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Biomechanical analysis of plates used in treatment of pectus excavatum

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ABSTRACT

Purpose: The paper presents computer simulation results of displacement, strain and stresses in the plate used in treatment of the pectus excavatum.

Design/methodology/approach: The numerical analysis was performed for selected models of the stabilizing plates made of the Cr-Ni-Mo stainless steel (AISI 316L) and Ti-6Al-4V ELI alloy.

Findings: The displacement, strain and stress analyses showed the diverse results depending on the plates geometry and the properties of the applied metallic biomaterial. The numerical analysis shows that stresses in plates didn't exceed the yield point: for the stainless steel $R_{p0,2}$min=690 MPa and Ti-6Al-4V ELI - $R_{p0,2}$min=895 MPa.

Research limitations/implications: The limitations were connected both with the necessity of simplifications applied to the numerical model and with the established boundary conditions.

Practical implications: The obtained results are the basis for the stabilizing plate optimization to ensure favorable conditions for the pectus excavatum treatment.

Originality/value: The work presents the displacement-strain-stress characteristics obtained on the basis of the numerical analysis.

Keywords: Numerical techniques; Biomechanical analysis

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Occurrence pactus excavatum is about 2% but surgical treatment is necessary for about 25% of patients. This type of deformation is almost 2 times frequent in boys than girls. In 1998 Donald Nuss introduced a new, minimally invasive technique of funnel chest treatment. Short hospitalization time and good temporary cosmetic result are doubtless advantages of this method. Implantation technique consists: general anaesthesia, selection of the proper length of the fixation plate and appropriate bent, incision of skin, insertion of thoracoscope, insertion of clamp, insertion of bent plate and reversion of the plate (180˚) and correction of deformation – fig. 1 [1-6].

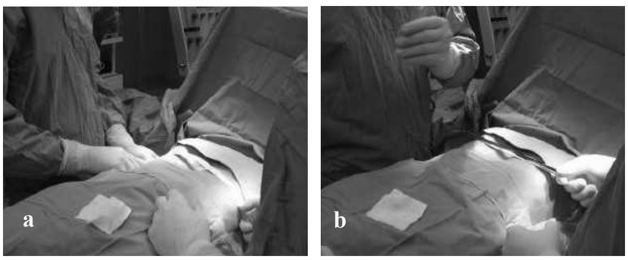

Fig. 1. Implantation technique of fixation plate - Nuss metod: a,b – selection of length of the plate [3]

Fig. 2. Implantation technique of fixation plate - Nuss metod: a,b – modelling of the plate, c - insertation of bent plate, d –Xray of the chest after implantation [3,5]

The aim of the work was numerical analysis of the plates used in funnel chest treatment.

2. Material and methods

The researches were performed on plates made of the Cr-Ni-Mo stainless steel (AISI 316LVM) of the highest purity, that meet all the requirements enclosed in PN ISO 5832-1 standard and Ti-6Al-4V ELI alloy [7÷10]. Steinless steel are also used in orthopaedic surgery, stomatology, operative cardiology and urology [11÷18].

The first part of the work was the creation of physical models of the stabilizing plate. The analyses were performed for 2 kind of plates:

- thickness g=2,5 and 3,5 mm,
- length l=160 and 200 mm.

On the basis of the geometrical models a finite element mesh was generated. The meshing was realized with the use of the SOLID45 element – fig. 3. This type of element is used for the three-dimensional modeling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions.

After discretisation the following boundary conditions were set:

- the outer plane of the plate was loaded with the force directed inward – the sternum reaction - F,
- the degrees of freedom were taken away in the way reflecting the displacement of the real object,
- the plate was loaded with the maximum force which didn't cause the exceeding of the metallic biomaterial yield stress (Cr-Ni-Mo - $R_{p0,2}$min=690 MPa and Ti-6Al-4V ELI - $R_{p0,2}$min=895 MPa),

The following material properties were set:

- stainless steel Cr-Ni-Mo [19]:
    - Young modulus E=200000 MPa,
    - Poisson's ratio ν= 0,33,
- titanium alloy - Ti-Al-4V ELI [20]:
    - Young modulus E=110000 MPa,
    - Poisson's ratio ν= 0,33.

