Personalized biomechanical analysis of mandible teeth loosening during periodontal treatment with non-removable polymer splints with considering the different approach to physical and mechanical characteristics determining of bone tissue

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Abstract. A 3-dimensional finite element model of mandible anterior section, including a segment of mandibular bone tissue, four incisors, periodontal ligament (PDL), polymethylmethacrylate (PMMA) immobilizing splint of 0.5 mm thickness was developed. The stress-strain state of the model components is considered for the cases of a splinting structure presence and absence from the action of a typical occlusal load $F = 200$ N. The influence of the physicomechanical properties determining method for mandible bone tissue on the obtained results is evaluated.

1. Introduction
Periodontal disease is one of the most common dental pathologies in the world. Parodontitis is characterized by the abnormal tooth movability which makes chewing food difficult [1]. Immobilization of such teeth with splints promotes the periodontal treatment effectiveness. With the introduction of dental CAD / CAM technologies, the subtractive (milling, grinding) and additive (3D printing) methods allowed the design of high quality dentures.

The purpose of this publication is to develop an individual biomechanical model of mandible anterior section, assessing the effectiveness of the chosen parodontitis treatment case based on the stress-strain state analysis of PMMA splinting structure and dentition before and after installation, assessment of the influence of the mandible physicomechanical properties determining method on the results obtained.

2. Materials and methods
A computed tomography (CT) scan of a 26-year-old male patient maxilla and mandible consisting of 539 DICOM images with a voxel size of 0.15×0.15×0.15 mm, was considered as the study initial data. Analysis of the images revealed the maxilla and mandible dentition continuity and absence of
parodontitis signs. A 3-dimensional finite-element model of mandible anterior segment which includes mandible bone, periodontal ligament (PDL) 0.25 mm thick and four incisors was created on the basis of obtained data. The case of personalized milled splint installation on the teeth oral side with a thickness of 0.5 mm was considered. The creation of a model based on 4-node tetrahedra was carried out using the Mimics 17.0 and 3-matic 6.1 software systems. A high degree of splint-to-teeth adhesion was considered, therefore the nodes located at the interface of the splint-tooth surface coincided. Thus, with the above parameters the number of model nodes was 175570, elements - 998214. The material of all model components was modelled as an isotropic homogeneous linearly elastic. Temp Basic is a PMMA used as a splint material. The values of model materials mechanical characteristics are shown in Table 1.

**Table 1. Mechanical characteristics of materials.**

| Material                   | Modulus of elasticity (MPa) | Poisson's ratio | Reference |
|----------------------------|-----------------------------|-----------------|-----------|
| Tooth                      | 20000                       | 0.26            | [2]       |
| PDL                        | 68.9                        | 0.45            | [3]       |
| Compact bone tissue (Case 2)| 5857-40924                 | 0.3             | [4]       |
| Spongy bone tissue (Case 2)| 4-3183                      | 0.3             | [4]       |
| Mandible bone tissue (Case 1)| 14400                     | 0.3             | [5]       |
| PMMA Temp Basic            | 2200                        | 0.35            | [6]       |

Given that the bulk of the model is occupied by the mandible bone tissue (76%), two cases for determining the physicomechanical properties of this component are considered: the value of the elastic modulus for all elements is taken equal to 14400 MPa (Case 1); the elastic modulus of mandible bone tissue was determined discretely for each element using the empirical expressions connecting x-ray and physical densities as well as physical density and elastic modulus (Mimics calculation module was used). By analogy with the approach proposed in [4], elements with an average X-ray density HU ≥ 1000 (ρ ≥ 0.67 g / cm³, E ≥ 4583 MPa) were assigned to compact bone tissue. After the model creation was completed it was exported to the ANSYS finite element software. All model elements were assigned with SOLID285 element.

