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An elastic rib modelling

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Abstract: Chest modelling approach to patients with pectus carinatum is presented. A mechanical model of flat rib under load is developed and a method for its parameters identification is proposed.

Keywords: biomechanical modeling, finite-dimensional model, parameter identification

1. Introduction

Keeled chest or pectus carinatum is one of the most widespread chest malformations. There is a way to correct this deformity with a special orthosis. To adjust the orthosis, it is necessary to conduct an experiment, in which the patient is subjected to pressure on the chest in order to find out the pressure of correction (POC), that is, the pressure at which the chest is deformed to normal. However, this experiment can be problematic and undesirable for many reasons. Mathematical modeling of chest deformation under the influence of various loads is a very urgent task. This problem can be solved by finite element methods (FEM) [1, 2], or, for example, by constructing phenomenological models that allow describing the dynamics of the chest and assessing important characteristics of its state. In this paper, a finite-dimensional model of a rib based on processing of CT images is proposed, as well as a 3D FEM model is built for calculation in the Ansys. Bone material is considered to be isotropic and linearly elastic. The coefficient of elasticity of the material is taken from the literature [3]. A technique for identifying the parameters of a finite-dimensional model is proposed.

2. Materials and methods

Due to the structural complexity of the rib cage, we limited ourselves to considering one rib under load. CT scans of a patient with pectus carinatum have been acquired and imported into various medical software. Then a 3D model of the 5th rib segmentation was created. Typical 3D file formats provided by medical software are STL, OBJ, PLY. However, Ansys does not work directly with faceted models such as the STL. We used the commercial medical software DICOM to PRINT (3D Systems, Inc.) to convert the facet model to the smoothed model. This approach allows us to save segmented regions in the IGES file format that can be utilized by Ansys.

To build mechanical model of a rib we made an assumption that the rib is flat, i.e. there is a plane that contains the whole rib. Our mechanical model of the rib consists of five rigid rods connected by linear spiral springs (Fig.1b). Compliance in costovertebral joint is modeled by two linear cylindrical springs that connects the head of the rib with fixed perpendicular planes (we assume that corresponding vertebra is fixed) so that at every moment elastic forces from

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these springs are directed along corresponding coordinate axes. There is also a linear spiral spring in the head of the rib that hinder the motion of the rib in costovertebral joint around axis, normal to the plane containing the rib. In initial state all springs in the system are undeformed and A_1 end of first rod coincide with origin O. Displacements x,y of the point A_1 and angles $\varphi_i, i = 1,..,5$ between corresponding rods and Ox axis were chosen as generalized coordinates. The force F with components F_x, F_y is applied to A_6 end of the last rod in the system.

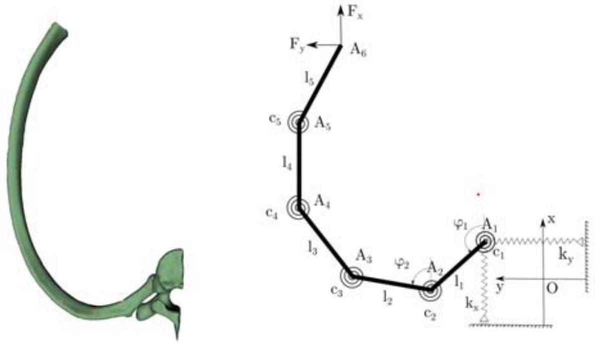

Fig. 1. Undeformed state of the mechanical system. Segmented rib (a), finite-dimensional mechanical model (b)

Lengths of the rods and initial angles between them were measured in open-source 3D Slicer software. The equations of equilibrium for described system were obtained. Numerical solution of these equations, however, depends on values of coefficients of springs' stiffness $k_x, k_y, c_i, i = 1,..,5$. The identification of the coefficients was made with assumption of equality of small displacements of corresponding rods and displacements of non-fixed end of curved beam, which were obtained by Maxwell-Mohr method.

3. Results

Numerical modeling of rib deformation was carried out using the finite-dimensional model and the FEM model built in the Ansys software. The difference in the amount of movement of the end point and several reference points of the rib at a given load does not exceed 10%.

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