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Study of Bridges between Natural Teeth and Implants during Chewing of Food Bolus

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Abstract

Application of finite element three-dimensional modeling in biomechanics can significantly expand the possibilities of solving many problems of practical and theoretical dentistry. These problems can be solved with the application of the principles of systemic structural strength analysis, which considers both geometric characteristics and mechanical properties of bone tissues. A development of a mathematical model of the system "prosthesis-the bone-implant" with the aim of identifying the most optimal placement of these elements relative to each other. With the application of different variants of the load on the implants in the bone tissue, the resulting pattern shows that prosthetic restorations experience a greater degree of tensile stress. It was observed that the situation of the dentition defect was due to an absence of the first and second premolars and the replacement of the first molar with the prosthesis. The load applied to bridges was defined as concentrated and distributed. The implant is installed on the site of the first premolar in the initial stage (concentrated load capacity). Thereafter, it is experiencing a minor internal stress, while chewing and increasing the area of the chewing surfaces, these stresses accumulate to a great extent with the participation of three teeth in chewing, a further increase in chewing surface leads to a decrease in stress values.

Keywords: Internal stress; Finite element method; Bridge; Implant; Mathematical model; Prosthetic dentistry

Introduction

Researchers are increasingly inclined to the view that for optimum results of orthopedic treatment of patients in each specific case, it is necessary to perform calculations and analyze systems planned for use on the basis of the clinical situation and data on individual peculiarities of the structure of the jaws of patients.

When designing the parameters of a denture, it is necessary to have an idea about the distribution of deformations and stresses, especially under conditions of load application in the process of exploitation of the prosthesis [1].

To quantify changes in the bone tissue of the jaw, a comprehensive criterion is used, allowing estimation of the stressstrain state of the investigated sections of the jaw as a whole and on individual parts (Schleicher-Nadai criterion). The properties of the jawbone and the artificial inclusions are modeled as a locally homogeneous continuum, which is shown by the constants of the theory of small elastic-plastic deformations. In the end, the fields of stress intensity were obtained, which describe the development of shear strains in biomechanical composite structures. Also, we calculated the probability of destruction of the biomechanical system [2].

Currently, one of the most informative methods of studying the biomechanics of dental system is the finite element method [3]. Convenience of its use is due to the several advantages of this approach compared to the full-scale trials, particularly in relation to the possibility of not only assessing the actual situations of the mouth but also testing the functional loads, which are nonstandard in magnitude, direction, and points of application [4].

The essence of the method lies in the fact that a model is created for the studied object. This model is divided into a finite number of simple elements. The results of the study are obtained in the form of stress fields and deformations of the object. Two-dimensional model most often consists of a triangular finite element with three points of interaction between each other. A three-dimensional model is composed of tetrahedrons that have four points of interaction [5].

The forces acting on the object in the real world should be applied to the model to study the stress—strain state of an object. In this case, the model should have the inherent physico-mechanical characteristics corresponding to the real characteristics for the studied object. After conducting the necessary calculations, the researcher will receive full information on the distribution of stresses, strains, and displacements at all points of the studied object [6,7].

From the point of view of mechanics of a deformable body, the task of determining the stresses in a natural way splits into three separate tasks: determination of residual technological stresses; identification of stress caused by the masticatory load; and the study of thermal stress caused by drinking hot or cold foods.

Chewing load is cyclic and, therefore, depends on the time. The power tension will be determined only for the maximum masticatory load that is considered the most dangerous.

Attempts were made to study various mathematical finite element models and systems: the implant–natural tooth, united by a bridge. The obtained result indicated that the method of fixation of the structure is not critical, since the stresses in the bone tissue are distributed almost equally [8-10].

A number of authors developed a mathematical model of the system "prosthesis-the bone-implant" with the aim of identifying the most optimal placement of these elements relative to each other. Various options were considered for the placement of implants in bone tissue and their number was obtained as the resulting pattern. It showed that prosthetic restorations experience a greater degree of compressive

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stress. The compressive stress in all the studied implants was ten times lower the ultimate strength of structural materials.

