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Biomechanical analysis of plate stabilization on cervical part of spine

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ABSTRACT

Purpose: The main aim of the work was determination of biomechanical analysis of cervical spine – stabilizer system made of stainless steel (Cr-Ni-Mo) and Ti-6Al-4V alloy.

Design/methodology/approach: To define biomechanical characteristic of the system the finite elements method (FEM) was applied. Geometric model of part of spine C5-C7 and stabilizer were discretized by SOLID95 element. Appropriate boundary conditions imitating phenomena in real system with appropriate accuracy were established.

Findings: The result of biomechanical analysis was calculation of displacements and stresses in the vertebras and the stabilizer in a function of the applied loading: 50-300 N for the stabilizer made of stainless steel (Cr-Ni-Mo) and Ti-6Al-4V alloy.

Research limitations/implications: The result of biomechanical analysis for plate stabilizer obtained by FEM can be use to determine a construction features of the stabilizer, and to select mechanical properties of metallic biomaterial and estimation of stabilization quality. The calculation of displacements for part C5-C7 show that the proposed type of stabilizer enables correct stabilization used to clinical apply.

Practical implications: The results of biomechanical analysis showed correct mechanical properties used to made the plate stabilizer.

Originality/value: The obtained numerical results should be verified in “in vitro” tests.

Keywords: Numerical techniques; Biomechanical analysis; Metallic materials; Biomaterials

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

The spine is fundamental part of human skeleton. With the pelvis bones carried loads for legs. In cooperation with chest and shoulder girdle participation in hand movement. It is support for head. It is protecting for the spinal cord [1, 2].

The cervical part of spine have 7 vertebras. Cervical spondylosis as reduction of water content in an intervertebral disc, leading to change of its height thus being conducive to slip, is caused by mobility of this part of spine [2].

The spine is subjected to very complex and variable mechanical loads, especially during movement. Correct distribution of loads in a spine ensures correct formation of osteoarticular system [3].

Increasing tendency of diseases and dysfunctions of spine, caused mainly by car or sport accidents, explains the purposefulness of research on operative treatment of spine diseases. The treatment is mostly realized with the use of metallic implants.

The selection of appropriate treatment is conditional upon the following factors: type of damage, mechanism of injury, presence and type of complications, accompanying damage, coexisting diseases, age of patient [1].

The plate stabilizer system of spine enables treatment of cervical and lumbar part of spine by anterior surgical approach. Geometry and size of spinal implants are suitable for treatment of different diseases and for patients in different age [1, 2].

2. Material and methods

System of plate stabilization of spine in the cervical segment implanted by means of anterior surgical approach was analyzed. Spine's stabilizer consists of bone screws and plate – Fig. 1.

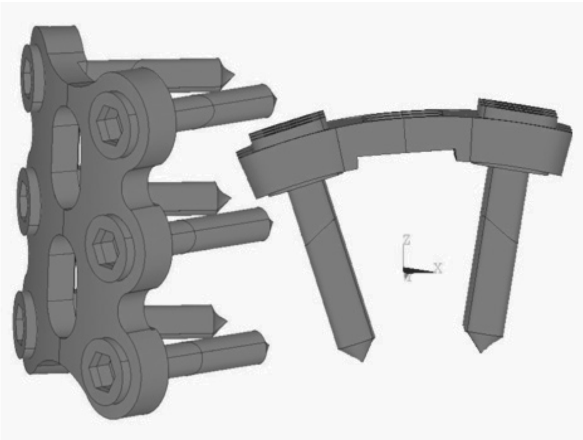

Fig. 1. Spine's plate stabilizer

Stabilization of three vertebras of cervical part of spine (C5 – C7) was analyzed in the work – Fig. 2. Geometrical model of cervical spine was prepared on the basis of data obtained from computer tomography of a real spine.

