23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

A FINITE ELEMENT STRESS ANALYSIS TO PREDICT THE RISK FACTORS OF AORTIC DISSECTION - PRELIMINARY STUDIES

M. Żak[*], J. Filipiak[**], T. Płonek[***]

Abstract: *The risk of cardiovascular disorders, including aortic aneurysms and aortic dissection increases with age. So far, there has been no effective method of diagnosing and predicting the risk of dissection of the aorta. The aim of the study was to examine the potential role of the finite elements method to predict the risk of aortic dissection and the impact of the geometry of the aorta, aortic root motion and blood pressure on the wall stress in the aortic wall.*

Keywords: Aorta, Dissection, Aneurysm, Numerical simulations, Mechanical properties.

1. Introduction

Aortic dissection is a catastrophic complication which usually occurs in patients with a dilated aorta. The risk of cardiovascular disorders, including aortic dissection, increases with age (Rylski et al., 2014). The mechanism of aortic dissection has not yet been fully explained. It is believed that the gradual structural remodeling caused by the histological alterations and mechanical stimuli (blood pressure, aortic root movement) may be responsible for aortic wall degeneration and subsequent dissection (Beller et al., 2004; Plonek et al., 2015).

The aim of the study was to analyze the impact of mechanical factors on the dynamics of the process of dissection of the ascending aorta and its physical properties. In this study was to determine whether: (1) the geometry of the vessel and its curvature have a significant impact on the formation and propagation of aortic dissection, (2) blood pressure acting on the blood vessel and aortic root movement on the stress in the aortic wall.

2. Materials and methods

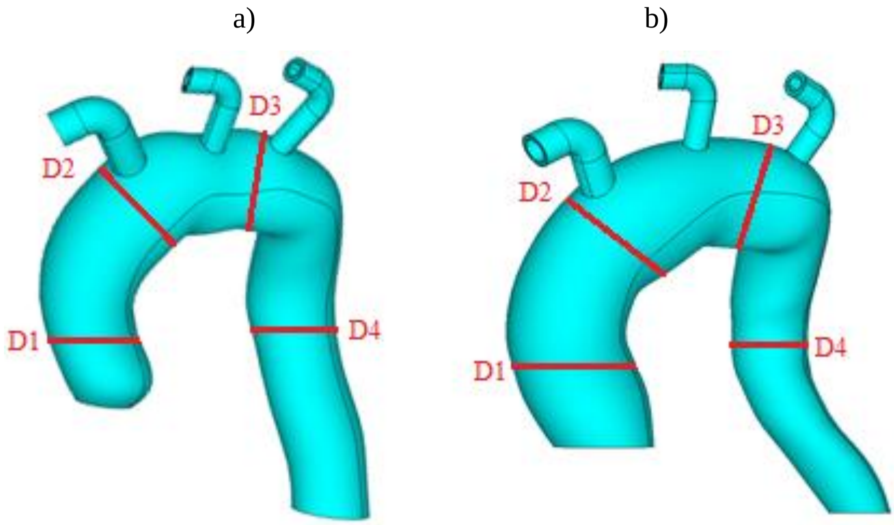
2.1. Geometry and wall properties

In this research, numerical models were obtained from computed tomography angiography (angio-CT) scans of two patients obtained before the occurrence of aortic dissection. External surface model of the aorta was performed on the 3D reconstruction of the thoracic aorta obtained from the angio-CT images (Fig. 1). The artifacts were to avoid discontinuity of the shape of the model of the aorta (Burzyńska et al., 2016). The blood vessel wall was modeled as a three-layer composite structure with a total thickness of 2 mm. It was assumed that the thickness of the individual layers of the vessel were as follows: intima t_i = 0.2 mm, media t_m = 1.2 mm, and adventitia t_a = 0.6 mm. The simplified reconstruction of the aortic arch branches were also included in the final model.

[*] PhD. Małgorzata Żak: Department of Biomedical Engineering, Mechatronics and Theory of Mechanisms, Wroclaw University of Science and Technology, ul. Lukasiewicza 7/9, 50-371 Wroclaw, Poland, malgorzata.a.zak@pwr.edu.pl

[**] Prof. Jarosław Filipiak: Department of Biomedical Engineering, Mechatronics and Theory of Mechanisms, Wroclaw University of Science and Technology, ul. Lukasiewicza 7/9, 50-371 Wroclaw, Poland, jaroslaw.filipiak@pwr.edu.wroc.pl

[***] MD PhD. Tomasz Płonek: Department of Cardiac Surgery, Wroclaw Medical University, ul. Borowska 213, 50-556 Wroclaw, Poland, tomaszplonek@gmail.com



