THE NUMERICAL ANALYSES OF BLOOD FLOW IN PULMONARY ARTERIES

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One of the most fundamental examinations in intensive care medicine is cardiac output measurement, realized by pulmonary artery catherization. The conducted researches consisted of two phases: the clinical examination to obtain anatomical data and numerical modeling to simulate the blood flows. The paper depicts investigations related for numerical analyses of asymmetric blood flow through pulmonary vessels.

***Keywords**: cardiac output measurement, pulmonary artery catherization, numerical modeling of blood flows in vessels.*

1. INTRODUCTION

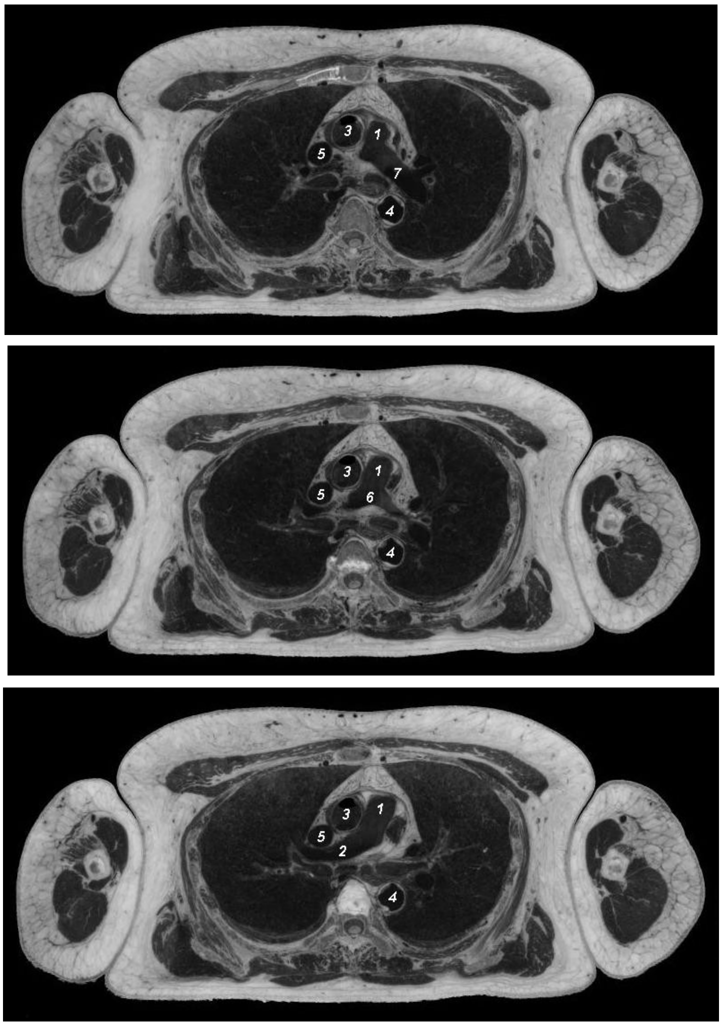
The cardiac output measurement is one of the most fundamental examination in cardiovascular system diagnostic [1]. This kind of examination allows to measure important hemodynamic parameters, like pulmonary artery pressure, pulmonary artery wedge pressure, which corresponds to the left atrial pressure and pulmonary vessels resistance [2,3].

The monitoring of illness progress and treatment results requires high sensitivity and specificity of applied cardiac output measurement method [4,5]. Moreover, the results of examination may be uncertain in case of accompanying diseases, like valve disease, arrhythmia or right ventricle hypertrophy. To improve the accuracy of considered method it is necessary theoretically identify the sources of its unreliability. Blood flows through right pulmonary artery (RPA) and left pulmonary artery (LPA) are not the same. The goal of presented analysis was to determine differences in anatomic structures of RPA and LPA influent on volumetric flow symmetry through those arteries. The aim of clinical examinations was to gather data for numerical model's verification and to estimate the variability of pulmonary arteries dimension. The data were applied in numerical analyses of the model of blood flows in pulmonary vessels.