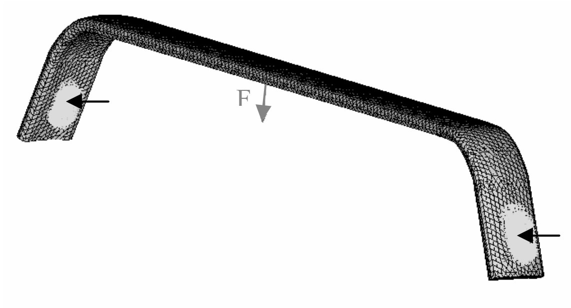

Fig. 3. Discrete model,
taken degrees of freedom ←
F – loading force

All calculations were performed with the use of the finite element method in the ANSYS 10 program.

3. Results

The obtained displacements, strains and stresses are the reduced values according to the Huber-Mises-Henck hypothesis. The obtained results were presented in table as well as in the graphic form – table 1, fig. 4-9.

Table 1.
The maximum forces affecting the plate depending on its thickness and metallic biomaterial

Biomat.	g, mm	l, mm	F, N	Displ., mm	Strain, %	Stress, MPa
Steel Cr-Ni-Mo	2,5	160	640	1,52	3	688
		200	430	2,55	3	690
Ti-6Al-4V ELI		160	825	3,56	8	887
		200	555	5,99	8	891
Steel Cr-Ni-Mo	3,5	160	1040	1,15	4	685
		200	795	2,04	3	689
Ti-6Al-4V ELI		160	1350	0,27	0.9	889
		200	1020	0,47	0.8	884

Biomat.- metallic biomaterials, g- thickness, l- length, F- the sternum reaction, Displ. – displacement

The differences in displacements, strains and reduced stresses depending on the thickness and the length of the analyzed plates and the applied biomaterial were observed.

The maximum reduced displacements were observed for the Ti-6Al-4V ELI plate (thickness g=2,5 mm and length l=200 mm). Increase of the thickness up to g=3,5 mm caused the reduction of displacements to 0,47 mm. The maximum reduced strains were also observed for the plate made of the titanium alloy (lengths l=160 mm and l=200 mm and thickness g=2,5 mm). The maximum displacements and stresses were observed in the middle part of the plate. For the applied forces the reduced stresses did not exceed the appropriate yield point: stainless steel (Cr-Ni-Mo) - $R_{p0,2}$min=690 MPa and titanium alloy (Ti-6Al-4V ELI) - $R_{p0,2}$min=895 MPa. The minimum displacement equal to 0,27 mm was observed for the plate made of the titanium alloy (length l=160 mm, thickness g=3,5 mm).

Fig . 4. Displacements distribution in the plate made of stainless steel Cr-Ni-Mo (l= 160 mm and g=2,5 mm)

Fig. 7. Displacements distribution in the plate made of titanium alloy Ti-6Al-4V ELI (l= 160 mm and g=2,5 mm)

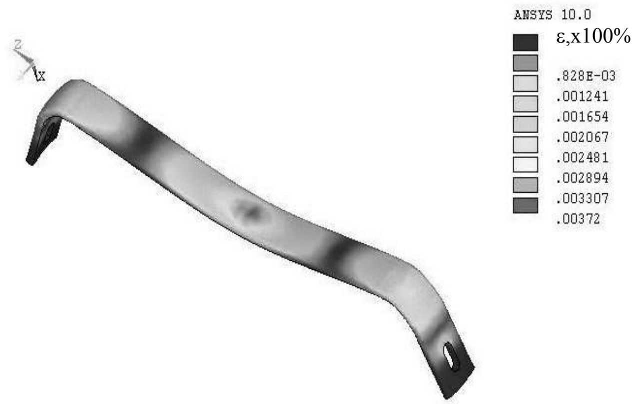

Fig. 5. Strain distribution in the plate made of stainless steel Cr-Ni-Mo (l= 160 mm and g=2,5 mm)