A number of studies were devoted to the regularities of biomechanics of dental implants. The obtained results allowed a number of researchers to conclude about the significant improvement of load distribution when applying intraosseous biodesign-implants for direct implantation [11].

Application of finite element three-dimensional modeling in biomechanics can significantly expand the possibilities of solving many problems of practical and theoretical dentistry. These problems can be solved with the application of the principles of systemic structural strength analysis, which considers both geometric characteristics and mechanical properties of bone tissues [10].

Researchers' attention is also directed to making the additional functional load on the abutment teeth at prosthetics with fixed designs bridges. The reaction of the periodontium to a functional overload remains a controversial issue [12].

A mathematical model was developed of various types of prostheses and produced the data on the distribution of stress intensity in the tissues of the abutment teeth and the components of denture at the action of a side load on the prosthesis.

The obtained data, according to the authors, will allow planning the treatment of patients more precisely, with partial loss of teeth, and optimizing the selection of the design of bridges without the distal support.

Methods

For a more complete and in-depth study of the functioning of the model using a bridge denture supported by implants, let's consider the distribution of internal stresses in two variants of load application. The first option—a concentrated chewing load—is applied to bridges not symmetrically; the second option—a distributed masticatory load—is applied to bridges evenly.

In the study of stress distribution in the jaw and teeth when using the bridge, the following conditions are used for the functioning of the model:

1. 100% of the density of cancellous bone 15×10^3 kg/cm^2, the density of the dentin 200×103 kg/cm^2, a Poisson's ratio of 0.30.
2. Strength of the masticatory load is defined as 100 H, attached to bridges when chewed food is of the average hardness.

In the study of masticatory load distribution, there are 59 fixing points whereas in the study of models with a concentrated load of chewing, there are 57 fixing points.

To describe and discuss the results on the basis of the selected lines, we will use the pattern of distribution of equivalent and internal stresses.

Results and Discussion

In the Figure 1, the model is under a positive tensile stresses, which are concentrated in the region of the implant, which is located at the projection of the first molar.

The zone of maximum internal stress is localized in the suprastructure of the implant in the coronal part of the dental bridge and covers the gingival part (Figure 2).

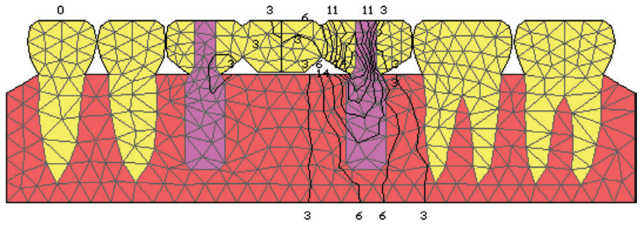

Figure 1: Equivalent distribution of internal stresses in bridge dentures with implant-centered chewing load

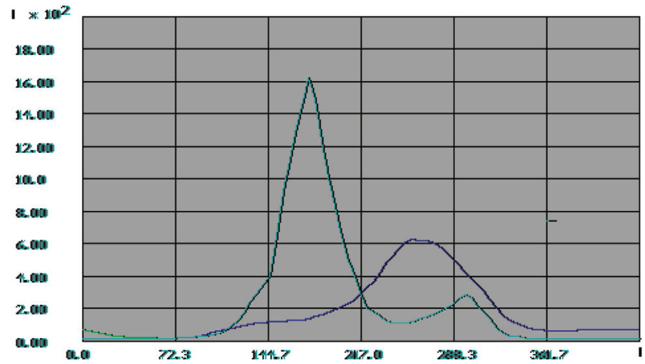

Figure 2: Schedule of distribution of internal stresses in the model of the perception of the point load by the bridge with a help of the prosthesis implant

Due to the distance from the point of application of load, internal stresses in the structure are gradually reduced and virtually unreported in the implant region of the first premolar.