Model of stabilizer was modified with use of the ANSYS program for realized calculations. The mechanical properties for analysis were as follows [4-18]:

- for Cr-Ni-Mo steel: $E = 2 \cdot 10^5$ MPa, $\upsilon = 0.33$,
- for Ti-6Al-4V alloy: $E = 1{,}06 \cdot 10^5$ MPa, $\upsilon = 0.33$,
- for vertebras: $E = 1{,}15 \cdot 10^4$ MPa, $\upsilon = 0.30$,
- for intervertebral discs: $E = 110$ MPa, $\upsilon = 0.40$.

In next step of the analysis the model was meshed. Meshing was realized with the use of SOLID 95 element – Figs. 3, 4.

In order of carry out calculations it was necessary to evaluate and estabilish initial and boundary conditions (Fig. 5) which imitate phenomena in real system with appropriate accuracy. The following assumptions were estabilished:

- the seventh vertebra part of cervical spine was immobilized (all degrees of freedom of surface nodes were taken away). It enabled displacements at last cervical vertebrae, blocking possible rotation,
- the first cervical vertebra was loaded with forces F: 50 N, 100 N, 150 N, 200 N, 250 N, 300 N on whole surface,
- in fifth, sixth and seventh vertebra the spine stabilizer was implanted according to the operating technique.

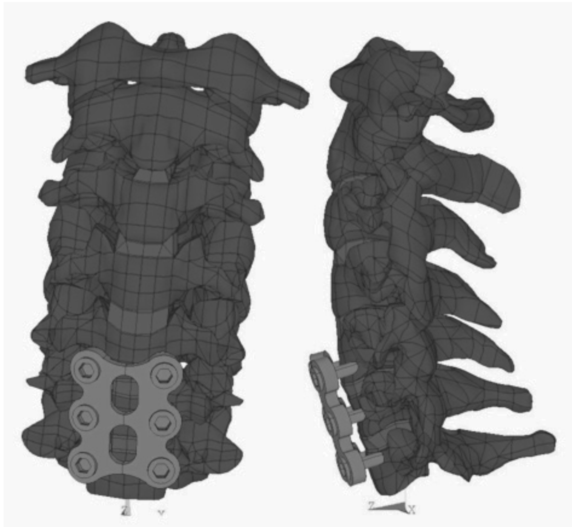

Fig. 2. Geometrical model of cervical spine – plate stabilizer system

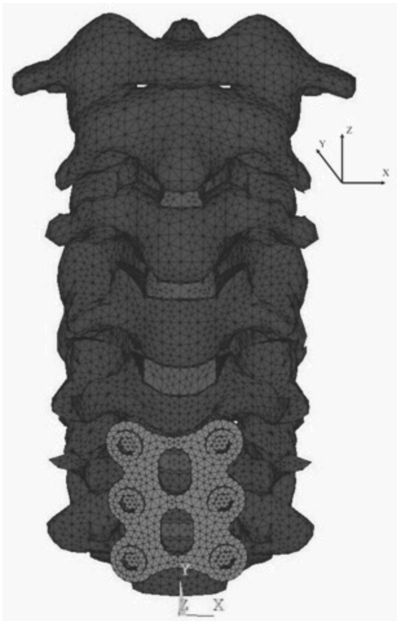

Fig. 3. Meshed model with use of SOLID 95 element

The scope of the analysis included determination of displacements and stresses:

- in the vertebras (C5 – C7) – stabilizer system made of Cr-Ni-Mo steel,
- in the vertebras (C5 – C7) – stabilizer system made of Ti-6Al-4V alloy.

