non-parallel canals, or in case there was no way to unseal the canals properly, the pin length was up to ⅓ of the canal length, while they were parallel to each other and to all the canals of the pulpless teeth.

well as to the other pins, in order to fix the splint on the intact teeth. The visible part of the cast splint on the respective teeth is covered with a ceramics layer to match the color of the latter. The splint was fixed through cement (GC Fuji I) in the root canals and in the prepared grooves of the clinical dental crowns.

The model did not shape a ceramic layer due to a low impact on the structure rigidity determined by the metal frame.

Fig. 3a shows a cermet monolithic splint. Fig. 3b offers an image of a jaw with a partially shown prosthesis and the prepared teeth. The point of this method was as follows: a whole-cast prosthesis from metal-ceramic crowns was made for preprepared teeth, while

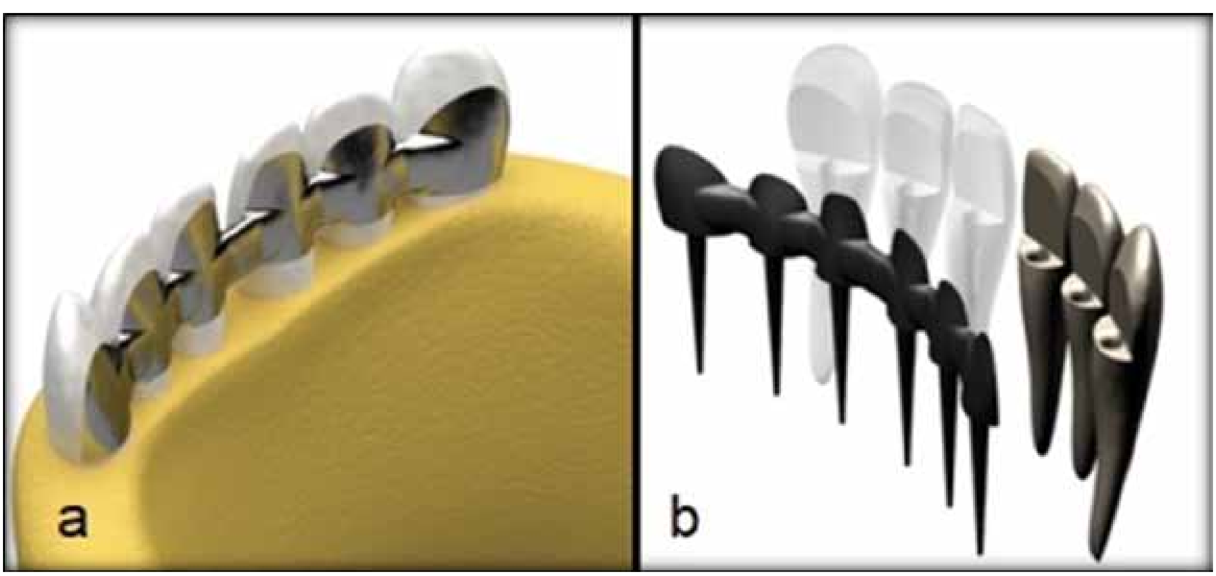

Fig. 2. Patented splint fitted to the lower jaw front teeth; a — splint, oral view; b — splint design

The splint featured paired parapulpar pins up to 2–2.5 mm long, which were parallel to each other as

the prosthesis was manufactured from cobalt-chrome alloy to be further coated with ceramics through bak-

