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APPLICATION OF BIOMECHANICAL MODELING TO OPTIMIZE CONSTRUCTIONS OF DENTAL CROWNS, PROSTHESES AND IMPLANTS

G.I. Rogozhnikov[*], Y.I. Nyashin[**], E.V. Suvorina[*], O.I. Dudar[**], M.Y. Nyashin[**], V.L. Sochnev[*], A.S. Butorin[*], N.B. Astashina[*], R.A. Letyagina[*], G.S. Byakova[*]

[*] Perm State Medical Academy, 39, Kuybishev Street, 614000, Perm, Russia
[**] Perm State Technical University, 29a, Komsomolsky Prospect, 614600, Perm, Russia

Abstract: In this paper, some results of biomechanical modeling which really helped in orthopedic dentistry practice are described. Such approach made possible optimizing several constructions of dental crowns, prostheses and implants.

Key words: dental biomechanics, crown, prosthesis, implant, optimization, finite element method

Introduction

Over many years there was mainly an empirical approach to choosing constructions of different dental devices and appliances. The development of natural sciences made it possible to use mathematical modeling on the stage of choosing devices and appliances for individual patients. The aim of this paper is to briefly review some results which were obtained and applied in clinics by Perm engineers (Department of Theoretical Mechanics of Perm State Technical University) and dentists (Orthopedic Dentistry Department of Perm State Medical Academy) during their collaboration [1-7]. Here several problems concerning optimizing constructions of dental crowns, prostheses and implants are discussed.

Optimal design of metal-ceramic crown

In this part of investigations, the causes of the metal-ceramic premolar crown failure in the process of its functional application were studied. We showed with the help of the finite element analysis two following facts. Firstly, the residual stress field arising after the dental drilling in the cooled crown because of various physical material properties turned out to be the main cause of the crown ceramics failure. Secondly, the residual and thermal stresses due to the cold water drinking appeared to be the most dangerous combination.

Having solved the problem of the crown structure optimal design we found the ways to decrease the maximum principal stress magnitude. These ways are the suitable choice of the shape and thickness of the crown's metal frame and the substitution of the initial cobalt-chrome alloy frame by the less stiff titanium alloy one.

As a result the maximum tensile stress in ceramic crown seemed to be 2.6 times less than that in the initial crown and to equal only 75 % of the tensile strength.

Investigation of the functional stress in dental crown restored by titanium inlay

Distinctions in stress states of sound teeth and teeth restored by titanium inlays were analyzed. The finite element method was used to study this problem. Five cases of restoration and three types of loading were considered. The following results were obtained.

1. The stress state of restored tooth was less uniform than that of sound tooth.

2. Thermal loading was more dangerous in comparison with force loading. The case of the inlay cooling down was found to be the most dangerous one. It is possible to reduce the maximum stress level by using restoration with the thick cement layer or using the metal-composite restoration.

3. In the case of force loading the increase of the inlay's radius and decrease of the inlay's height raise the maximum tensile stress in the enamel and reduce the maximum tensile stress in the dentin. In the case of thermal loading the increase of the inlay's sizes raises the maximum tensile stress both in the enamel and dentin.

4. The application of inlays with inclined walls to tooth restoration raises the maximum tensile stress both in the dentin and enamel. Consequently, the classical cavity preparation with parallel walls is more acceptable than preparation with inclined ones.

5. The increase of cement layer's thickness reduces a level of dangerous tensile stress in the enamel. The cement acts as a soft layer and smoothes out a stress concentration.

Optimization of the construction of removable denture with magnetic fixative

We have developed a construction of the removable denture with the magnetic fixative. It should be emphasized that both teeth used as support for fixation of any prosthesis and the surrounding tissues are subjected to increased loads since they carry load acting on the denture's basis. The bed of a denture bears a part of this load. It, in turn, leads to deformation of the gingiva's mucous membrane and disorder of blood supply in this tissue. Then blood supply is impaired or even terminated in the surrounding alveolar bone which by the way bears most of the applied load and alveolar bone remodeling occurs. Eventually the height of the alveolar process decreases and as a consequence a tooth mobility is enhanced markedly.

The finite element method calculations show that the use of the developed construction denture leads to an increased load on the tissues around the denture (such situation takes place with the use of any denture). However the stress and displacement distributions in the tooth's root and surrounding tissues are similar to ones in the sound tooth and around it.

