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Numerical and experimental analysis of spine's transpedicular stabilizer

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Analysis and modelling

ABSTRACT

Purpose: The aim of the work was a numerical and experimental analysis of spine's transpedicular stabilizer on lumbar part of spine. The result of the analysis was determination of displacements of the stabilizers' elements.
Design/methodology/approach: To define numerical characteristic of the lumbar spine – transpedicular spine stabilizer system, the finite element method was applied. Geometrical models of lumbar part of spine and transpedicular stabilizer were discretized by SOLID95 element. The boundary conditions imitating phenomena in real system with appropriate accuracy were established. The experimental analysis was carried out for spine's transpedicular stabilizers which were implanted on lumbar part of pig spine. The analysis was realized by means of testing machine MTS Insight with the use of videoextensometer. Numerical and experimental analysis were carried out for stabilizer made of stainless steel Cr-Ni-Mo. System was loaded by uniaxial compression with forces from 50 N to 1600 N.
Findings: The result of analysis was calculation of relative displacements of the transpedicular stabilizer in a function of the applied loading; F = 700 - 1600 N for numerical model and F = 50 - 1600 N for experimental model.
Research limitations/implications: The results of numerical analysis for transpedicular stabilizer obtained by finite element method were used to determine a construction features of the stabilizer, and to select mechanical properties of metallic biomaterial. The calculation of displacements for stabilizer show that the proposed type of stabilizer enables correct stabilization of spine.
Practical implications: Both results of numerical and experimental analysis showed correct selection of mechanical properties of metallic biomaterial which were used to made the proposed type of transpedicular stabilizer.
Originality/value: Advantageous results of analysis showed that the type of stabilizer may be used in clinical practice.
Keywords: Numerical techniques; Biomechanical analysis; Metallic materials; Biomaterials

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1. Introduction

The spine is extraordinary important part of skeleton, which performs three fundamental functions: supporting, protecting (for core and roots of a spinal nerve) and motor activity (thanks to segmental building and to muscles). Its upper part (cervical part) is connecting with braincase. The particular vertebras are connecting with each other by joints, ligaments and intervertebral discs. Movements between vertebras have limited range, however their summation (especially in cervical and lumbar part of spine) gives possibility of significant change of shape, what is very helpful for everyday life. Composed biomechanical functions of spine presents wide spectrum of loading and deformation, which are submitted during movement. Correct distribution of load ensures the proper formation of anatomical characteristic in osteo–muscular system and the correct functioning of spine [1-4].

Increasing tendency of affections and dysfunctions of spine which result from little mobile activity of society, communication injuries, sport activity, especially extreme sports is observed in last years. This tendency is also supported by ageing of population. Medical statistics indicate that the main reason of inefficiency in middle age and older people is a spine pain. About 70-80 % of population are suffering from this reason [1, 2].

Degenerative and overloaded changes are often observed in lumbar part of spine. There is the result of considerable load in this area. Human's centre of gravity is located in lumbar part of spine and maximum loading forces influenced the vertebras and intervertebral discs are observed. About 62 % of pathological changes in the vertebra – intervertebral disc system refers to the L3–L4 segment [4, 5].

Post–injury and pathology state treatment of spine is realized with the use of complex, multicomponent stabilizers and complicated operating procedures [1, 2, 4, 5].

The transpedicular stabilization system of spine enables treatment of thoracic, thoracic – lumbar and lumbar segment of spine by posterior surgical approach. Geometric features of stabilizers' elements match individual anthropometric features of patients [5-7]. These type of implants can immobilize the sick part of spine and let achieve the stable adhesion.

Increasingly the experimental analysis were carried out to verification the numerical analysis [8-11].They are showed the correct mechanical properties used to made the different type stabilizers.

2. Material and methods

2.1. Numerical analysis

System of transpedicular stabilization of spine in the lumbar segment implanted by means of posterior surgical approach was analyzed in numerical analysis. The transpedicular system consists of transpedicular screw, clamp element, nut, contact arm and supporting rod – Fig. 1.

Geometrical model of transpedicular stabilizer was made using Inventor software. A geometrical model of lumbar part of spine was prepared too. Geometrical model of lumbar spine was prepared on the basis of data obtained from computer tomography of a real spine – Fig. 2.