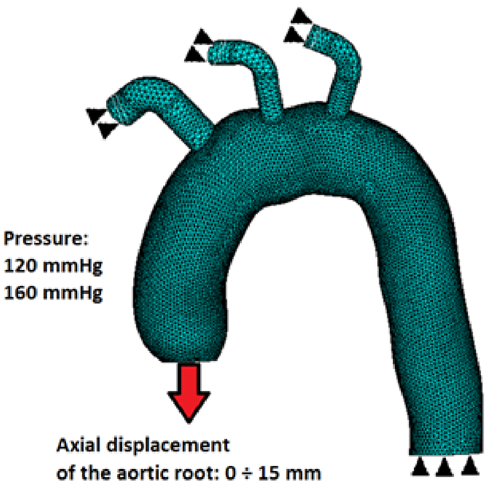
Model	Diameter of the aorta [mm]			
	D1	D2	D3	D4
Patient A	37.49	41.09	37.97	32.37
Patient B	45.23	48.75	32.37	28.06

Fig. 1: The three-dimensional models of the aortas reconstructed from the angio-CT images: (a) patient A, (b) patient B.

2.2. Finite element modeling

Numerical finite elements models of the human aorta were built for stress analyses using the ANSYS 17.2 software (ANSYS). The models were discretized into 632000 (in patient A) and 423000 (in patient B) tetrahedral structural solid elements (SOLID187). The material properties of the aortic wall were represented as linear elastic, and isotropic, with a Young's modulus of: intima Ei = 2.98 MPa, media Em = 8.95 MPa, adventitia Ea = 2.98 MPa and a Poisson's ratio of 0.49 for all layers (Gao et al., 2006).

Luminal pressures of 120 mmHg and 160 mmHg were used in both aortic models (Fig. 2). Additionally, aortic root base axial displacement (0mm - 15 mm) was applied in the models. The distal end of the aorta (descending aorta) and at the distal ends of the aortic arch branches were fixed in all directions to better represent the immobilization of the vessel in the chest.



Model	Number of elements		
	Intima	Media	Adventitia
Patient A	78500	208500	345000
Patient B	78100	141200	203700

Fig. 2: Exemplary front view of the finite element model of the aorta with number of elements throughout the individual layers in model: patient A and patient B.

3. Results

The results of numerical simulations show how the geometry of the vessel, blood pressure and aortic root motion influenced the distribution of stress exerted on the aortic wall.

In patient A, the aorta had smaller diameter than in patient B (Fig. 1). In patient A, the area of the highest stress was located mainly in the aortic arch (Fig. 3). In the model of aorta of patient B, this area also included part of the ascending aorta (Fig. 4).

As expected, higher stress values were observed at blood pressure of 160 mmHg compared to 120 mmHg. In patient A the maximum stress was 0.6 MPa at 120 mmHg and 1.0 MPa at 160 mmHg. In patient B the maximum stress was 0.8 MPa at 120 mm Hg and increased to 1.2 MPa at 160 mmHg.

The aortic root axial displacement has also an impact on the stress in the aortic wall. When the movement of the aortic root was changed from 0mm to 15mm the maximal stress in the aortic wall increased to 1.0 MPa at a pressure 120 mmHg and to 1.5 MPa at a pressure 160 mmHg (in patient A). In patient B the stress was changed from 1.1 MPa to 1.75 MPa at a pressure 160 mmHg and they were greater than at the pressure of 120 mmHg.