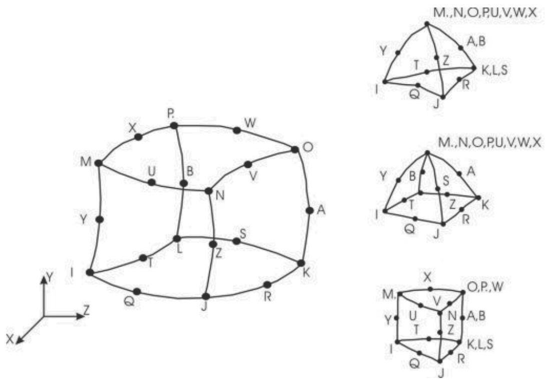

Fig. 4. Geometrical SOLID 95 element

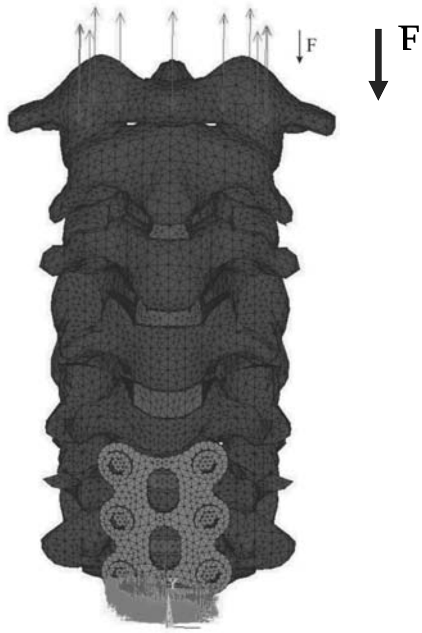

Fig. 5. Meshed model with boundary conditions and loads

Stresses and displacements obtained in the analysis are equivalent values according to the Huber – Misses hypothesis.

3. Results

Results Results of the analysis carried out for the part of cervical spine – plate stabilizer system (made of Cr-Ni-Mo steel) are presented in Table 1 and 2 and Figs. 6-12.

On the basis of the analysis it was affirmed that maximum equivalent stress was equal to 22 MPa for the forces of 300 N – Fig. 6. The maximum stresses were localized in the assembly hole of the stabilizer. Maximum stresses occurred in the middle and in the lower part of stabilizer (in C6 and C7 vertebras)

Maximum equivalent stresses in the screws were equal to 22 MPa – Fig. 7 and were localized in the middle part of the screws (in C6 vertebra).

Table 1.
Maximum equivalent stress values evaluated for the part of cervical spine – plate stabilizer made of Cr-Ni-Mo steel

Load, N	Stabilizer	Vertebras C5-C7	Screws	Intervertebral discs: C5-C6, C6-C7
	Stress, MPa			
50	4	2	4	0.06
100	7	4	7	0.13
150	11	5	11	0.19
200	15	7	15	0.26
250	19	10	19	0.32
300	22	12	22	0.38

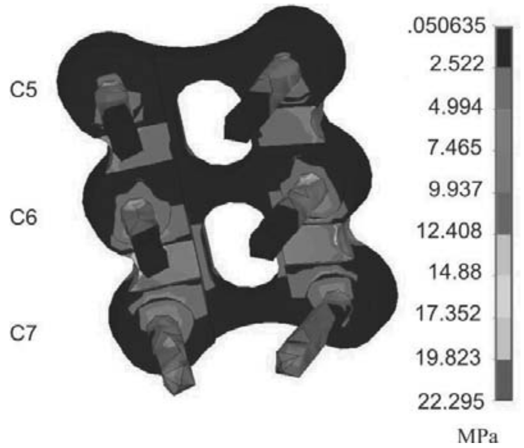

Fig. 6. Equivalent stresses in spine's plate stabilizer loaded with the force 300 N

Maximum equivalent stresses for plate stabilizer and screws were comparable.

Maximum equivalent stresses in C5-C7 vertebras loaded with the force 300 N were equal 12 MPa. The maximum stresses were localized in the assembly hole of the stabilizer (in C7 vertebra)-Fig. 8.

Maximum equivalent stresses in the intervertebral discs loaded with the force 300 N equal to 0.38 MPa – Fig. 9. Stress was localized in lower intervertebral disc, between C6 and C7 vertebras.

