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# Effect of horizontal loading on orthodontic microimplants functioning as temporary support of provisional orthopedic constructions

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## ABSTRACT

Orthodontic implants are currently widely used in dental practice. They are actively used because they provide a fixed support function, which allows using implants to move teeth and their groups. Using the finite element method, this article presents a mathematical analysis of stress distribution in the bone tissue and orthodontic implants providing both temporary support for provisional crowns and temporary support for tooth movement. This study aimed to examine the effect of horizontal load on orthodontic implants by applying mathematical modeling using the finite element method. The use of the finite element method for modeling stress–strain states in the “microimplant–surrounding bone tissue” system was performed with the reproduction of the material properties and parameters of the microimplant and surrounding bone tissue. 3D models of microimplants were created in the Kompas-3D program (Russia), and the stress distribution analysis was performed in the Autodesk Inventor program (USA). In this study, the peak stress values on the microimplants did not exceed 0.218 MPa with the maximum values of 880 MPa. The maximum stress values in the bone tissue were not higher than 0.024 MPa. Thus, the level of the obtained stress–strain states in both the bone tissue and microimplants is safe for horizontal loads.

**Keywords:** orthodontic implants; finite element method; stress distribution.

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# Изучение влияния горизонтальной нагрузки на ортодонтические микроимплантаты, способные нести функцию временной опоры провизорных ортопедических конструкций

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## АННОТАЦИЯ

В настоящее время в стоматологической практике широко используются ортодонтические имплантаты. Их активное применение обусловлено обеспечением функции неподвижной опоры, что позволяет использовать имплантаты для перемещения зубов и их групп. В статье представлен математический анализ распределения напряжений в костной ткани и ортодонтических имплантатах, способных нести функцию как временной опоры провизорных коронок, так и функцию временной опоры для перемещения зубов, с помощью метода конечных элементов. Цель работы — изучение влияния горизонтальной нагрузки на ортодонтические имплантаты путем применения математического моделирования методом конечных элементов. Исследование осуществлялось с использованием математического способа моделирования напряженно-деформированных состояний в системе «микроимплантат — окружающая костная ткань» с воспроизведением свойств материала и параметров микроимплантата и окружающей костной ткани методом конечных элементов. Для выполнения анализа созданы трехмерные модели микроимплантатов в программе «Компас-3D» (Россия), анализ распределения напряжений проводился в программе «Autodesk Inventor» (США). Пиковые значения напряжений на микроимплантаты не превышали 0,218 МПа при предельных значениях 880 МПа. Максимальные значения напряжений в костной ткани оказались не выше 0,024 МПа. Таким образом, уровень полученных напряженно-деформированных состояний как в костной ткани, так и в микроимплантатах является безопасным для горизонтальных нагрузок.

**Ключевые слова:** ортодонтические имплантаты; метод конечных элементов; распределение напряжений.

## Как цитировать

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## BACKGROUND

Currently, orthodontic implants are a widely used treatment option in modern dental practice. They are actively used because they provide fixed support, which allows for the movement of teeth and their groups [1–10].

In addition to providing a fixed support for tooth movement, orthodontic implants can also provide temporary support for provisional prosthetic crowns in patients with partial tooth loss. This allows for the restoration of the integrity of the dentition during orthodontic treatment before prosthetics and consequently the elimination of traumatic occlusion and restoration of masticatory function throughout the orthodontic treatment period [11].

Nevertheless, the use of conventional orthodontic implants as a provisional support for provisional crowns is associated with certain disadvantages, such as difficulties in the laboratory fabrication of crowns, disruption of crown fixation, and the need for additional restoration of the crown base after fabrication. These issues arise because the supragingival aspect of conventional orthodontic implants is not intended for use as a foundation for a provisional prosthetic crown. In light of these considerations, we proposed a microimplant system, and its design can be used as a provisional support for a provisional orthopedic structure (Fig. 1) [12].