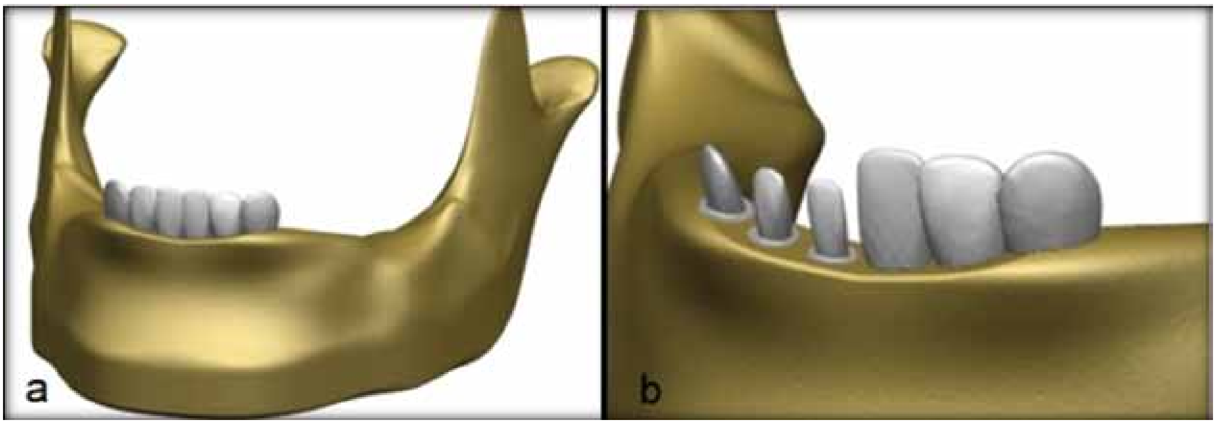

Fig. 3. *Metal-ceramic monolithic splint: a — view of splint on the jaw; b — prepared teeth and the splint shown partially*

ing. The structure was fixed on the teeth stumps with cement (GC Fuji I).

Calculation of the stress-strain state relied on the data regarding the components of mathematical models (properties of the tooth, lower jaw cortical bone, periodontium) [8–12], as can be seen from Table 1.

and cortical bone. Given that the analyzed materials feature different properties, several stress options were employed to assess the stress state. One was the equivalent of Von Mises stress for dental tissues, periodontium and the maximum major stresses (recommended for fragile bodies, such as cortical bone, for instance).

Table 1. *Properties of the materials employed through the study*

Material	Young's module, MPa	Poisson's ratio	Strength limit	
			Compressive, MPa	Rupture, MPa
Cortical bone	13700	0.26	156	85
Periodontium	0.6668	0.15	20	15
Teeth	19613.3	0.33	310	105

At the masticatory muscle (m. masseter) attachment point to the lower jaw, no vertical movement was allowed. When simulating biting, the models were loaded through applying force to the occlusal surfaces of the clinical dental crowns.

The strength analysis of the above models was performed with two loading options, hereinafter referred to as Step 1 and Step 2. The loading value was chosen so as to have a response at the masticatory muscle attachment area equal to 130 N. Given the model in question, this corresponded to a vertical load of 20 N per tooth. At Step 1 (Fig. 4a), a compressive load of 20 N was applied to the incisor surface of the teeth with a constant intensity, directed strictly downward relative to the tooth longitudinal axis (vertically), thus simulating food biting and chewing. At Step 2 (Fig. 4b), a load of 20 N was applied as well, featuring constant intensity at an angle of 45° relative to the longitudinal axis of the tooth [13].

The model was analyzed in relation to the stress distribution in the periodontium, dental tissues

For a more detailed understanding, we obtained the results of stresses occurring in the periodontium, dental tissues, and cortical bone separately.

RESEARCH OUTCOMES

Results of the stress-strain state, Group 1.

The maximum stresses in the periodontium under vertical load for Group 1 were: for the tooth 3.1 — 0.51 MPa; for the tooth 3.2 — 0.48 MPa; for the tooth 3.3 — 0.52 MPa (Fig. 5a). There is some uneven periodontium loading to be observed, while the maximum stresses at an angle of 45° were: for the tooth 3.1 — 0.92 MPa; for the tooth 3.2 — 0.95 MPa; for the tooth 3.3 — 0.86 MPa (Fig. 5b). The maximums localized on the periodontal dentoalveolar fibers (periodontium circular ligament).

