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# NUMERICAL ANALYSIS OF DIFFERENT METHODS OF STERNUM OSTEOSYNTHESIS AFTER STERNOTOMY PROCEDURE

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**Abstract:** *The article presents results of numerical simulations which aimed at the assessment of different methods of sternum osteosynthesis following the sternotomy procedure. The scope of work included the development of a numerical model of the thorax of a fifty-year-old male patient on the basis of computed tomography images as well as models of three methods of sternum osteosynthesis: steel wires, plate implant "SternaLockBlu" and implant "Tritium Sternal Plate System". On the grounds of the results of the numerical simulations in the ANSYS Workbench software programme, the comparison of effectiveness of the analyzed methods was performed.*

**Keywords: Sternotomy, Sternum osteosynthesis, Numerical model, Thorax.**

## 1. Introduction

In cardiothoracic surgery, a preferred method of opening the thorax is sternotomy enabling the performance of a surgical procedure with anterior approach. Median sternotomy is widely used by surgeons, as it provides excellent access to the heart, mediastinum and large blood vessels (Hota et al 2018). Following the completion of the major part of the surgical procedure, two halves of the sternum are joined and held together, most often, by means of standard techniques of the sternum closure, such as: steel wires, surgical sutures, staples, etc., (Song et al. 2004; Alhalawani et al.2013). A decisive factor contributing to the synostosis and success of the treatment is good mechanical stabilization. With a view to this fact, biomechanical tests are being conducted in search of more favourable alternative solutions. Such new solutions exert relatively low pressure on the sternal bone tissue and provide high stability of osteosynthesis which is adaptable to the patient's breathing cycle. Biomechanical analyses make it possible to evaluate which of the available methods are more effective than others and which measures should be taken to improve the systems of sternum osteosynthesis in order to minimize the failure rate (Russo et al. 2014; Steingrimsson et al. 2016). The literature provides information on the biomechanical analyses of various anatomical structures, including sternum osteosynthesis, however, there is no research which would compare the existing solutions (Burkacki et al. 2020; Gzik et al. 2016; Gzik-Zroska et al. 2009; Gzik-Zroska et al. 2011; Joszko et al. 2018). Taking into consideration the above, an attempt was made to assess the impact of the selected methods of sternum osteosynthesis after the median sternotomy (full sternotomy) on the state of stresses in the thorax.

## 2. Methods

To perform numerical analyses, a numerical model of thorax (Fig. 1) and models of selected methods of sternum osteosynthesis (Fig. 2) were developed within the framework of this research. The development of the thorax model was a multiphase process, consisting of three major stages: 1) segmentation of

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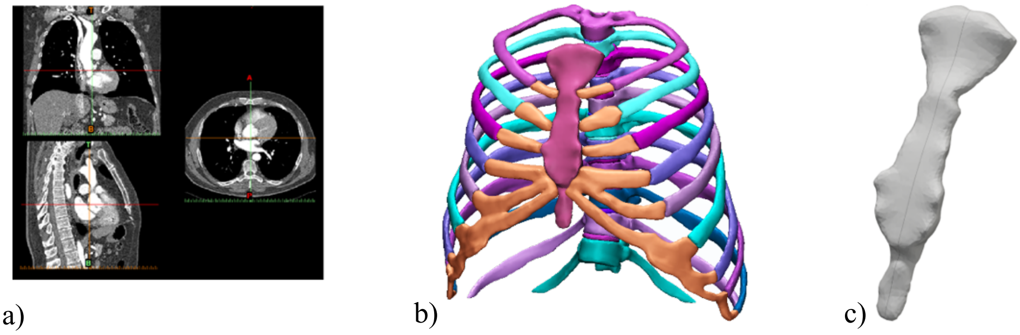
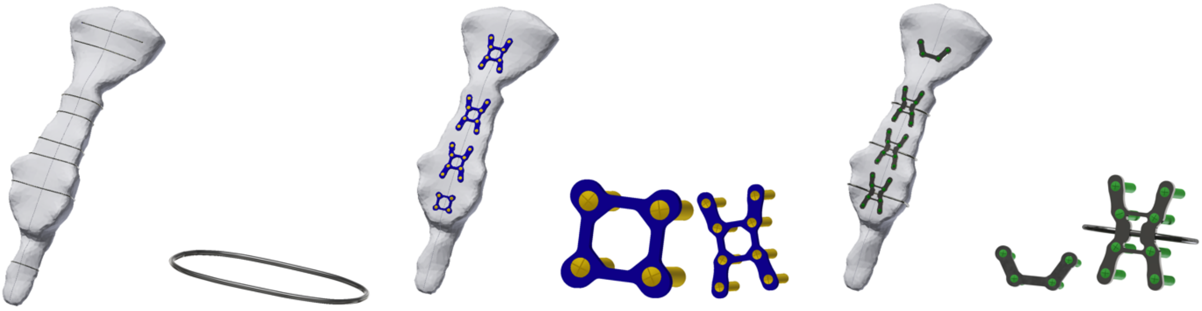
thoracic anatomical structures on the basis of the computed tomography (CT) images of a fifty-year-old male in the Mimics software programme, 2) model editing and 3) generation of a solid object.