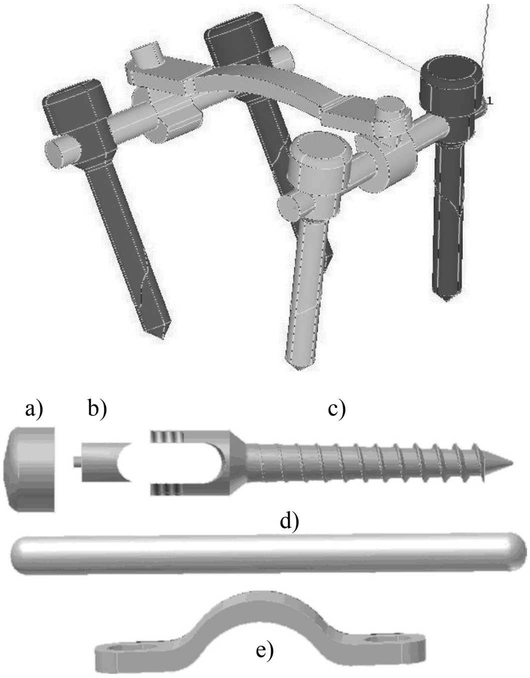

Fig. 1. Geometrical model of transpedicular stabilizer: a) nut, b) clamp element, c) transpedicular screw, d) supporting rod, e) contact arm

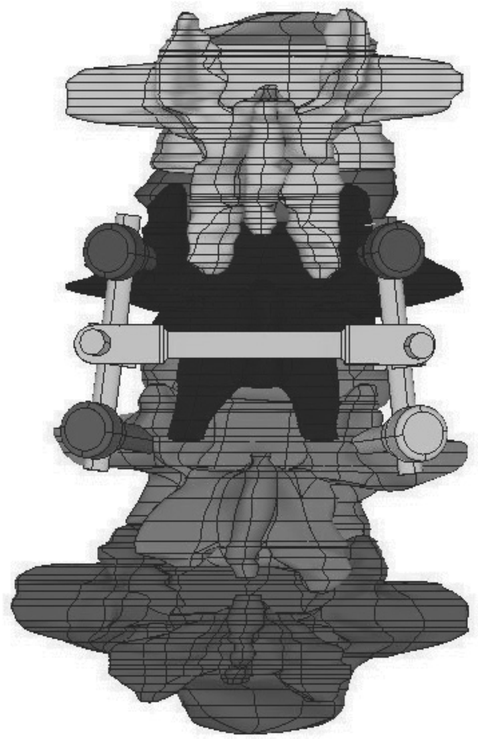

Fig. 2. Geometrical model of lumbar spine – transpedicular stabilizer system

Stabilization of two vertebras of lumbar part of spine (L3 – L4) was analyzed in the work .

The analyzed elements of the system were meshed by means of ANSYS software. Meshing was realized with the use of SOLID 95 element. This type of element is defined by 20 nodes having three degrees of freedom per node (translations in the nodal x, y and z directions) – Figs. 3, 4.