![Figure 1](image1.png)

**Figure 1.** Mandible segment finite element model with an indication of vertical forces location in modelling biting process, as well as the fixing model conditions (on the left); 4-incisors, splint and periodontium models (on the right)
Destructive changes of periodontal tissues (gum recession, dental alveolus lysis) during periodontitis and accordingly tooth root exposure were modelled by deactivating part of PDL model finite elements through “elements death” option use which reduces their stiffness to a negligible value (see figure 1). The loading of the model for all design cases corresponded to the biting food process. To this end, a vertical force equal to a typical occlusive load $F = 200$ N [4] was evenly distributed between the nodes belonging to teeth cutting edge (each tooth perceived a vertical load equal to 50 N). In order to assess the effect of tooth splinting on the model stress strain state, a calculation was also performed without taking into account the presence of a splint.

3. Results

The maximum total displacement and equivalent stress (von Mises stress) of teeth, mandible bone tissue and splint were evaluated during analysis. The results of determining the stress strain state of the model components taking into account the presence of a splint and determining the elastic modulus of the mandible bone tissue according to Case 2, are presented in Fig. 2. In this study, the teeth stress-strain state analysis is of the greatest interest.

![Figure 2](image_url)

An analysis of the results showed that in the absence of a splint the maximum total displacements occur in the region of the teeth 31, 32 cutting edge for which the greatest degree of roots exposure is specified and the maximum equivalent stresses are found in the upper and middle parts of the same teeth roots. Splinting operation allows redistributing both displacements and stresses between all teeth. Maximum total displacements of the tooth 31, 32 are reduced by 21.5% и 4.3% and teeth 42 is decreased by 23.1%, respectively. A similar picture is observed at stress estimation (see Fig. 3a) and stress-strain state of mandible remains almost unchanged. Maximum equivalent stresses in the splint located in out of contact with teeth vestibular surface and reduced cross-sectional areas. Also stresses do not exceed the strength limit of considered splint material – 50.7 MPa [6]. From a comparison of...
the modelling results presented in Fig. 3b, it can be seen that the method for determining the elastic modulus of mandible bone tissue slightly affects the stress strain state of the model components.

![Histograms displaying a modelling results comparison obtained for maximum total displacements and maximum equivalent stresses: a – for model without and with splint, b – with various Cases for determining the modulus of elasticity of the mandible bone tissue](image)

**Figure 3.** Histograms displaying a modelling results comparison obtained for maximum total displacements and maximum equivalent stresses: a – for model without and with splint, b – with various Cases for determining the modulus of elasticity of the mandible bone tissue

4. Conclusion

According to the results of the study, the following conclusions can be drawn:

- the presented technology allows to take into account individual geometric and mechanical characteristics of particular patient bone structures when planning parodontitis orthopedic treatment;
- the results of the study proved teeth splinting effectiveness in order to create conditions for a more uniform distribution of displacements and stresses in teeth and as a result stabilization of destructive processes in periodontal disease;
- for the case considered in the study the elastic modulus of mandible bone tissue can be determined in a simplified way - by assigning all components of the model a single value (as in Case 1).

References

[1] Zbarzh Y M 1996 On the need for objectification of the technique for determining the mobility of teeth *Parodontologiya* 1 pp 16-19
[2] Pedram P, Ghadirian H, and Arab S 2018 Anterior Teeth Splint with Various Degrees of Alveolar Bone Loss; A 3D Finite Element Study *Iran J Ortho.* 13(2):e7981
[3] Ted S F, Jason P C, Roger W T and Paul W M 2011 Experimentally Determined Mechanical Properties of, and Models for, the Periodontal Ligament: Critical Review of Current Literature *Journal of Dental Biomechanics* 2011 pp 1-10
[4] Horita S, Sugiura T, Yamamoto K, Murakami K, Imai Y and Kirita T 2017 Biomechanical
analysis of immediately loaded implants according to the “All-on-Four” concept *Journal of Prosthodontic Research* 61 pp 123-132

[5] Bin Deng, Kesong B.C. Tan, Gui-Rong Liu, Jian-Ping Geng and Wei-Qi Yan 2008 A new numerical approach for evaluation of dental implant stability using electromagnetic impulse *Int Chin J Dent.* 8 pp 1-9

[6] Pivovarov A A, Arutyunov S D, Muslov S A, Raimova D B and Kozlov S S 2014 Strength properties of milled dental-maxillary prostheses from structural dental material *Modern problems of science and education* 4 pp 1-9