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Stress in the bone and prosthetic components due to "All-on-4" system with polyether-ether-ketone screwing prosthesis. Analysis using 3D finite element method

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SUMMARY

Objective. To identify and analyze distribution of bone stress in the implant area using a PEEK prosthesis fixed on four dental implants depending on different positions of the functional loading point on a cantilever in a 3D modeled system.

Material and methods. The fragment of the lower jaw with dental implants and over-the-implant prosthetic part was represented by geometrical 3D models and diagonal loads were placed on the distal cantilever of the prosthesis. 3D models were exported to SolidWorks® Student Edition 2018 (Dassault Systemes SE, France) software. Average von Mises stress around the outer perimeter of the implant was measured in MPa. Relative stress was identified using a graded color scale in relative units. A 0.95 confidence level (P), 0.05 significance level (p), maximum error of 10% (Δ) were set. The data was analyzed using Statistical Package for Social Sciences® (IBM, Armonk, USA) version 137.

Results. The distal implant on the same side as the point of loading receives 45.01-53.88% of all forces created. Stress at the frontal implants is distributed almost evenly. The pair of implants on the same side of the loading force suffers 66.38-74.68% of all forces. The implant on the opposite side of the loading force receives the smallest stress which is hardly influenced by the length of the console.

Conclusion. A full arch restoration in an edentulous lower jaw using a four-implant fixed PEEK prosthesis system generates unevenly distributed internal stress in the bone next to the implants but does not go over the critical resistance of the bone.

Key words: edentulous mandible treatment, dental implants, polyetheretherketone, bone stress, finite element analysis.

INTRODUCTION

Full adentia remains a relevant and current problem (1, 2). Full removable dentures – a solution to this problem for many years, are being replaced by a stable and providing undisputedly more masticatory comfort prosthesis fixed on four or six dental implants. It is common for the four implants to be positioned in the frontal part of edentulous jaw (3, 4). In such systems the most often used metal construction materials have excellent physico-mechanical survival and good biocompatibility (3, 5, 6). Polyether-ether ketone (PEEK), analogous to metals due to its biocompatibility and approximately as stable, also closely resembling bone due to its elasticity and lightweight, is used in traumatology (7, 8) and is becoming increasingly more popular in odontology for fixed prostheses on implants (5, 6). PEEK is known to be biocompatible and bioinert in hard and soft tissues when present as a bulk form. PEEK is chemically inert with a hydrophobic surface; it does not readily allow protein adsorption on its surface. An inert biomaterial has no adverse reaction or release of ions or constituents (9). The effect of supraconstructions tensions in the bone is currently a topic of interest (10, 11). The aim of work was to identify and analyze distribution of bone stress in the implant area using a PEEK prosthesis fixed on four dental implants depending on

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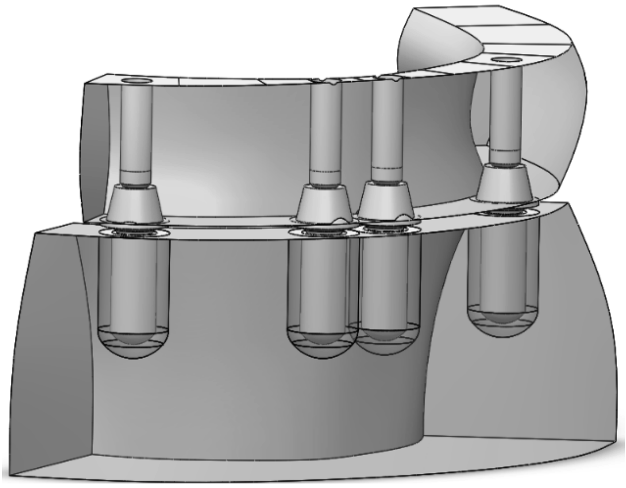

Fig 1. Finite element method model of lower jaw with dental implants and prosthesis from PEEK fixed on four implants

different positions of the functional loading point on a cantilever in a 3D modeled system.

MATERIAL AND METHODS

The fragment of the lower jaw with dental implants and over-the-implant prosthetic part was represented by geometrical 3D models (Fig. 1) and diagonal loads were placed on the distal cantilever of the prosthesis. 3D models were exported to SolidWorks® Student Edition 2018 (Dassault Systemes SE, France) software in Kaunas University of Technology. The research was conducted after received a permit from LSMU Bioethics Center (protocol No. BEC-OF-81).