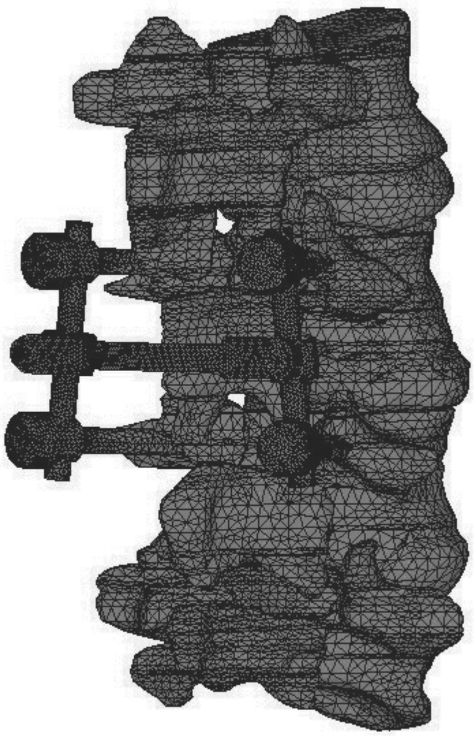

Fig. 3. Meshed model with use of SOLID 95 element

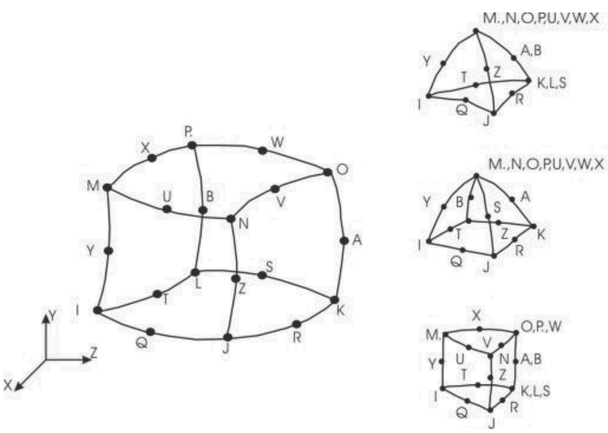

Fig. 4. SOLID 95 geometry

In order of carry out the calculations it was necessary to evaluate and establish initial and boundary conditions which imitate phenomena in real system with appropriate accuracy – Fig. 5.

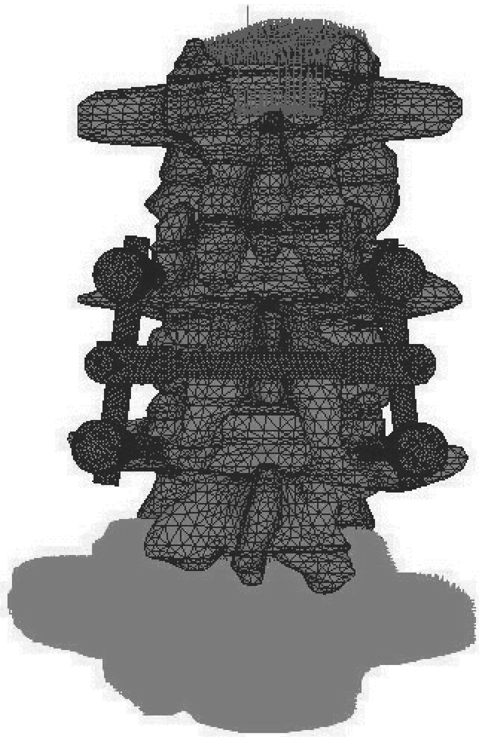

Fig. 5. Meshed model with boundary conditions and loads

The following assumptions were established:

- the fifth vertebra part of lumbar spine was immobilized (all degrees of freedom of surface nodes were taken away). It enabled displacements at last cervical vertebrae, blocking possible rotation,
- the second spine vertebra was loaded with forces F: 700 N, 1000 N, 1300 N, 1600 N on whole surface,
- in the third and fourth vertebra the spine stabilizer was implanted according to the operating technique.

The scope of the analysis included determination of relative displacements of transpedicular screws against supporting rod. Displacements obtained in the analysis are equivalent values according to the Huber – Misses hypothesis. The muscle system of spine was omitted in settlement of boundary conditions. In the effect all the loads and displacements of the parts of spine were carried by stabilizer – vertebras – intervertebral discs system.

The mechanical properties for analysis were as follows [12-23]:

- for Cr-Ni-Mo steel: $E = 2 \cdot 105$ MPa, $\upsilon = 0.33$,
- for vertebras: $E = 1,15 \cdot 104$ MPa, $\upsilon = 0.30$,
- for intervertebral discs: $E = 110$ MPa, $\upsilon = 0.40$.

2.2. Experimental analysis

System of transpedicular stabilization of spine in the lumbar segment implanted was analyzed in experimental analysis. Stabilizer was made of stainless steel Cr-Ni-Mo. The transpedicular system consists of: transpedicular screws, supporting rods, connector – Fig. 6.