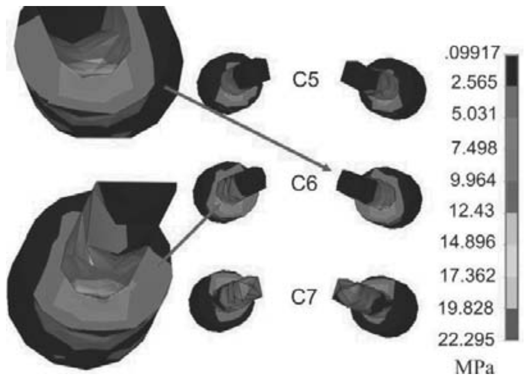

Fig. 7. Equivalent stresses in the screws loaded with the force 300 N

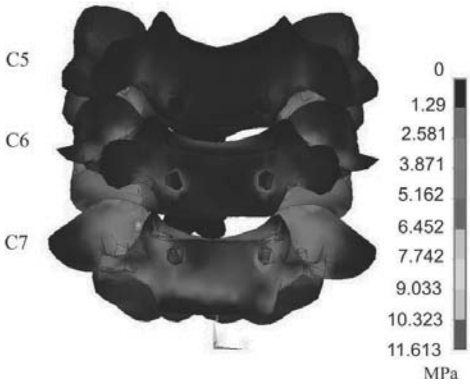

Fig. 8. Equivalent stresses in the vertebras (C5 – C7) loaded with the force 300 N

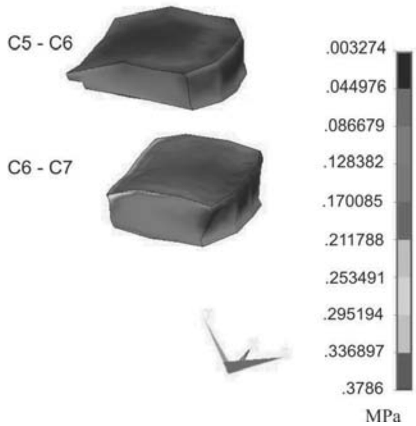

Fig. 9. Equivalent stresses in the intervertebral disc loaded with the force 300 N

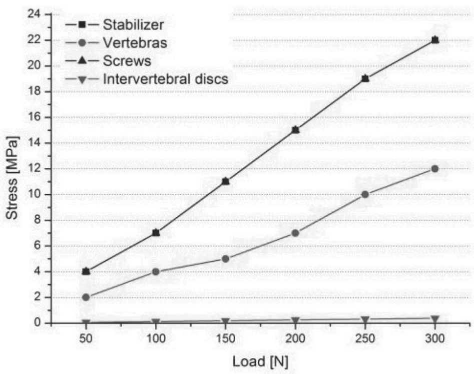

Fig. 10. Relations between maximum equivalent stresses and the part of cervical spine – plate stabilizer system as a function of the applied loading

Relative displacement in the OX axis was 0.004 mm and it was insignificant – Fig. 11 a. It was localized in the upper part of stabilizer (C5).

Relative displacement in OY axis was 0.015 mm and was localized on the part C5 too – Fig. 11 b.

Table 2.
Relative displacements of spine's stabilizer for different loads and directions

Load, N	Displacement, mm		
	OX	OY	OZ
50	0.001	0.003	0.003
100	0.001	0.005	0.005
150	0.000	0.006	0.004
200	0.001	0.008	0.006
250	0.003	0.013	0.013
300	0.004	0.015	0.015

Displacement in the gap calculated along the OZ axis, for the applied force was 0.015 mm – Fig. 11 c and it was localized in the left corner of stabilizer, on the part C7.