Description of the analyzed 3D system

- Fragment of the lower jaw between mental foramens.
- Implant placement in the area of 34, 31, 41, 44 teeth; cylindrical shape, Ø 3.5 mm, 8 mm length, contact point reduced by not modelling outer and inner threads.
- Angle of implant abutment patrix slope is 15°.
- Screw for fixation of prosthesis is without threads. Other parameters match those of the abutments.
- The system elements uniformly connected in the thread areas and not connected in fixation screw – prosthesis and abutment – prosthesis areas.
- 1 mm of periimplant bone.
- Width and height of bridge type PEEK dental prosthesis: 10×2.2 mm in the front teeth and 10×9.5 mm in the back teeth area, cantilever in 35, 36, 37 teeth area.
- Occlusal plane is divided and marked analogous to standard teeth lengths.
- Single sided fragment force of 100N acting on 35, 36 and 37 teeth separately at an angle of 75° on the occlusal plane.
- For tendency verification results were calculated changing only the size of the grid of the finite elements around the distal implant. Case 1: 0.25-0.5 mm; Case 2: 0.15-0.5 mm.

Table 1. Characteristics of materials based on “SolidWorks®” database of material specifications and scientific data (12, 13)

Material, structure	Elastic modulus (E), Gpa	*Poisson‘s* ratio (ν)
Bone	10.63	0.313
Bone around the implant	12.51	0.313
Titanium, implant‘s parts	110	0.3
PEEK dental prosthesis	3.9	0.4

Test conditions

Based on “SolidWorks®” database of material specifications and scientific data (12, 13) biomechanical properties were specified for implants and prostheses construction parts and bone tissue (Table 1).

The materials were assumed to be homogenous, isotropic and uniformly elastic, the osseointegration of the implant was even over the full length of the implant, all materials of the system fitted close together with each other.

Evaluation of data:

In the area of the implant, average von Mises stress around the outer perimeter of the implant was measured in MPa. Relative stress was identified using a graded color scale in relative units (Fig. 2). A 0.95 confidence level (P), 0.05 significance level (p), maximum error of 10% (Δ) were set. The data was analyzed using Microsoft® Excel® (Microsoft® Corporation, Redmond, USA) and Statistical Package for Social Sciences® (IBM, Armonk, USA) version 137.

RESULTS

Bone stress in the implant area of the prosthesis was evaluated in the analysed system while changing the length of the cantilever (Table 2). The implant closest to the point of loading receives the highest load. The distal implant on the same side as the point of loading, depending on the exact point loading, receives 45.01 – 53.88% of all forces created. Stress at the frontal