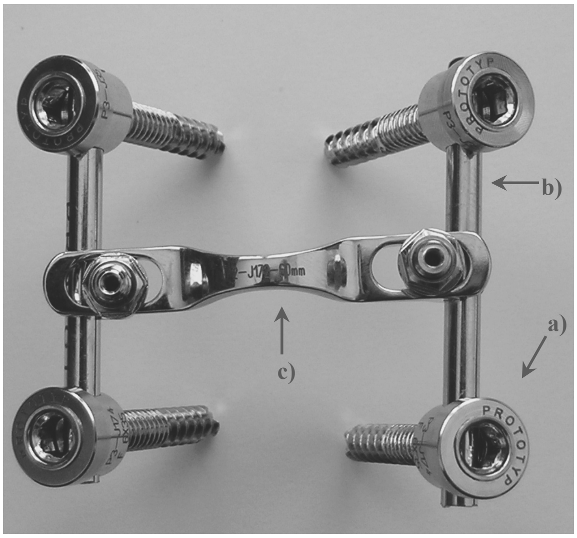

Fig. 6. Transpedicular stabilizer: a) transpedicular screw, b) supporting rod, c) connector

The stabilizer was implanted on lumbar part of pig's spine, which properties correspond with human spine. Six vertebras of pig spine were analyzed. Stabilizer was implanted according to the operating technique by orthopedic surgeon. Stabilization of two vertebras of lumbar part of spine was analyzed.

The analysis was performed with the use of testing machine MTS Insight − Fig. 7. Model was loaded by uniaxial compression with forces 50 N − 1600 N.

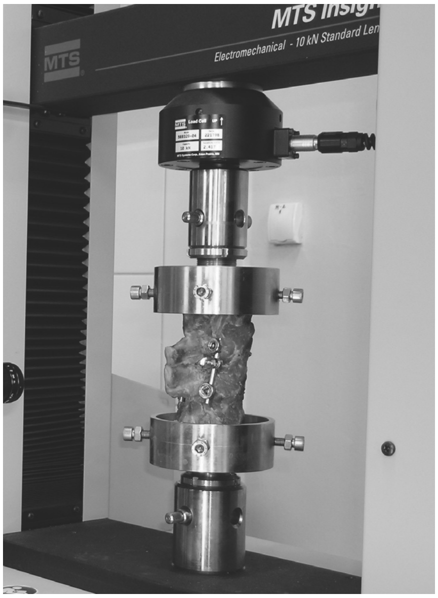

Fig. 7. Lumbar spine – transpedicular stabilizer system located in testing machine MTS Insight

Relative displacements of the stabilizer elements (transpedicular screw with regard to the supporting rod) were determined with the use of videoexstensometer for carried out calculations – Fig. 8. Videoexstensometer consists of camera, which was focused was set up on testing sample (transpedicular stabilizer), contrast markers were addend for the sample. The received view was analyzed by computer video processor in real time. Measurement of distance between markers through all the time of the investigation was provided by suitable software.

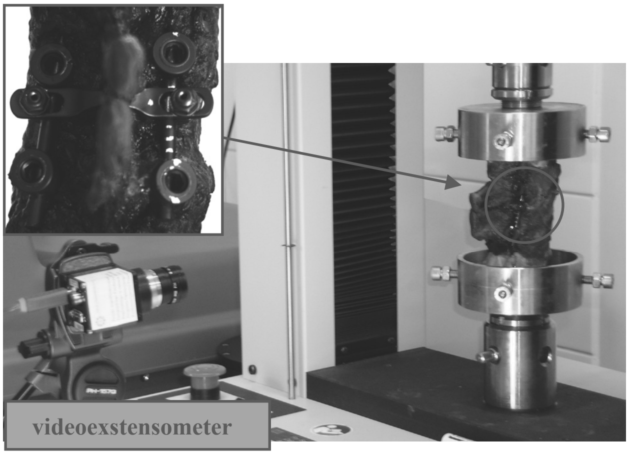

Fig. 8. Lumbar spine – transpedicular stabilizer system analyzed with the use of videoexstensometer

Analyzed model was blackening by spray, for better measurement conditions. It allowed to determine reference markers. Analyzed system with reference markers is presented in Fig. 9.