On the graphs of the distribution of internal stresses, we register a surge in the implant installed in the region of the first molar. In the surface layers of the model, internal stresses are 2.6 times higher than on the top. The stress in the implant region of the first premolar is virtually unreported.

This pattern of distribution of internal stresses indicates that there is a significant loading of the implant installed in the area of the first molar. Excessive loads in the superstructure can lead to its destruction and the loss of the whole structure. Permanent tensile stresses in the cervical region may trigger the occurrence of inflammatory processes in the area of the implant coupled with poor hygiene. The next step was to study the effect of a distributed chewing load on the bridge, as it is the most common variant of the functioning of the denture when chewing food. The conditions for the functioning of the model are assumed to be similar to those in the previous study.

In Figure 3, we can notice that the model is under a positive tensile stresses. Internal stresses are localized along the axis of the implants and are distributed in the surrounding bone tissue.

Comparing the distribution of internal stresses in the implant, it should be noted that the magnitude of values are almost comparable, but the area of localization of maximum values in the region of the superstructure of the implant (in place of the first molar) is more extensive than in the region of the second supporting implants.

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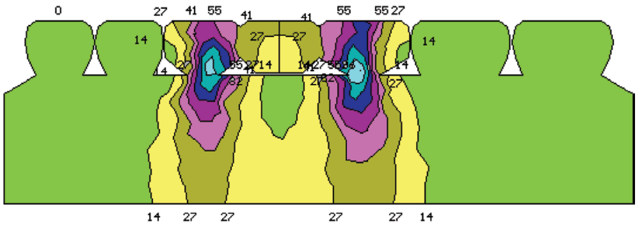

Figure 3: Equivalent distribution of internal stresses in bridge prosthesis, the distributed masticatory stress (three teeth)

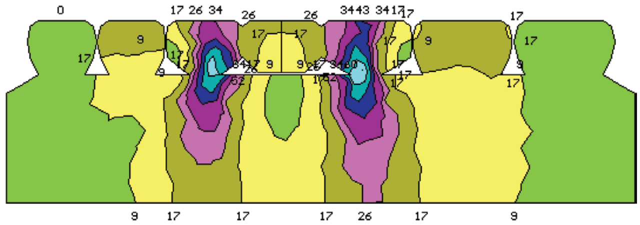

Figure 5: Equivalent distribution of internal stresses in the denture bridge, the distributed chewing load (five teeth)

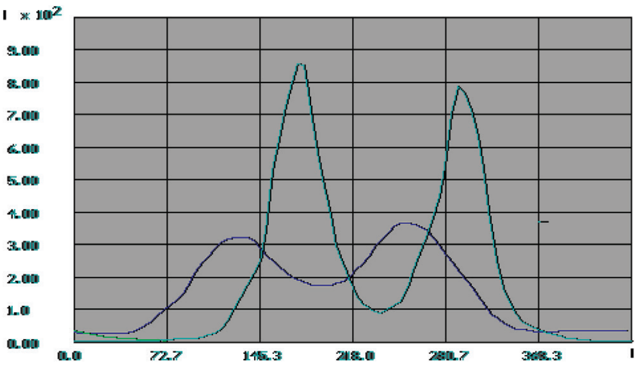

Figure 4: Schedule of distribution of internal stresses in the model of the perception of the distributed load by the denture bridge (three teeth)

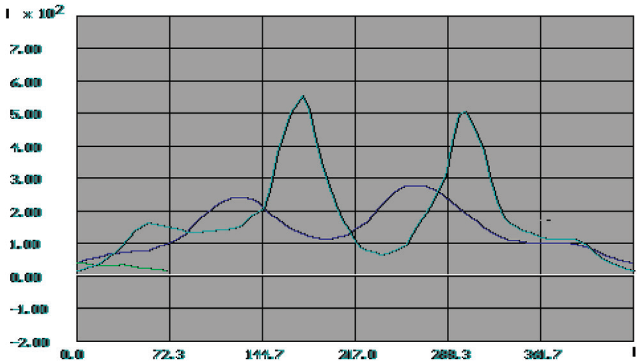

Figure 6: Schedule of distribution of internal stresses in the model in the perception of the distributed load by bridge (five teeth)

The significant stresses in the superstructure and the cervical region of the implants can lead to poor circulation in this area and the development of inflammatory processes leading to the destruction of the implant and hence loss of the whole structure. The alveolar part of the bone tissue between the implants is also under the positive tension.