The maximum stresses on the dental tissues in Group 1 under a vertical load for teeth 3.1 and 3.2 were 25.22 MPa; for tooth 3.3 — 22.17 MPa (Fig. 6a),

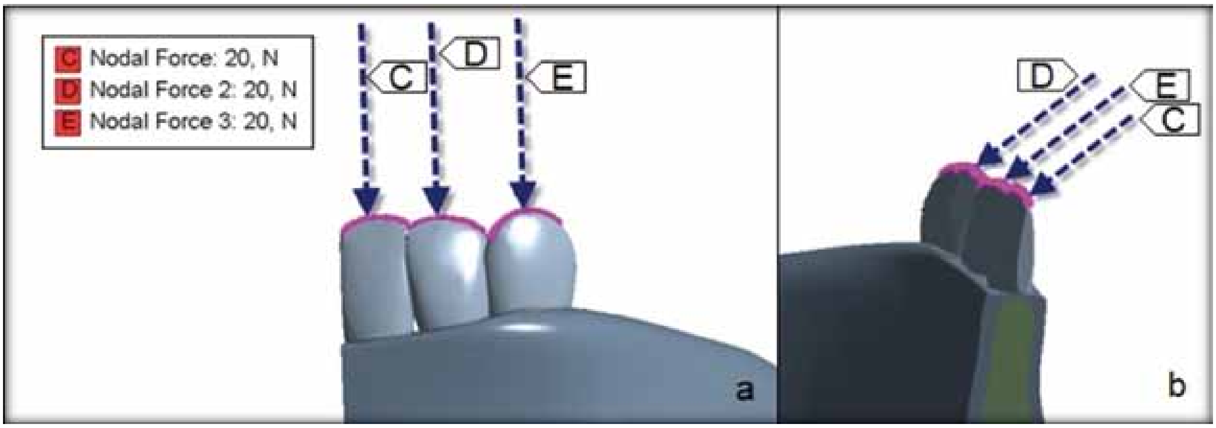

Fig. 4. *Areas of load application on the lower jaw teeth: a — step 1, vertical load; b — step 2, load at an angle of 45°*

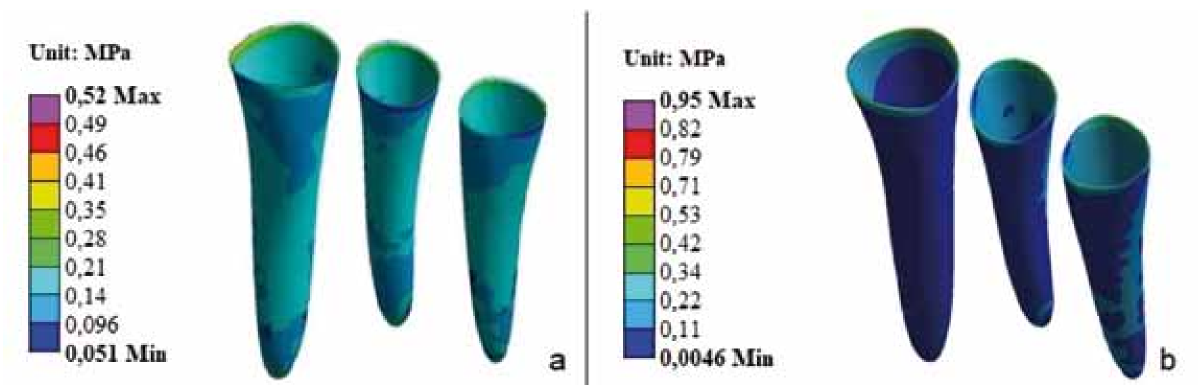

Fig. 5. *Maximum stresses occurring in the periodontium. Group 1: a — Step 1 (vertical load); b — Step 2 (45° load)*

while under a 45° load these were 59.81 MPa, 65.53 MPa and 68.35 MPa, respectively (Fig. 6b).

The maximum stress fields in the jaw cortical bone tissues in Group 1 were localized in the alveolar socket of tooth 3.3 and were 10.92 MPa; for tooth 3.2 — 9.15 MPa, and for tooth 3.1 — 10.11 (Fig. 7a). The maximum stresses at an angle of 45° in the cortical bone were 21.35 MPa for the teeth 3.3, 3.2 — 21.12 MPa; for 3.1 — 19.73 MPa (Fig. 7b).

Results of the stress-strain state, Group 2.

Fig. 8a shows the results of the maximum major stresses in the periodontium in Group 2: for the tooth 3.1 — 0.35 MPa; for the tooth 3.2 — 0.35 MPa; for the tooth 3.3 — 0.38 MPa. Under a loading at an angle of 45°, there was already a uniform loading to be observed in the periodontium, while the maximum stresses were: for the tooth 3.1 — 0.61 MPa; for the tooth 3.2 — 0.62 MPa; for the tooth 3.3 — 0.62 MPa (Fig. 8b).