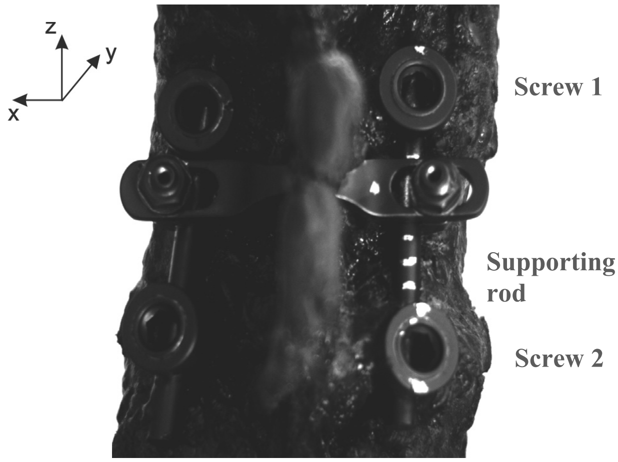

Fig. 9. Determination of stabilizer elements with the reference markers

The analysis included multiloaded system with uniaxial compression forces 50-1600 N. The muscle system of spine was omitted in settlement of boundary conditions too.

3. Results

3.1. Results of numerical analysis

Results of numerical analysis for transpedicular stabilizer made of stainless steel Cr-Ni-Mo are presented in Table 1.

Table 1.
Distribution of relative displacements of screw 1 and 2 with regard to the supporting rod, along OX and OZ axis

Load, N	Displacements, mm			
	Screw 1 with regard to the supporting rod		Screw 2 with regard to the supporting rod	
	OX	OZ	OX	OZ
700	-0.04	-0.09	-0.03	-0.06
1000	-0.07	-0.12	-0.04	-0.12
1300	-0.09	-0.17	-0.04	-0.17
1600	-0.11	-0.20	-0.05	-0.20

Results of numerical analysis enable the determination of relative displacements of transpedicular screw with regard to the the supporting rod by determination of points whose are adequate with reference markers from experimental analysis. Displacements were analyzed for the forces: 700 N, 1000 N, 1300 N, 1600 N along OX and OZ axis. Transpedicular stabilizer with the reference markers is presented in Fig. 10.

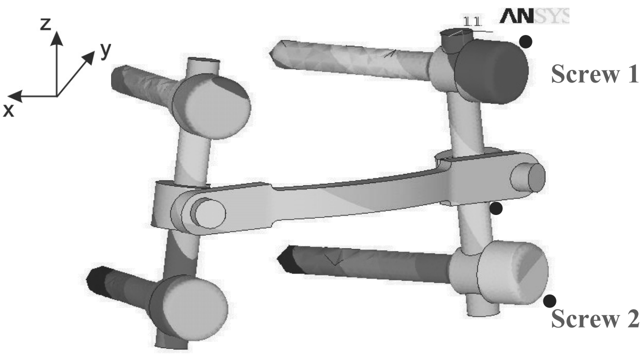

Fig. 10. Determination of transpedicular stabilizer with the reference markers

The numerical analysis enabled determination of values of relative displacements of screw 1 and 2 with regard to the supporting rod as a function of the applied loading, along OX and OZ axis – Figs. 11-14.

The analysis showed that the maximum values of relative displacements for the maximum force of 1600 N were equal to 0.20 mm. These displacements were localized along OZ axis. While the maximum values of relative displacements along OX axis were equal to 0.11 mm.

The relative displacements of screw 1 and 2 with regard to the supporting rod along OZ axis were comparable. While the relative displacements for these screws analyzed determinate along OX axis were insignificantly different.

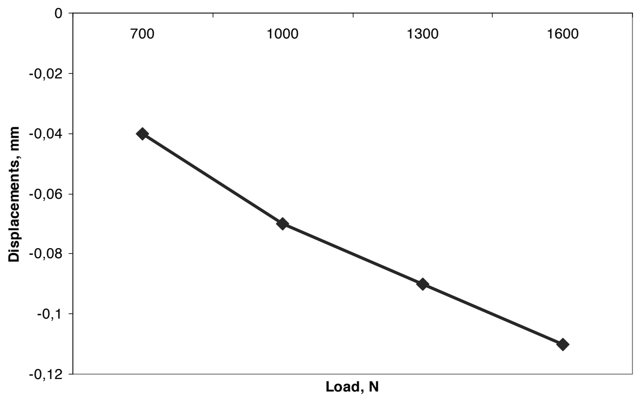

Fig. 11. Distribution of relative displacements of screw 1 with regard to the supporting rod along OX axis