A previous study investigated the effect of vertical loading on orthodontic implants using finite-element mathematical modeling, which demonstrated the safety of vertical loading.

*This study aimed to* examine the effect of horizontal loading on our proposed microimplant system using the finite-element method.

The finite-element method is a mathematical approach to calculating the physical capabilities of materials and systems within a computer environment. This

is achieved through differential equations. The method is founded upon the partitioning of the subject matter into virtual fragments of a specified magnitude, through which the strength characteristics of the primary object are calculated [2, 14–16].

When studying the stress distribution in the microimplant area, the following tasks were set:

1) Characterizing the stress distribution patterns under horizontal loading of the microimplant.

2) Determining possible differences in stress distribution in bone tissue in the presence of cancellous bone only and cancellous bone covered with the compact lamina.

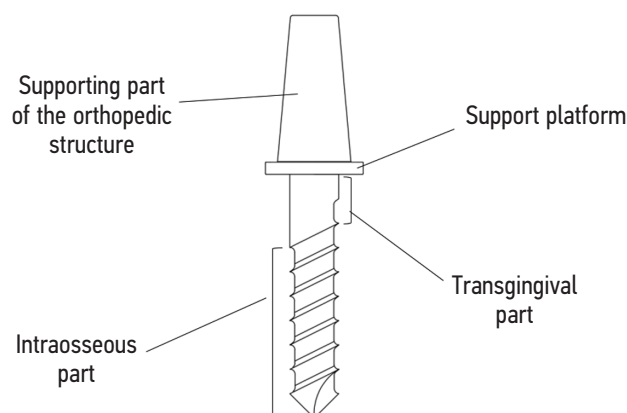
3) Determining the microimplant zones that experience maximum stresses.

## MATERIALS AND METHODS

Geometric models of orthodontic implants and two bone tissue models were developed to solve the given tasks. The first model consisted only of spongy substance, whereas the second model included spongy substance and compact lamina. The two experimental models of bone tissues were created because in the area of missing teeth in the upper jaw, spongy bone without a pronounced cortical layer is commonly found, whereas in the lower jaw, the spongy bone is often surrounded by a pronounced compact lamina.

The following bone tissue parameters were used: compact lamina thickness of 1.5 mm, spongy substance density of 1400 Hounsfield units (HU), and compact lamina density of 1800 HU [17]. The horizontal load applied to the microimplants was equivalent to the maximum force level of intraoral elastic traction, amounting to 1.7 H [18].

Six groups of geometric models were constructed based on the orthodontic implant and bone tissue models, with variations in implant size and bone tissue model.



**Fig. 1.** Model of the orthodontic microimplant performing the function of a temporary support for an orthopedic structure developed by R.A. Fadeev and M.A. Cheban

**Рис. 1.** Модель разработанного Р.А. Фадеевым и М.А. Чебаном ортодонтического микроимплантата, способного выполнять функцию временной опоры ортопедической конструкции

**Table 1.** Physical and mechanical characteristics of the bone tissue and titanium

**Таблица 1.** Физико-механические характеристики костной ткани и титана

| Material                      | Modulus of elasticity, hPa | Poisson's ratio | Yield strength, MPa | Tensile strength, MPa |
|-------------------------------|----------------------------|-----------------|---------------------|-----------------------|
| Compact lamina of bone tissue | 13.70                      | 0.26            | –                   | 60                    |
| Spongy bone                   | 1.37                       | 0.30            | –                   | 60                    |
| Titanium                      | 113.80                     | 0.32            | 880                 | –                     |

**Table 2.** Magnitude of stresses in the first bone tissue model (spongy substance only)

**Таблица 2.** Величина напряжений в первой модели костной ткани (только губчатое вещество)

| Microimplant size, mm | Maximum stress in the microimplant, MPa | Maximum stress in bone tissue, MPa |
|-----------------------|-----------------------------------------|------------------------------------|
| 2 × 8                 | 0.204                                   | 0.003                              |
| 2 × 10                | 0.187                                   | 0.004                              |
| 2 × 12                | 0.201                                   | 0.004                              |