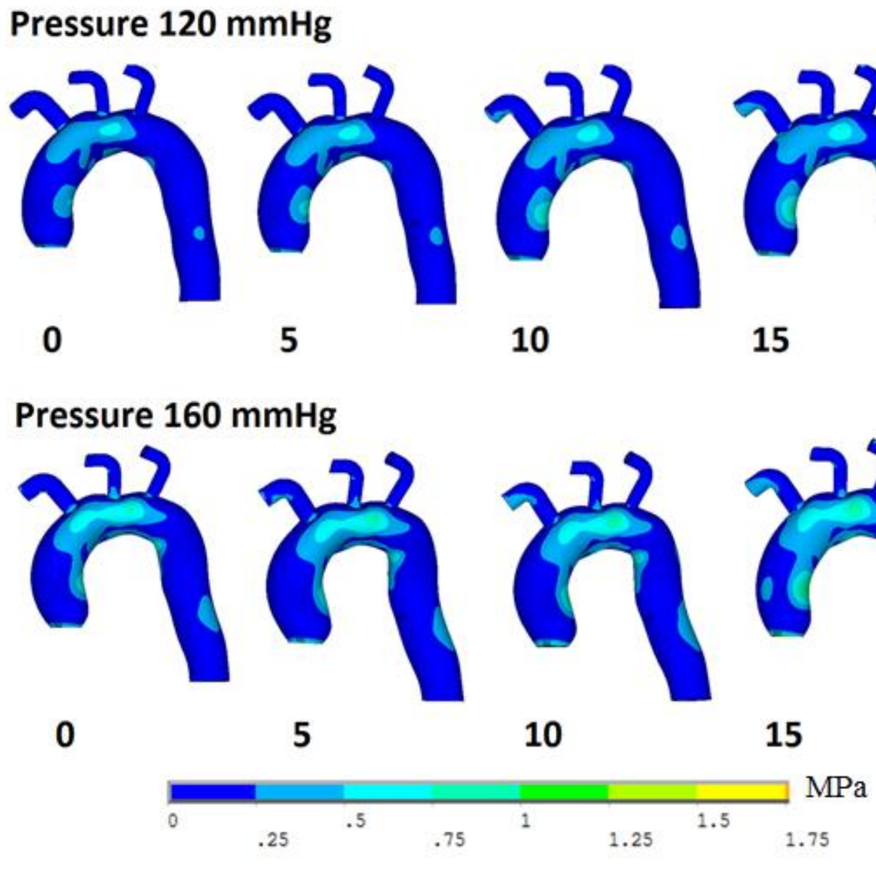


Fig. 3: The map of the wall von Mises stress values distribution on its surface throughout the aorta wall patient A, after finite element analysis in pressure: 120 mmHg and 160 mmHg and displacement of the aortic root 0÷15 mm.

4. Conclusions

Our research results show that the physical properties of the aorta and mechanical factors (blood pressure and aortic root movement) influence significantly aortic wall stress and subsequently the risk of its dissection. Finite elements method has a potential to be a good tool to evaluate the risk of aortic dissection.

Acknowledgement

Calculations have been carried out using resources provided by Wroclaw Centre for Networking and Supercomputing (http://wcss.pl), grant No. 423.

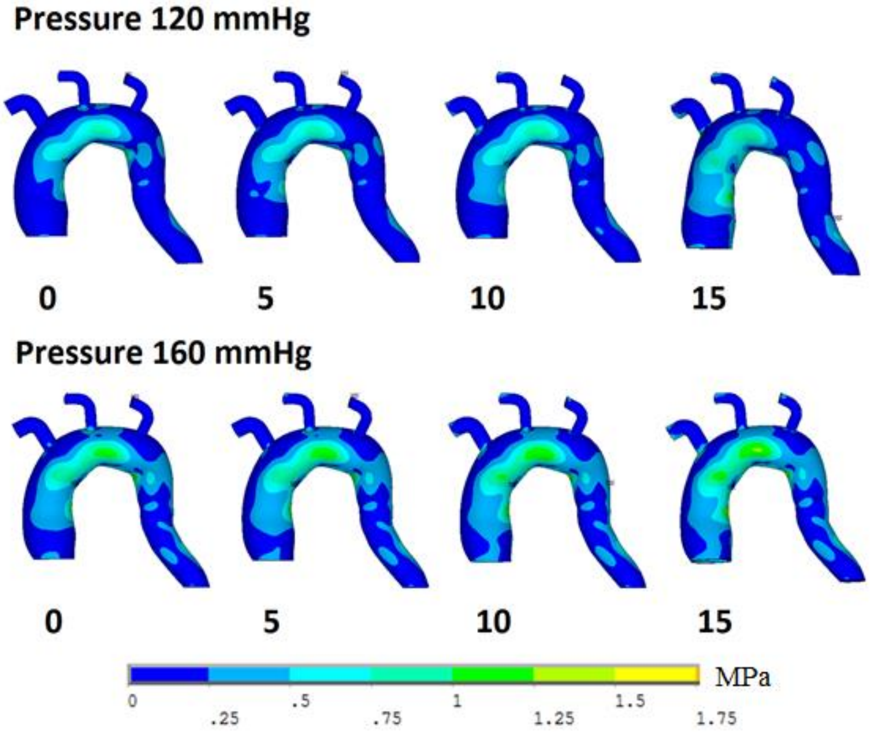


Fig. 4: The map of the wall von Mises stress values on its surface throughout the aorta wall patient B, after Finite Element Analysis in pressure: 120 mmHg and 160 mmHg and displacement of the aortic root 0÷15 mm.

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