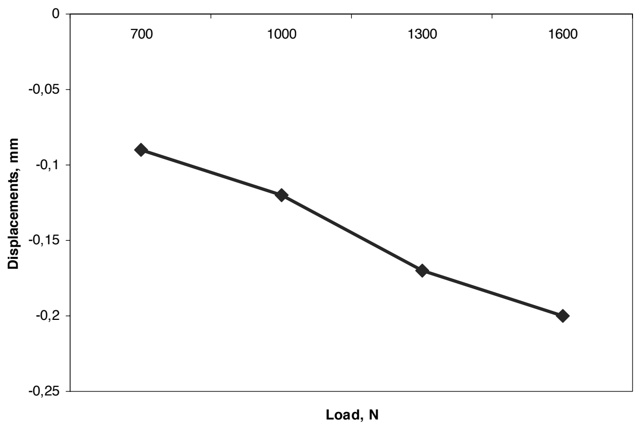

Fig. 12. Distribution of relative displacements of screw 1 with regard to the supporting rod along OZ axis

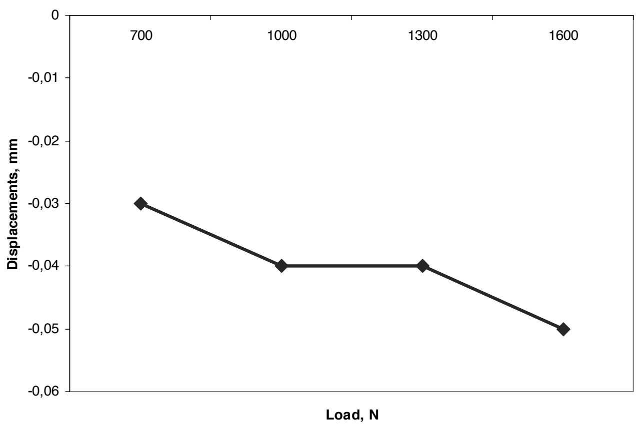

Fig. 13. Distribution of relative displacements of screw 2 with regard to the supporting rod along OX axis

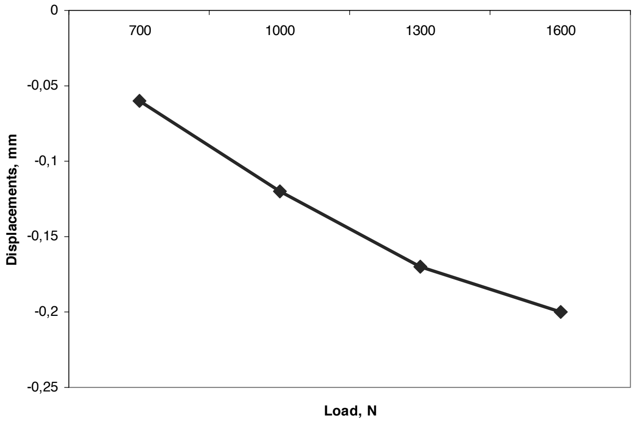

Fig. 14. Distribution of relative displacements of screw 2 with regard to the supporting rod along OZ axis

3.2. Results of experimental analysis

Results of the experimental analysis for transpedicular stabilizer made of stainless steel Cr-Ni-Mo are presented in Figs. 15-18.

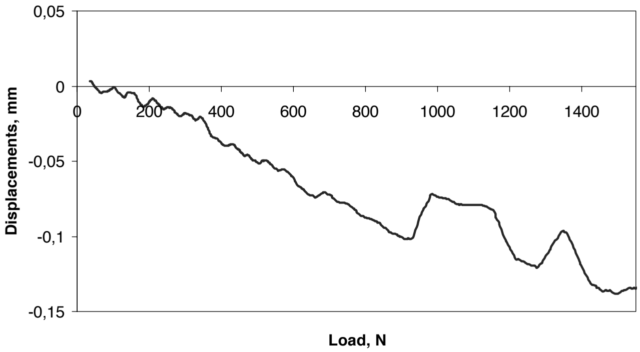

Fig. 15. Distribution of relative displacements of screw 1 with regard o the supporting rod along OZ axis