Subsequently, the following finite-element models were developed for the aforementioned groups: Group 1 consisted of a bone model and a microimplant with an internal part size of 2 × 8 mm (thread height, 6 mm; transgingival height, 2 mm); group 2, bone model 1 and a microimplant with an internal part size of 2 × 10 mm (thread height, 8 mm; transgingival part height, 2 mm); group 3, bone model 1 and a microimplant with an internal part size of 2 × 12 mm (thread height, 10 mm; transgingival part height, 2 mm); group 4, bone model 2 and a microimplant with an internal part size of 2 × 8 mm (thread height, 6 mm; transgingival part height, 2 mm); group 5, bone model 2 and a microimplant with an internal part size of 2 × 10 mm (thread height, 8 mm; transgingival part height, 2 mm); group 6, bone tissue model and a microimplant with an internal part size of 2 × 12 mm (thread height, 10 mm; transgingival part height, 2 mm);

The study employed a mathematical modeling approach to investigate the stress–strain states within the microimplant surrounding bone tissue system. This involved reproducing the material properties and parameters of the microimplant and the surrounding bone tissue through the finite-element method. For the analysis, three-dimensional models of microimplants were constructed in “Compass 3D,” (Russia) and a stress distribution analysis was performed in “Autodesk Inventor” (USA).

The physical and mechanical characteristics (elastic modulus, Poisson's ratio, yield strength, tensile strength) of the bone tissue and titanium were obtained from specialized literature sources and are presented in Table 1 [2, 15, 16, 19, 20].

## RESULTS

The results of the finite-element method study investigating stress distribution in microimplants and surrounding bone tissue are presented below.

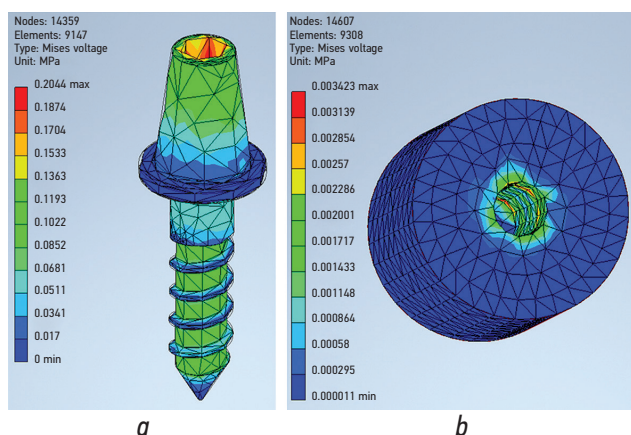
Group 1 consisted of a bone tissue model and a microimplant with an inner part size of 2 × 8 mm (Fig. 2); group 2, bone tissue model 1 and a microimplant with an internal part size of 2 × 10 mm (Fig. 3); group 3, bone tissue model 1 and a microimplant with an internal part size of 2 × 12 mm (Fig. 4); group 4, bone model 2 and a microimplant with an internal part size of 2 × 8 mm (Fig. 5); group 5, bone model 2 and a microimplant with an internal part size of 2 × 10 mm (Fig. 6); group 6, bone model 2 and a microimplant with an internal part size of 2 × 12 mm (Fig. 7).

Tables 2 and 3 illustrate the maximum stress values in microimplants and bone tissue, respectively, as a function of the bone tissue model.

The characteristics of stress distribution under horizontal loading on the microimplant were evaluated, and the maximum stresses were concentrated in the area of the supragingival part of the construct. In this area, the stresses ranged from 0.187 to 0.218 MPa. In contrast, the load was distributed evenly in the area of the intraosseous and transgingival parts.