This is because one of the features of the developed construction in contrast to for example the construction developed by M. Schwab. We have modified the form of the denture's cup. Such a modification eliminates movement of the magnetic fixative's surface with respect to the cup's surface. Owing to this the overloading of the gingiva decreases.

So the developed denture's construction allows us to considerably reduce probability of ischemia of the gingiva's mucous membrane, alveolar bone atrophy and in consequence tooth mobility increase.

Optimal construction of titanium basis of laminar removable denture

One of the important aims of prosthetics is development of a thin strong basis of the removable denture. At this point in our research 3 bases made from titanium alloy VT1-00 were considered, namely 0.3 mm thick basis; 0.16 mm thick basis; 0.16 mm thick basis reinforced by 0.28 mm thick plate.

The obtained numerical results show that in all the cases the stress intensity and the associated equivalent stress peaked in the osteosuture zone. Moreover the most optimal construction of the basis was determined.

Determination of the rational construction of the clasp prosthesis for patients with terminal defects of the dental arch

The optimal design problem of the clasp prosthesis structure in the most unfavorable case of marginal tooth defect was formulated. The maximum magnitude of the resultant moment of forces acting on the most loaded abutment tooth for the occlusional loading cycle was chosen as the criterion of optimality. A behavior of the mucous membrane – clasp prosthesis – abutment teeth system was analyzed with the help of the finite element method. The model gave an opportunity to compare (in correspondence with the criterion of optimality) different structures of clasp prostheses and different materials from which the prostheses were made.

Study of the "Uglecon-M" composite material as a material for implantation

The dental implants are produced from different materials. In this study, the implant made from "Uglecon-M" (material developed by Ural Institute of Composite Materials, Perm, Russia) was taken into consideration. The mathematical model consisted of the cylindrical implant with the artificial crown, the cortical and spongy bones and the mandibular canal was created. The width of the alveolar process allows the use of the cylindrical implant in diameter up to 5 mm. In calculations, the implants with diameters of 3 mm and 5 mm were studied, their lengths being 20 mm.

The following results were obtained. The stress in both the implant and the surrounding tissues essentially depended on the implant's diameter and decreased as the implant's diameter increased.

Under the maximum functional loads, the stress in the implant with diameter of 3 mm was close to the strength limit of "Uglecon-M". Moreover the stress in the cortical bone around the implant's neck was even in excess of the strength limit of the cortical bone. It is in this zone that resorption of bone around the used cylindrical implants made from titanium is observed.

The stress in both the implant with diameter of 5 mm and the surrounding bone were significantly below the respective strength limits. Therefore the implants with diameter of 5 mm which are made from "Uglecon-M" may be used as solitary supports, whereas the implants which are smaller in diameter would be appropriate for use as intermediate supports for dental prostheses.

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ОПТИМИЗАЦИЯ КОНСТРУКЦИЙ ЗУБНЫХ КОРОНОК, ПРОТЕЗОВ И ИМПЛАНТАТОВ С ИСПОЛЬЗОВАНИЕМ МЕТОДОВ БИОМЕХАНИЧЕСКОГО МОДЕЛИРОВАНИЯ

Г.И. Рогожников, Ю.И. Няшин, Е.В. Суворина, О.И. Дударь, М.Ю. Няшин, В.Л. Сочнев, А.С. Буторин, Н.Б. Асташина, Р.А. Летягина, Ж.С. Бякова
(Пермь, Россия)

На протяжении многих лет в ортопедической стоматологии существовал эмпирический подход к выбору конструкций ортопедических аппаратов. Развитие современной науки дало возможность проектирования оптимальных ортопедических конструкций с использованием методов биомеханического моделирования. В данной работе приведен обзор результатов части совместных биомеханических исследований сотрудников кафедры теоретической механики Пермского государственного технического университета (заведующий – профессор Ю.И. Няшин) и кафедры ортопедической стоматологии Пермской государственной медицинской академии (заведующий – профессор Г.И. Рогожников). Эти исследования посвящены оптимальному проектированию различных зубных коронок, протезов и имплантатов. Библ. 7.

Ключевые слова: биомеханика зубочелюстной системы, коронка, протез, имплантат, оптимизация, метод конечных элементов

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