On the graphs of the distribution of internal stresses (Figure 4), we can observe a surge in the field of implants, both in the deep and superficial layers of the model. In the implant that is installed in the region of the first molar in the surface layers, the internal stress is 2.36 times higher than in the deeper layers of the model. In the implant that is installed in the region of the first premolar in the surface layers, the internal stress is 2.46 times higher than in the deeper layers of the model.

Comparing the internal stresses in the implant, it should be noted that in the region of the first molar the stress is 7.5% higher than in the implant installed on the site of the first premolar in the surface layers and is 12.5% higher than in the deeper layers of the model.

The next stage of the study of the denture is the extension of the receptive surface from canine to the second molar when exposed to the distributed load of chewing.

In Figure 5, the model is under a positive tensile stresses that are localized at the axis of the installed implants and are spreading to the surrounding bone tissue.

Comparing the distribution of internal stresses in the supporting implant, it should be noted that the maximum values are almost identical and are located in the superstructures. The zone of maximum values of internal stresses is more significant in the area of the implant in the first molar.

Significant and persistent stresses in the superstructure and the cervical region can lead to impaired circulation, which in turn will lead to the change of stability of the implant and the development of chronic inflammatory process. Alveolar part in the area of the intermediate part of bridge prosthesis is under a slight tension.

In the graphs of the distributions of internal stresses (Figure 6), notice the surge in the field of implants both in the deep and superficial layers of the model.

In the implant that is installed in the region of the first molar in the surface layers, the internal stress is 1.96 times higher than in the deeper layers of the model. In the implant that is installed in the region of the first premolar in the surface layers, the internal stress is 2.10 times higher than in the deeper layers of the model.

Comparing the internal stresses in the implant, it should be noted that in the region of the first molar the tension is 8.9% higher than in the implant installed on the site of the first premolar in the surface layers and is 16.7% higher than in the deeper layers of the model.

Comparing the distribution of internal stresses in the implants in the study of models exposed to a distributed chewing load, it can be noted that in the model with the receptive surface the internal tension on three teeth in the implant placed at the site of the first molar in the surface layers is 56.36% higher than in the model with distributed load on five teeth. In the deeper layers of the model in the field of the same implant the internal tension is 32.14% higher than in the model with distributed load on five teeth.

Internal stresses in the implant in the first premolar in the study of the distributed masticatory load on three teeth in the surface layers are 54.45% higher than in the study of the same implant in a model with a load on five teeth. In the deeper layers of the model in the region of the implant, the internal tension is 33.33% higher than in the study of model with a distributed load on five teeth.

Thus, when studying the distribution of internal stresses in the implants it should be noted that in the initial stage (concentrated load) an implant in the region of the first molar experiences the maximum internal stresses, which is almost twice the values in the next stage of the study (distributed load).

As shredding of chewing food increases the surface and the number of teeth involved in the process of eating, thus the internal stresses in the studied implant are reduced and the difference becomes three times higher between the initial and the final stages of mastication.

Conclusions

The implant that is installed on the site of the first premolar in the initial stage (concentrated load capacity) experiences a minor internal stress, and during chewing, and due to the increasing of the area of the chewing surfaces, the internal stresses accumulate to a great extent with the participation of three teeth in chewing; a further increase in chewing surface leads to a decrease in stress values. Thus, in the system of implants, which support dentures, the weak link is the support on the site of the first molar.

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