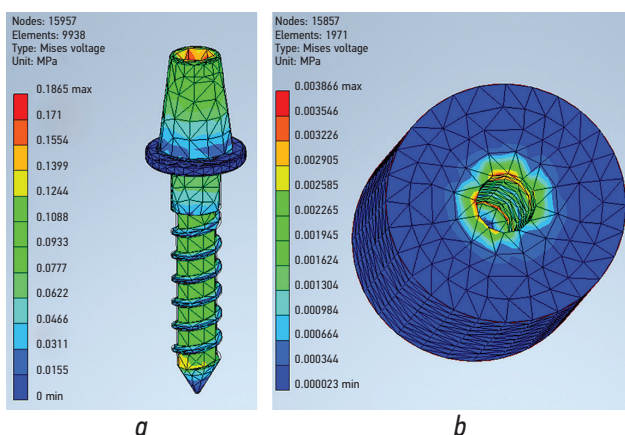
The study of stress distribution in the bone tissue demonstrated that when a load was applied to a microimplant situated solely within the cancellous bone, uniform stresses were observed throughout the microimplant's body. Upon examination of the stresses in the second bone tissue model, the compact plate within the bone did not result in the accumulation of stresses within the area of this layer. Instead, the stresses were primarily





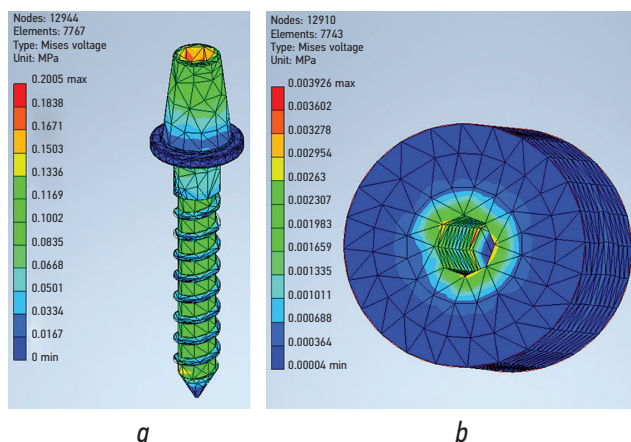
**Fig. 2.** Group 1: stress distribution in the microimplant (a) and bone tissue (b)

**Рис. 2.** Группа 1 — распределение напряжений в микроимплантате (a) и костной ткани (b)



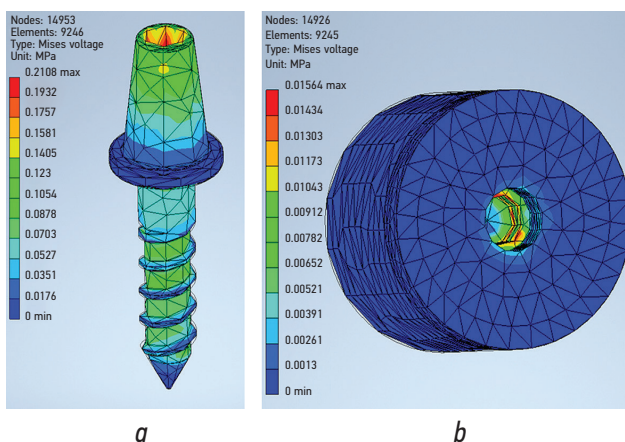
**Fig. 3.** Group 2: stress distribution in the microimplant (a) and bone tissue (b)