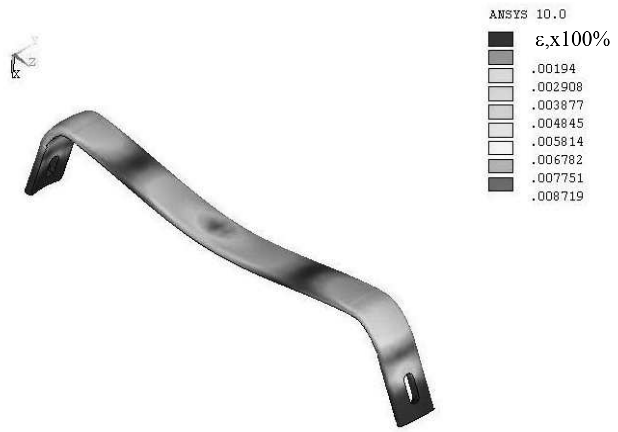

Fig. 8. Strain distribution in the plate made of titanium alloy Ti-6Al-4V ELI (l= 160 mm and g=2,5 mm)

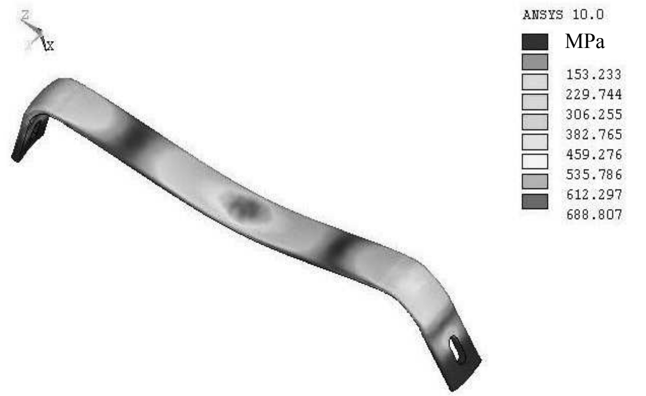

Fig. 6. Stress distribution in the plate made of stainless steel Cr-Ni-Mo (l= 160 mm and g=2,5 mm)

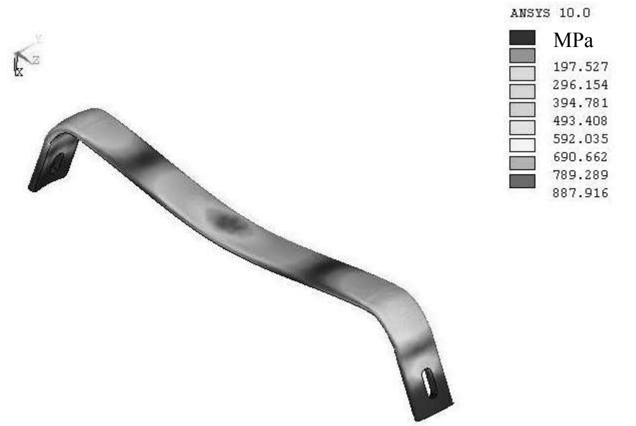

Fig. 9. Stress distribution in the plate made of titanium alloy Ti-6Al-4V ELI (l= 160 mm and g=2,5 mm)

4. Conclusions

In order to calculate in displacements, strains and stresses of plates used in treatment of pectus excavatum the numerical analysis was applied. The obtained results are the basis for selection of the structure and mechanical properties of the metallic biomaterials intended for stabilization plates.

On the basis of the performed displacement, strain and stresses analyses of the stabilizing plate it can be stated that:

- maximum displacement, strain and stresses occurring in the plate can not exceed $R_{p0,2}$min=690 MPa and $R_{p0,2}$min=895 MPa which are equal to the force affecting the plate in the place where it sticks to the sternum,
- the minimum displacement was observed for the titanium-alloy plate of length l=160 mm and thickness g=3,5 mm (loading force F=1350 N),
- generally, lower displacement values are observed for the plates of the thickness of g=3,5 mm, both for the stainless steel and the titanium alloy,
- geometrical features and mechanical properties of the analyzed plates enable elastic strains during loading. It determines the basic criterion of clinical application.

References

[1] J. Bohosiewicz, G. Kudela, T. Koszutski, Results of Nuss procedures for the correction of pectus excavatum, European Jurnal of Pediatric Surgery 15 (2005) 6–10.

[2] J. Czernik, J. Bohosiewicz, Children Surgery, Medical publishing PZWL, Warsaw (2005) 368–374 (in Polish).

[3] J. Dzielicki, W. Korlacki, T. Sitkiewicz, Nuss'es minimally invasive method in pectus excavatum treatment, Polish Surgical Review 72 (2000) 524-530 (In polish).