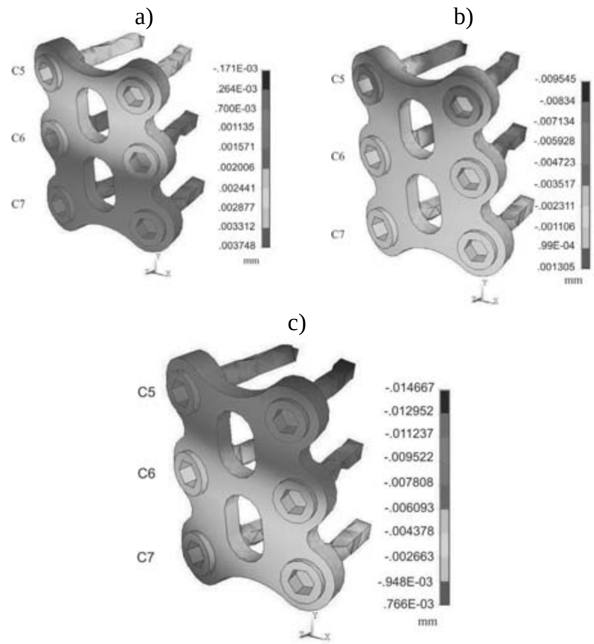

Fig. 11. Displacements in the spine of stabilizer loaded with the force 300 N: a) OX axis, b) OY axis, c) OZ axis

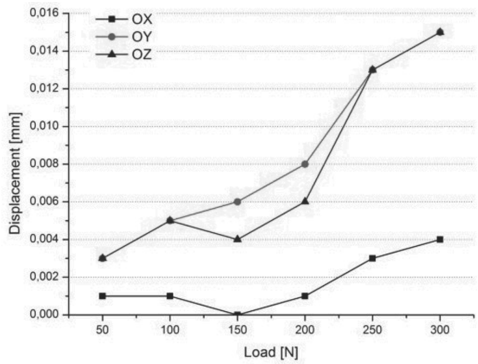

Fig. 12. Relations maximum relative displacement of plate stabilizer as a function of the applied loading

Results of the analysis carried out for the part of cervical spine – plate stabilizer system (made of Ti-6Al-4V alloy) are presented in Tables 3 and 4 and Figs 13-19.

On the basis of the analysis it was affirmed that maximum equivalent stress was equal to 14 MPa for the forces of 300 N – Fig. 13. The maximum stresses were localized in the assembly hole of the stabilizer. Maximum stresses occurred in the middle part of the stabilizer (in C6 vertebra).

Maximum equivalent stresses in screws were 14 MPa – Fig. 14, and were localized in the middle part of screws too (in C6 vertebra).

Maximum equivalent stresses for plate stabilizer and screws were comparable and were 14 MPa.

Table 3.
Maximum equivalent stresses values evaluated for the part of cervical spine – plate stabilizer made of Ti-6Al-4V alloy

Load, N	Stabilizer	Vertebras C5-C7	Screws	Intervertebral discs: C5-C6, C6-C7
	Stress, MPa			
50	2	2	2	0.07
100	5	5	5	0.14
150	7	5	7	0.20
200	9	7	9	0.27
250	12	9	12	0.34
300	14	11	14	0.41

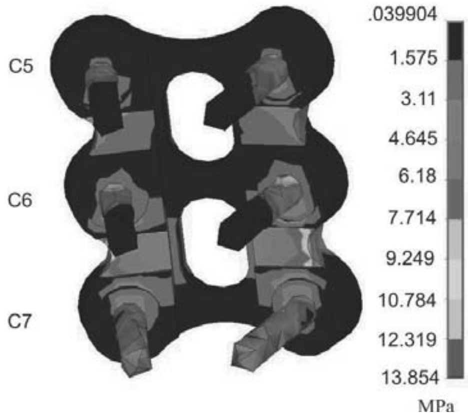

Fig. 13. Equivalent stresses in spine's plate stabilizer loaded with the force 300 N

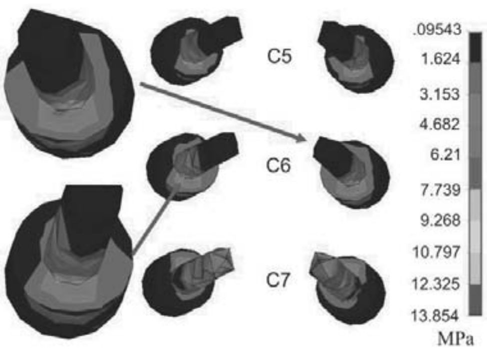

Fig. 14. Equivalent stresses in screws loaded with the force 300 N

Maximum equivalent stresses in C5 – C7 vertebras loaded with the force 300 N were 11 MPa and they were localized near the whole, which moved in screw (in C7 vertebra) – Fig. 15. Maximum equivalent stresses in the intervertebral discs loaded with the force 300 N equal to 0.41 MPa – Fig. 16. Stress was localized in lower intervertebral disc, between C6 and C7 vertebras.