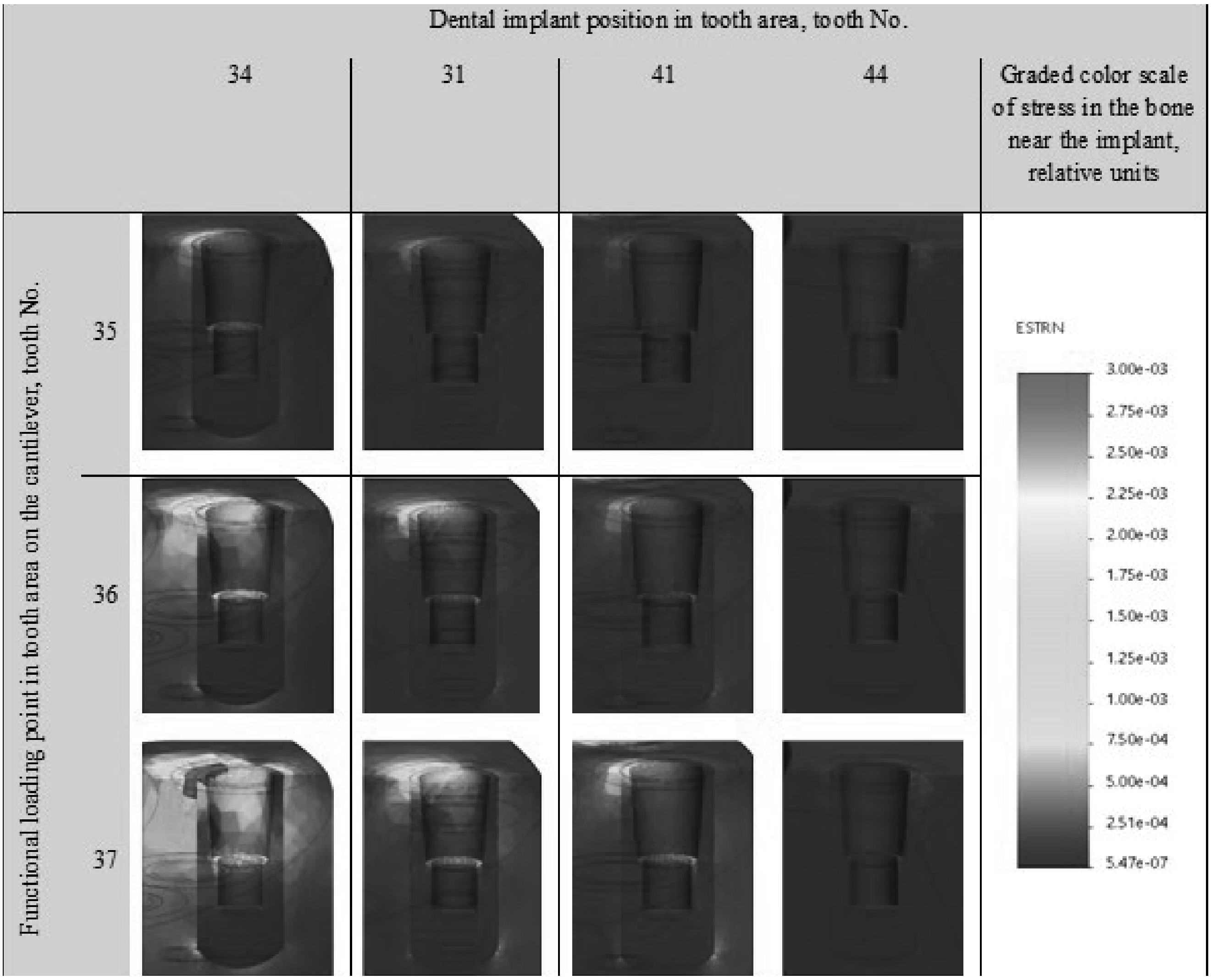

Fig 2. Distribution of stress in the bone near the implants during functional loading on the different point of cantilever (SolidWorks® Student Edition 2018)

implants is distributed almost evenly, a bigger part is received by the implant on the same side as the loading. The pair of implants on the same side of the loading force suffers 66.38 – 74.68% of all forces. In the modelled system, the implant on the opposite side of the loading force receives the smallest stress which is hardly influenced by the length of the console.

Table 2. Average of the stress in the bone with full arch lower jaw PEEK prosthesis fixed on four implants by different cantilever length during functional load

	Point where occlusal force was loaded on the cantilever, tooth No.	**Average Von Mises bone stress near all the implants ± standard deviation, MPa**	
		Case 1 (grid 0.25–0.5 mm)	**Case 2 (grid 0.15–0.5 mm)**
	35	4.92±2.67	5.19±2.92
	36	10.50±7.83	11.37±9.20
	37	18.24±14.72	20.24±17.82
Difference of averages	35-36	5.59	6.18
	36-37	7.74	8.87
	35-37	13.33	15.05

DISCUSSION

This study is the first one that analyzes the distribution of bone stress in the implant-fixed prosthesis on four dental implants area, when the prosthesis is made from PEEK material, thus there is no possibility to compare the obtained results from this study with analogous results from other studies.

Results from other authors' study (14), conducted two years ago, where the all-on-4 prosthesis was made from titanium and implants were positioned vertically, show that the frontal implant and its associated components on the same side as the point of loading receive the highest stress in the bone, on the contrary, it was the distal implant on the same side in our study. One may assume that PEEK, which is more elastic than titanium, influences the different distribution of bone stress. Although in another study (15), conducted this year, where the rigid monolithic zirconia prosthesis was fixed on four implants, the highest stress was received by the distal implant on the loading side as in our study, stress near the distal implant decreased when extending the cantilever, meanwhile in our study the result was opposite.

After summarizing other authors' and our results it may be possible to establish that construction material of the prosthesis could be related to the distribution of bone stress near the implant in an all-on-4 system, but this cannot be confirmed because of inhomogeneous conditions of the studies.

CONCLUSIONS

This study has shown that the finite element model is an effective method for virtual analysis of stress distribution while modelling the distribution of forces, which is practically impossible in a clinical environment, and would be beneficial for further analysis of distribution of stress and changes of load in a bone-implant-supraimplant construction from PEEK and/or other materials in different scenarios.

The conclusion of the study – a full arch restoration in an edentulous lower jaw using a four-implant fixed PEEK prosthesis system generates unevenly distributed internal stress in the bone next to the implants but does not go over the critical resistance of the bone.

STATEMENT OF CONFLICTS OF INTEREST

The authors state no conflict of interest.

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