a) b) c)

*Fig. 1: Modeling process : a) CT image, b) geometrical model of thorax, c) sternum with median incision.*

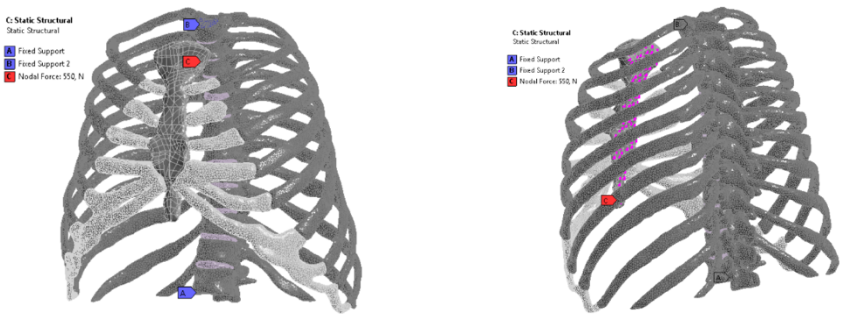
All models of the sternum osteosynthesis systems and necessary modifications of the sternum, including the incision of the sternum along the median line, were developed in the AutodeskInventor software programme.



a) b) c)

*Fig. 2: Geometrical models of sternum osteosynthesis: a) steel wires, b) plate implants "SternaLockBlu", c) implants "Tritium Sternal Plate System".*

The developed thorax model and models of the sternum osteosynthesis systems were imported into the ANSYS Workbench software programme which enables the computer simulation by means of a finite element method. To perform the computations, it was necessary to set the boundary and loading conditions, which would simulate phenomena occurring in a real-life system. To meet this objective, the posterior wall of the thorax was fixed by eliminating all degrees of freedom in all nodes of vertebrae Th2 and L1. The model simulated the most unfavourable situation for the patient, namely during coughing or sneezing. The value of force (load) was adopted on the basis of Cash's model, where the value of force exerted on the sternum of an adult male during medium cough amounts to approx. 550 N(Pai 2005). The load was set as a nodal force applied evenly to many nodes of the posterior sternal wall (Fig. 3).

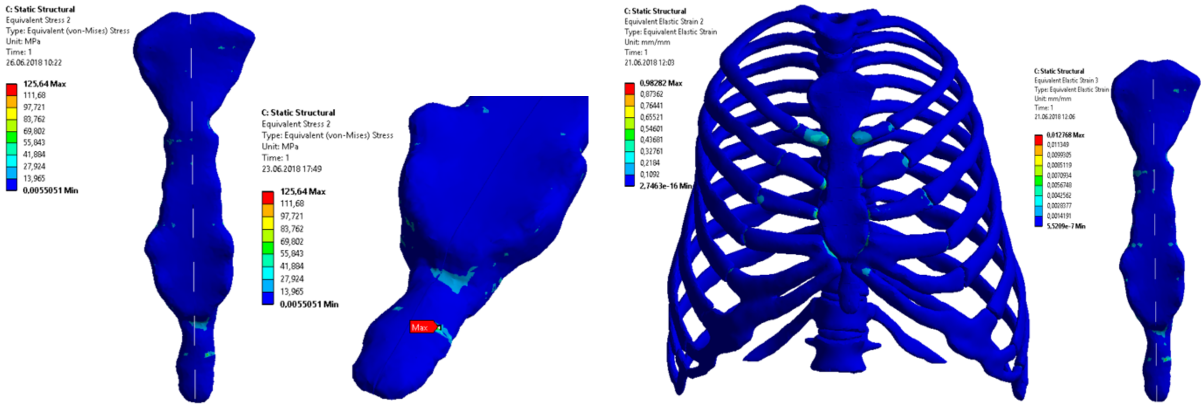



a) b)