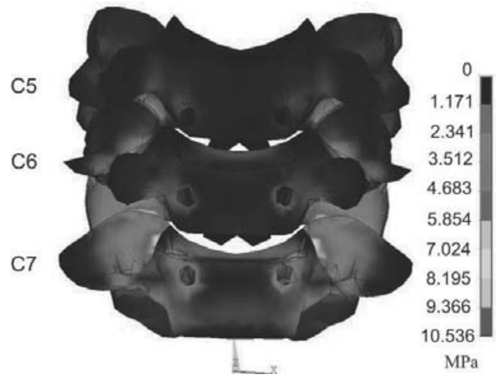

Fig. 15. Equivalent stresses in vertebras (C5-C7) loaded with the force 300 N

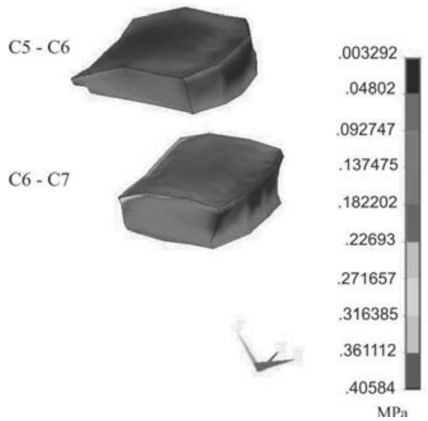

Fig. 16. Equivalent stresses in intervertebral discs loaded with the force 300 N

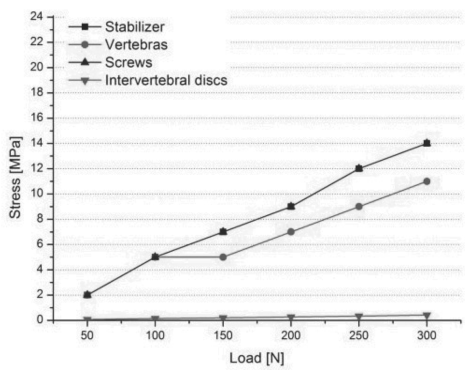

Fig. 17. Relations between maximum equivalent stresses and the part of cervical spine – plate stabilizer system as a function of the applied loading

a) b) c)