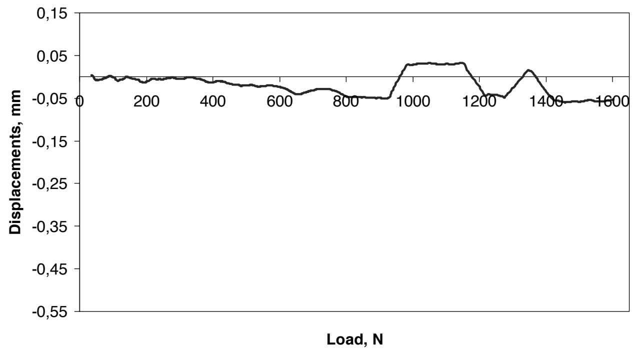

Fig. 16. Distribution of relative displacements of screw 1 with regard to the supporting rod along OX axis

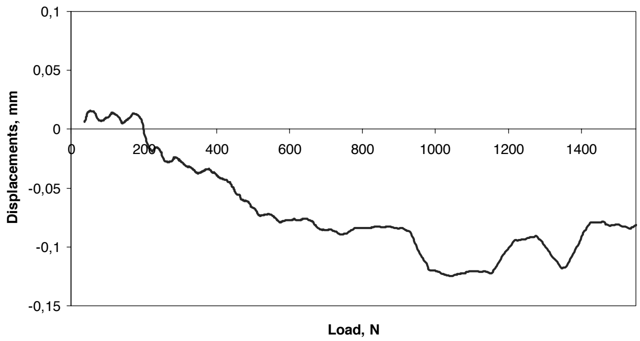

Fig. 17. Distribution of relative displacements of screw 2 with regard to the supporting rod along OZ axis

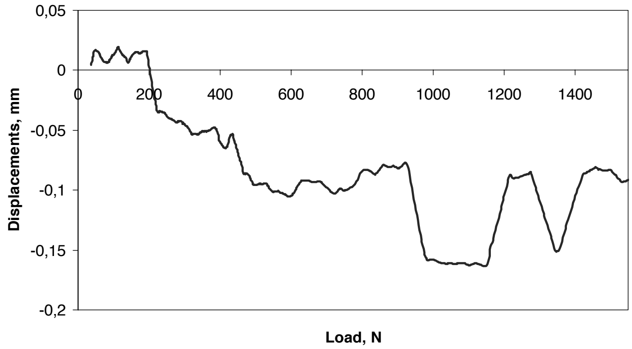

Fig. 18. Distribution of relative displacements of screw 2 with regard to the supporting rod along OX axis

The relationship of relative displacements of transpedicular screw with regard to the supporting rod as a function of the applied loading are presented on the graphs only to the force of 1550 N, because of the reason of instability of the analyzed system.

The analysis showed that the maximum values of relative displacements for the force of 1550 N were equal to 0.17 mm. These displacements were localized along OX axis. While the maximum values of relative displacements along OX axis were equal to 0.14 mm.

4. Conclusions

Numerical and experimental analysis were carried out in order to compare the values of relative displacements of transpedicular screw with regard to the supporting rod.

For numerical analysis the finite element method was applied. The analysis was carried out for transpedicular stabilizer made of stainless steel loaded with the maximum force 1600 N. The results of the analysis were determined on the basis of relative displacements of transpedicular screw with regard to the supporting rod by determination of the points which are adequate with reference markers from experimental analysis. The maximum relative displacements of screw 1 and 2 with regard to the supporting rod were equal 0.20 mm along OZ axis. Maximum relative displacements didn't exceed the value of 1 mm, that proves stability and stiffness of the analyzed system.

The experimental analysis was carried out for spine's transpedicular stabilizer, which was implanted on lumbar part of pig spine. The testing machine MTS Insight and videoextensometer were applied. The relative displacements of transpedicular screw with regard to the supporting rod with the reference markers were registered during the analysis. The maximum value of relative displacements was determined for load with the force 1550 N along OX axis and was equal to 0.17 mm. Maximum relative displacements didn't exceed the value of 1 mm too.

The values of relative displacements obtained in numerical and experimental analysis are comparable along OX as well as OZ axis. The calculation of displacements for stabilizer showed that the proposed type of stabilizer enables correct stabilization of spine. The results of numerical analysis as well as experimental analysis showed the correct selection of mechanical properties of metallic biomaterial which was used to made the proposed type of transpedicular stabilizer.

Coincident results of numerical and experimental analysis are very valuable information source both for engineers and producers as well as for doctors and patients.

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