[4] E.W. Fronkalsrud, J.C.Y. Dunn, J.B. Atkinson, Repair of Pectus Excavatum Deformities: 30 Years of Experience with 375 Patients, Annals of Surgery 3, 443-448.

[5] U. Izwaryn, Comparison of epidural analgesia with bilateral pleura analgesia in children after funnel chest treatment realized by the Nuss' method – phD dissertation. Supervisor: Prof. dr hab. n. med. Anna Dyaczynska-Herman.

[6] D. Nuss, R.E. Kelly, P. Croitoru, M.E. Katz, A 10-year of minimally invasive technique for the correction of pectus excavatum. Journal of Pediatric Surgery 33 (1998) 545-552.

[7] A. Krauze, J. Marciniak, J. Dzielicki, Corrosion resistance of plate used in pectus excavatum treatment, XVI Conference on Biomaterials in Medicine and Veterinary Medicine. October 12th – 15th, Rytro, Engineering of biomaterials 58-60 (2006) 149-152.

[8] A. Krauze, W. Kajzer, J. Dzielicki, J. Marciniak, Influence of mechanical damage on corrosion resistance of plates used in funnel chest treatment, Journal of Medical Informatics and Technologies 10 (2006), 133-141.

[9] A. Krauze, W. Kajzer, J. Dzielicki, Evaluation of surface damage of plates used in funnel chest treatment, XI International Conference, Medical Informatics and Technologies (2006) 289-295.

[10] A. Krauze, W. Kajzer, W. Walke, J. Dzielicki, Physico-chemical properties of fixation plates used in funnel chest treatment, Journal of Achievements in Material and Manufacturing Engineering 18 (2006) 151-154.

[11] W. Kajzer, W. Chrzanowski, J. Marciniak, Corrosion resistance of Cr-Ni-Mo steel intended for urological stents, Proceedings of the 11th Scientific International Conference on Contemporary Achievements in Mechanics, Manufacturing and Materials Science, Gliwice – Zakopane, 2005, 444-449.

[12] A. Krauze., A. Ziębowicz, J. Marciniak, Corrosion resistance of intramedullary nails used in elastic osteosynthesis of children, The Worldwide Congress of Materials and Manufacturing Engineering and Technology COMMENT'2005. Journal of Materials Processing Technology Vol. 162-163, 15 May (2005), 209-214.

[13] J. Szewczenko, J. Marciniak, W. Chrzanowski, Corrosion of Cr-Ni-Mo steel implants in conditions of sinusoidal current electrostimulation, Proceedings of the 9th International Scientific Conference „Achievements in Mechanical and Materials Engineering 2000", Gliwice-Sopot-Gdansk, 2000, 511-514.

[14] Z. Paszenda, J. Tyrlik-Held, J. Lelątko, Structure investigations of passive layer on Cr-Ni-Mo implants. Proceedings of the 3rd Scientific Conference on Materials, Mechanical and Manufacturing Engineering, Gliwice-Wisla 2005, 335-340.

[15] W. Walke, Z. Paszenda, J. Tyrlik-Held, Corrosion resistance and chemical composition investigations of passive layer on the implants surface of Co-Cr-W-Ni alloy, Journal of Achievements in Materials and Manufacturing Engineering, 16 1-2 (2006) 4-79.

[16] Z. Paszenda, J. Tyrlik-Held, Corrosion resistance of coronary stents made of Cr-Ni-Mo steel, Proceedings of the 10th Jubilee International Scientific Conference „Achievements in Mechanical and Materials Engineering 2001", Gliwice-Krakow-Zakopane, 2001, 453-460.

[17] W. Walke, Z. Paszenda, J. Tyrlik-Held, Corrosion resistance and chemical composition investigations of passive layer on the implants surface of Co-Cr-W-Ni alloy, Journal of Achievements in Materials and Manufacturing Engineering, 16 (2006) 4-79.

[18] W. Walke, Z. Paszenda, J. Filipiak, Experimental and numerical biomechanical analysis of vascular stent. Proceedings of the 13th Scientific International Conference on "Achievements in Materials and Mechanical Engineering AMME'2005, Gliwice-Wisla, 2005, 699-702.

[19] ISO 5832-1, Implants for surgery metallic materials, Part I: Wrought stainless steel, (1997).

[20] Norm: ISO 5832-3.