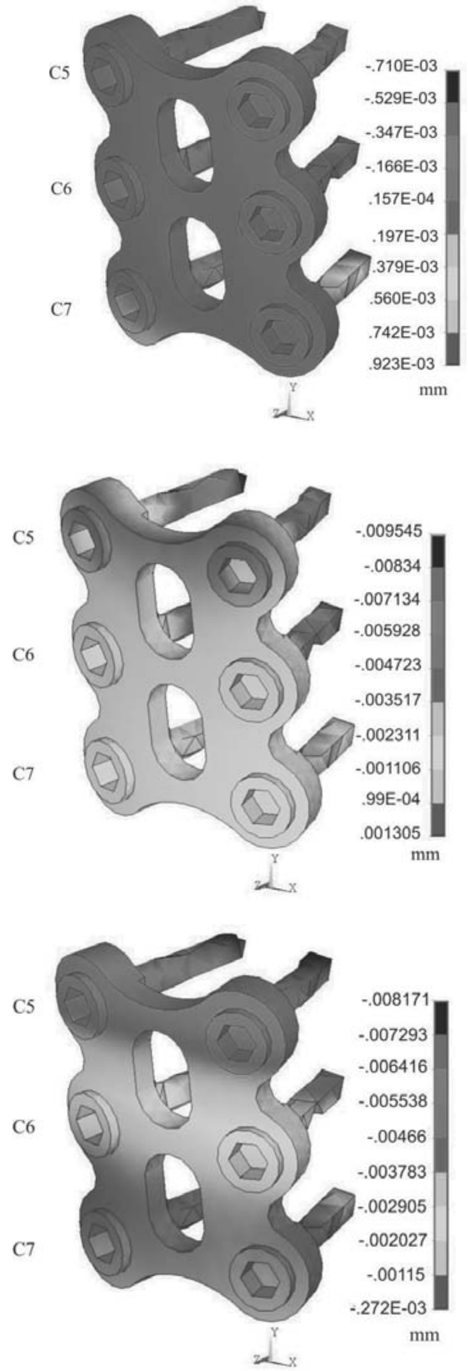

Fig. 18. Displacements in the spine of stabilizer loaded with the force 300 N: a) OX axis, b) OY axis, c) OZ axis

Relative displacement in the OX axis was 0.002 mm and it was insignificant – Fig. 18 a. It was localized in the lower part of stabilizer in the end of screw (C5).

Relative displacement in OY axis was 0.011 mm and was localized in the upper part of stabilizer, on the level C5 vertebra – Fig. 18 b.

Displacement in the gap calculated along the OZ axis, for the applied force was 0.008 mm – Fig. 11c and it was localized in lower part of stabilizer, on the level C7 vertebra.

Table 4.
Relative displacements of spine's stabilizer for different loads and directions

Load, N	Displacement, mm		
	OX	OY	OZ
50	0.001	0.002	0.002
100	0.001	0.005	0.004
150	0.001	0.005	0.004
200	0.001	0.007	0.005
250	0.001	0.009	0.006
300	0.002	0.011	0.008

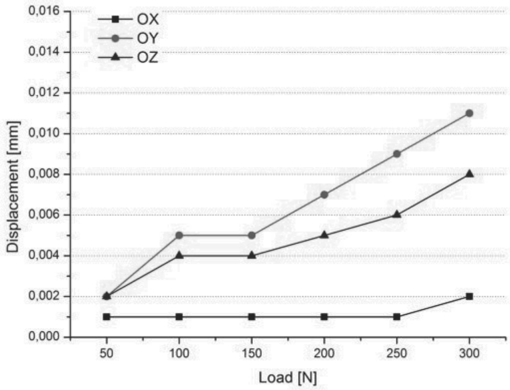

Fig. 19. Relations maximum relative displacement of plate stabilizer as a function of the applied loading

4. Conclusions

The aim of the biomechanical analysis was determination of displacements and stresses for cervical spine – plate stabilizer system. Effective stabilization of part of spine C5 – C7 was the fundamental parameter for flexibility all system for strains applied loading. Registered small difference in displacements in the gap calculated along the OZ axis depended on the applied biomaterial. For stabilizer made of Cr-Ni-Mo steel and Ti-6Al-4V alloy displacements were insignificant and were adequate 0.015 mm i 0.008 mm. Maximum displacements for both biomaterials didn't exceed the value of 0.10 mm, that proves stability and stiffness of the analyzed system.

Maximum equivalent stresses in stabilizer and screws were comparable. They were localized in the assembly hole of the stabilizer. For stabilizer made of Cr-Ni-Mo steel stress was 22 MPa, for stabilizer made of Ti-6Al-4V alloy – 14 MPa. Assembly of the stabilizer in C5 – C7 segment and applying the maximum force of 1600 N does not cause the stress increase in the vertebral segments exceeding the value 160 MPa [3], what is very fundamental factor for correct treatment.

The result of biomechanical analysis for plate stabilizer obtained by FEM are very valuable for determination of construction features of the stabilizer, and to select mechanical properties of metallic biomaterial and degree of strain hardening of the metallic biomaterial. The obtained numerical results should be verified in "in vitro" tests.

Acknowledgements

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