*Fig. 3: Boundary conditions adopted in the model: a) fixation, b) load.*

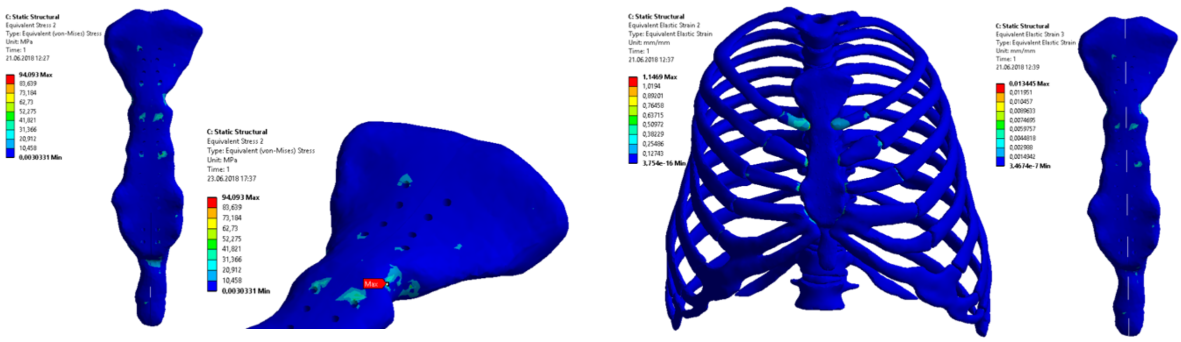
## 3. Results

In the presented work, the comparative analysis encompassed three methods of sternum osteosynthesis: steel wires, plate implants ”SternaLockBlu” and implants ”Tritium Sternal Plate System”. The conducted numerical simulations provided information on the conditions within the thorax (stresses, displacements and strains) following the sternum osteosynthesis after the median sternotomy at a loading resulting from the coughing force. In conditions of a cough there occur movements of ribs, costal cartilages and the sternum displacement. Depending on the applied system of sternum osteosynthesis, either lower part of the sternum (like during exhalation) or upper part of the sternum moved more forwards. The observed values of stresses, strains and displacements of thoracic bone structures are presented in Figures 4,5,6 and in Table 1.



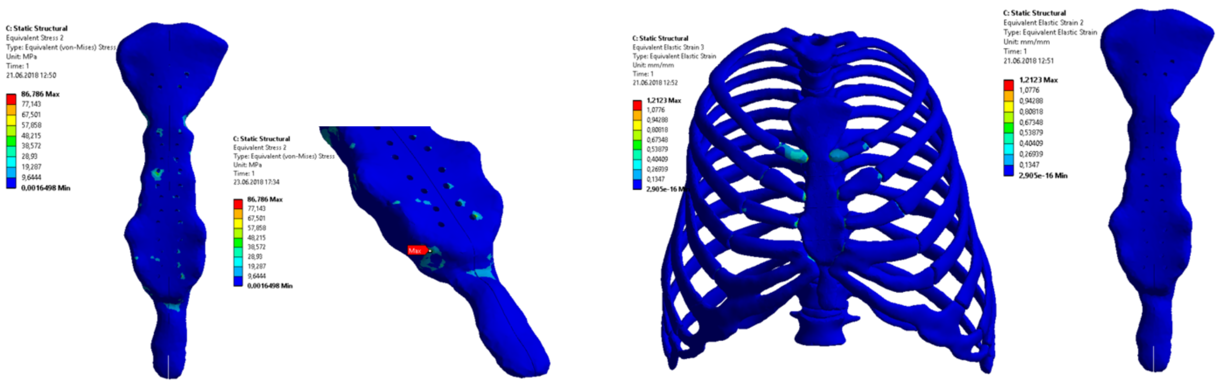
a) b)

*Fig. 4: Steel wires: a) stress, b) strain*



a) b)

*Fig. 5: Plate implant ”SternaLockBlu”: a) stress, b) strain*



a) b)

*Fig. 6: Implant ”Tritium Sternal Plate System”: a) stress, b) strain*

*Tab. 1: Results of numerical simulations*

| Sternum osteosynthesis method | Maximum displacement of thoracic structures [mm] | Size of the dehiscence between sternal edges [mm] | Maximum stresses reduced on sternum [MPa] | Maximum strains reduced on sternum [mm/mm] |
|---|---|---|---|---|
| Steel wires | 63.2 | 3.39 (Manubrium ) | 126 | 0.0127 |
| Plate implants “SternaLock Blu” | 49.1 | 2.46 (Xiphoid process) | 94 | 0.0134 |
| Plate implants “Tritium SPS” | 54.4 | 3.93 (Xiphoid process) | 87 | 0.0108 |

## 4. Conclusions

This article is concerned with the issues of sternum osteosynthesis following the median sternotomy. The biomechanical analysis of the implant-thorax interaction system encompassed three methods of sternum osteosynthesis, namely: steel wires, plate implants ”SternaLockBlu” and plate implants ”Tritium SPS”. The dehiscence of the edges of the incised sternum poses a great challenge during the process of synostosis To assess the stability of osteosynthesis, the researchers tested the maximum displacement of the sternal halves in relation to each other depending on the applied stabilization method. The least stable method of osteosynthesis has proven to be plate implant ”Tritium SPS”, as the size of the dehiscence of the sternal edges amounted to 3.93 mm. On the other hand, the best solution has proven to be plate implant ”SternaLockBlu”, where the size of the sternal dehiscence amounted to 2.46 mm.

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