The maximum stresses on the dental tissues in Group 2 under a vertical load for the tooth 3.1 were 18.55 MPa; for the tooth 3.2 — 18.53 MPa, and for the tooth 3.3 — 17.65 MPa (Fig. 9a), at an angle of 45°, the load on the tooth 3.3 was 44.25 MPa; on the tooth 3.2 — 44.23 MPa, while on the tooth 3.1 it was 44.23 MPa (Fig. 9b).

The maximum stress on the lower jaw model cortical bone in Group 2 under a vertical load for tooth 3.3 was 7.35 MPa; for tooth 3.2 — 7.31 MPa, and for tooth 3.1 — 7.28 MPa (Fig. 10a). The maximum stress at 45° in the cortical bone was 13.97 MPa for the tooth 3.3; for the tooth 3.2 — 13.16 MPa, and for the tooth 3.1 — 13.73 MPa (Fig. 10b).

Tables 2–4 offer a comparative analysis of the obtained quantitative indicators for the maximum stresses depending on the design and the part of the system.

The data in Table 2 shows that the resulting maximum stresses in the periodontium are high in Group 1, where the monolithic metal-ceramic splint was used. These indicators were the highest for both the vertical load (0.52 MPa) and the lateral (45°) load

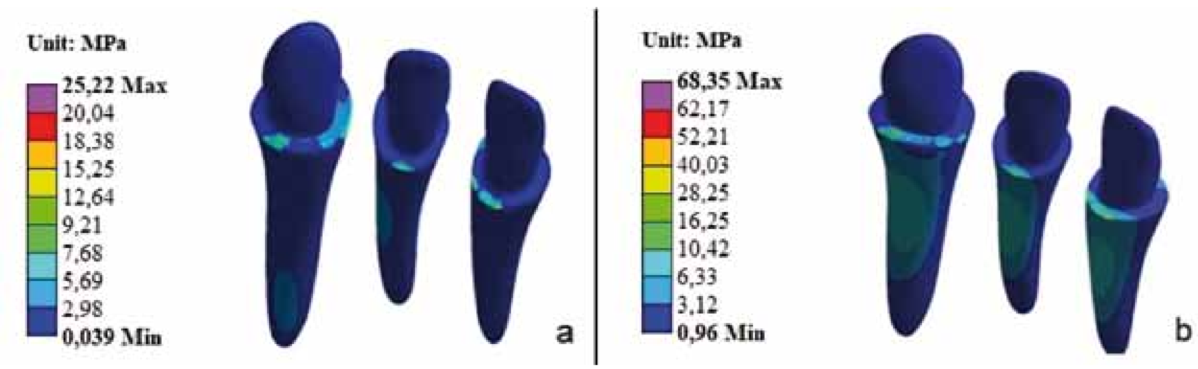

Fig. 6. *Maximum stresses occurring on the dental tissues. Group 1: a — Step 1 (vertical load); b — Step 2 (45° load)*

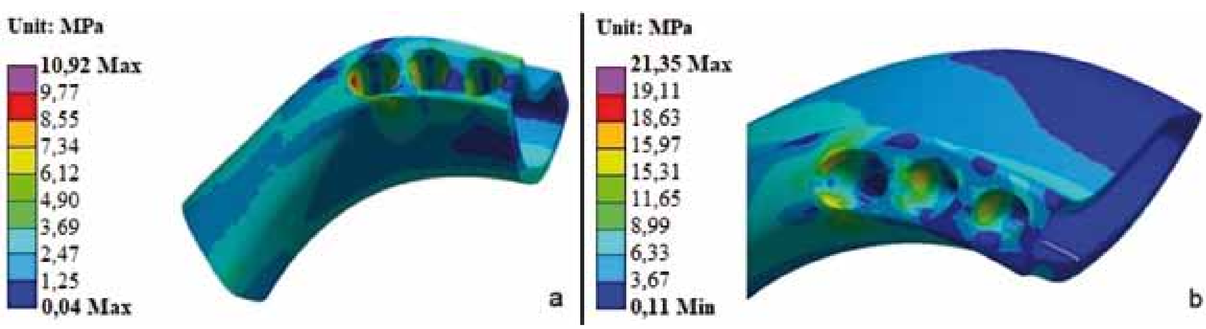

Fig. 7. *Maximum stress on the jaw cortical bone. Group 1: a — Step 1 (vertical load); b — Step 2 (45° load)*