**Рис. 3.** Группа 2 — распределение напряжений в микроимплантате (a) и костной ткани (b)



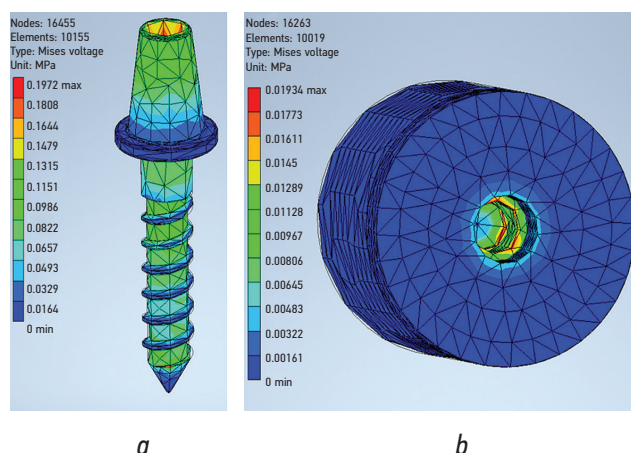
**Fig. 4.** Group 3: stress distribution in the microimplant (a) and bone tissue (b)

**Рис. 4.** Группа 3 — распределение напряжений в микроимплантате (a) и костной ткани (b)



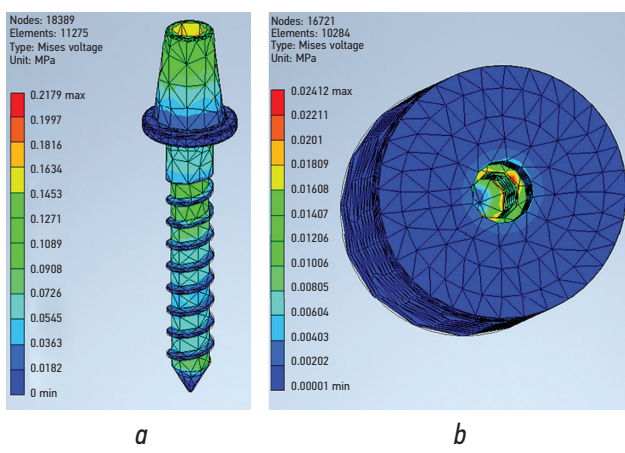
**Fig. 5.** Group 4: stress distribution in the microimplant (a) and bone tissue (b)

**Рис. 5.** Группа 4 — распределение напряжений в микроимплантате (a) и костной ткани (b)



**Fig. 6.** Group 5: stress distribution in the microimplant (a) and bone tissue (b)

**Рис. 6.** Группа 5 — распределение напряжений в микроимплантате (a) и костной ткани (b)



**Fig. 7.** Group 6: stress distribution in the microimplant (a) and bone tissue (b)

**Рис. 7.** Группа 6 — распределение напряжений в микроимплантате (a) и костной ткани (b)

**Table 3.** Magnitude of stresses in the second model of bone tissue (spongy substance and compact plate)

**Таблица 3.** Величина напряжений во второй модели костной ткани (губчатое вещество и компактная пластинка)

| Microimplant size, mm | Maximum stress in the microimplant, MPa | Maximum stress in bone tissue, MPa |
|-----------------------|-----------------------------------------|------------------------------------|
| 2 × 8                 | 0.211                                   | 0.016                              |
| 2 × 10                | 0.197                                   | 0.019                              |
| 2 × 12                | 0.218                                   | 0.024                              |

concentrated in the cancellous bone along the microimplant's body.

CONCLUSIONS

1. The results demonstrate that microimplants can withstand horizontal loads without compromising their structural integrity.
2. The maximum stresses experienced by the microimplants do not exceed 0.218 MPa, with a limit value of 880 MPa.
3. The application of a horizontal load to the microimplant resulted in the distribution of stresses predominantly around the cancellous bone, irrespective of the presence of the compact lamina. The maximum stress values in the bone tissue were <0.024 MPa, indicating a high reserve of bone tissue strength at the current loading level.

ADDITIONAL INFORMATION

**Authors' contribution.** All the authors made a significant contribution to the preparation of the article, read and approved the final version before publication. Personal contribution of each author: R.A. Fadeev — writing and editing the text of the manuscript;

M.A. Cheban — collecting material, analyzing the data obtained, writing the text of the manuscript.

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