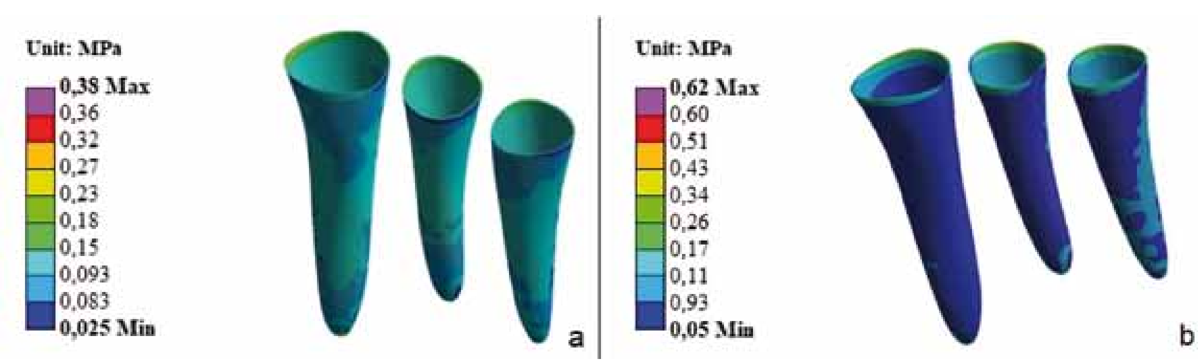

Fig. 8. *Maximum stresses occurring in the periodontium. Group 2: a — Step 1 (vertical load); b — Step 2 (45° load)*

(0.95 MPa). The use of the proposed splint allowed reducing the occurrence of maximum stresses in the periodontium, as well as distributing the equal load delivered through the structure to the periodontium. Mathematical analysis in Group 2, therefore, revealed a 26.9% decrease in this value under the vertical load (0.14 MPa), while under the lateral load the decrease was 34.7% (0.33 MPa), if compared to Group 1.

The obtained values of maximum stresses in dental tissues (Table 3) under the vertical load (90°), were the highest in Group 1 (25.22 MPa) and the lowest in Group 2 (18.55 MPa), with the statistically significant difference between the groups 26.4% (6.67 MPa). In case of the lateral load of 45°, the maximum stresses in the tooth tissues in Group 1 were 68.35 MPa, and in Group 2 — 44.25 MPa. Given the fact that the critical stresses in Group 2 proved higher for both loading options, the destruction of tooth tissues would occur faster while using a monolithic metal-ceramic splint.

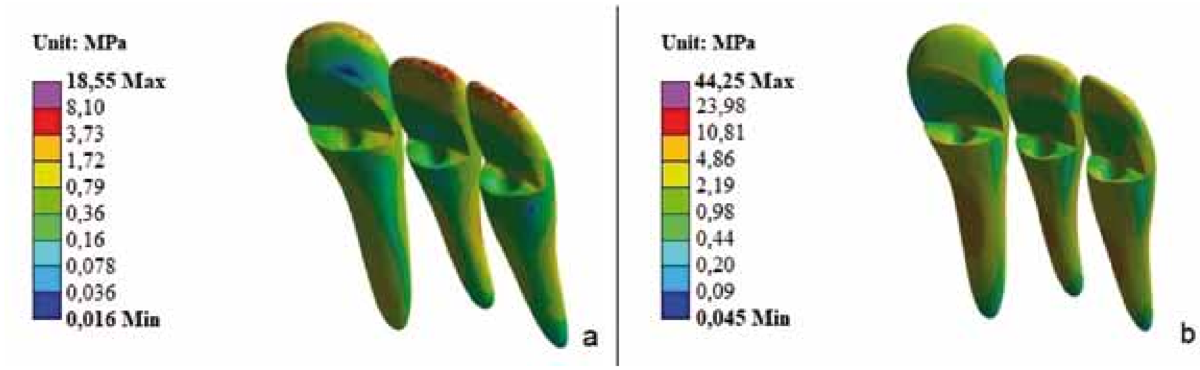

Fig. 9. *Maximum stresses occurring on the dental tissues. Group 2: a — Step 1 (vertical load); b — Step 2 (45° load)*

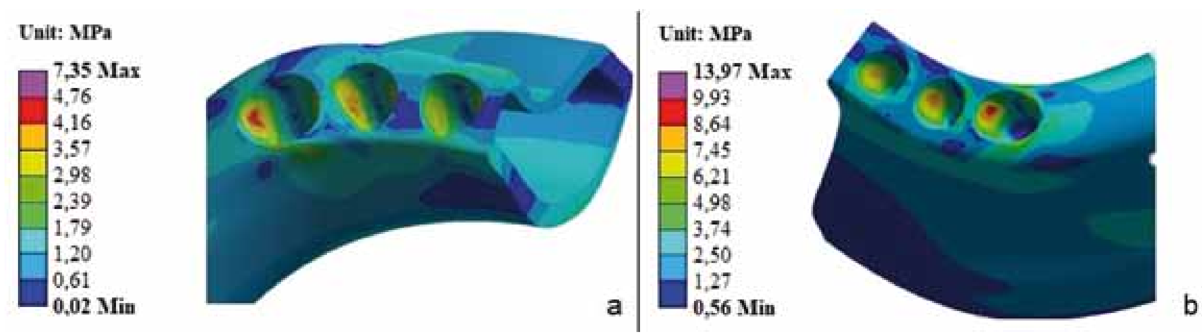

Fig. 10. *Maximum stresses occurring on the cortical bone. Group 2: a — Step 1 (vertical load); b — Step 2 (45° load)*

Table 2. *Results of maximum stresses in periodontium*

Group	Maximum stress, MPa						Critical stress resulting in periodontium trauma, MPa
	90°			45°			
	3.1	3.2	3.3	3.1	3.2	3.3	
1	0.51	0.48	0.52	0.92	0.95	0.86	18
2	0.35	0.35	0.38	0.61	0.62	0.62	

Table 4. *Results of maximum stresses in cortical bone*

Group	Maximum stress, MPa						Critical stress resulting in cortical bone trauma, MPa
	90°			45°			
	3.1	3.2	3.3	3.1	3.2	3.3	
1	10.11	9.15	10.92	19.73	21.12	21.35	73
2	7.35	7.31	7.35	13.73	13.16	13.97	

Table 3. *Results of maximum stresses in dental tissues*

Group	Maximum stress, MPa						Critical stress resulting in tooth collapse, MPa
	90°			45°			
	3.1	3.2	3.3	3.1	3.2	3.3	
1	25.22	25.22	22.17	59.81	65.53	68.35	22
2	18.55	18.53	17.65	44.23	44.23	44.25	

The results of maximum stresses occurring in the cortical bone (Table 4) under the vertical load and at an angle of 45° were highest in Group 1 — 10.92 and 21.35 MPa, respectively. In group 2, the vertical and the lateral loads entailed maximum stresses of 7.35 and 13.97 MPa, respectively, which is 32.6 and 34.5% below similar values in Group 1, which indicates rather a significant load in the cortical bone, and in case of bending loads there is destruction possible of the cortical bone marginal zones in the Group 2.

CONCLUSION

In view of our outcomes of the stress-strain state analysis performed using 3D mathematical models of lower jaws with chronic moderate localized periodontitis, splinted with constructions of various design, the following conclusions can be made:

1. The stress distribution pattern of all the types of splinting structures examined above corresponds to the nature of the stress distribution typical of rigid bodies with a predominant load concentration on the tooth circular ligament. Significant stress reduction in the patented design, if compared to the conventional splint, is due to significantly reduced stresses at the *tooth–splint* boundary subjected to a vertical and a lateral load.

2. Using the patented splint allows a significant reduction in the equivalent stresses not only on the border of different tissues, in the dentine, in the tooth root, yet also in periodontal tissues as well as in the cortical bone with no risk of dangerous load concentration, thus minimizing the likelihood of overload that the teeth may be subjected to.

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