2. NUMERICAL ANALYSES

The goal of numerical modeling was to simulate the blood flow through the pulmonary vessels in order to estimate flow symmetry through the LPA and RPA. Performed numerical modeling was based on clinical data verified in literature [1-4] as well as on results own measurements.

The anatomic structure of the pulmonary trunk (PT) and its bifurcation for right and left pulmonary arteries were reconstructed from transverse scan of human body. The scans come from free data base of *"Visible Human" project* [6]. Three examples of them were depicted on Fig. 1.



Legend: 1-pulmonary trunk (*PT*), 2-right pulmonary artery (*RPA*), 3-ascending aorta (*AO*), 4-descending aorta (*AO*), 5-vena cava (*VC*), 6-pulmonary trunk bifurcation, 7-left pulmonary artery (*LPA*)

Fig. 1 Transverse section of human body (male) [6] - the pulmonary vessels were shown

The result of reconstruction was a 3D computer model of pulmonary vessels, containing information about arteries diameter, length and their orientation in three-dimensional space. In next step, the 3D numerical model was simplified (in *SolidEdge CAD Environment*) and parameterized, to prepare it for meshing (Fig. 2). There was made an assumption, that specified vessels diameter (D_{PT}, D_{RPA}, D_{LPA}) will be variable and their length will be constant. From theoretical study [7] and clinical investigations the following vessels diameters were assumed for further numerical flow simulation: D_{PT}=20mm, D_{RPA}=16mm, D_{LPA}=12mm.

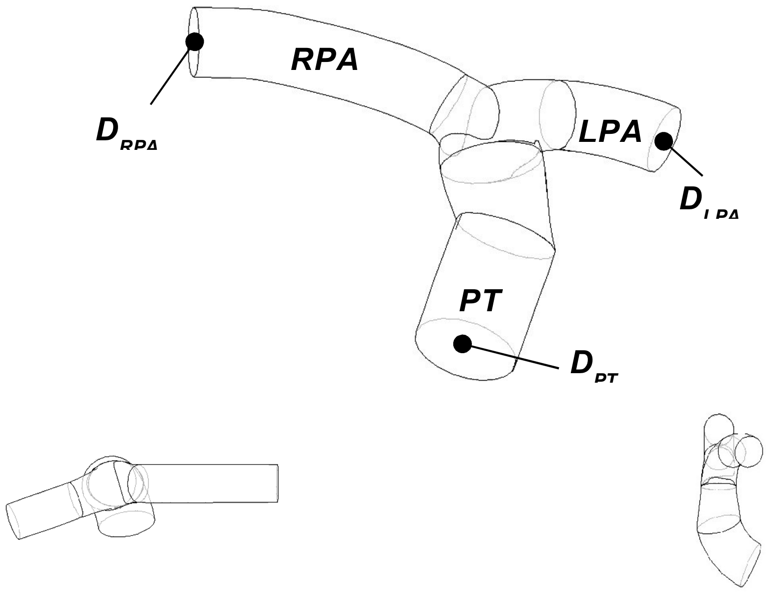


Fig. 2The simplified and parameterized model of pulmonary vessels (upper picture) and its top and side views (lower pictures)

The validation of reconstructed model geometry was performed by comparison of two patterns: model's front geometry projection and ultrasonic projection of pulmonary vessels (Fig. 3) [8]. The result of comparison turned out positive and it allowed to find a good correlation between numerical model and anatomical structures.

The analyzed geometry was meshed in *the Gambit environment*. The mesh consisted of about 78.000 tetrahedral elements and contained three faces: one velocity inlet type (at the beginning of the pulmonary trunk) and two pressure outlet type (at the ends of LPA and RPA). The load pressures of output vessels were set to 12[mmHg], which is a typical pressure in pulmonary circulation [9]. To simulate the flow phenomena the finite element method was utilized (Fluent 6.3.26 solver, single precision digits).

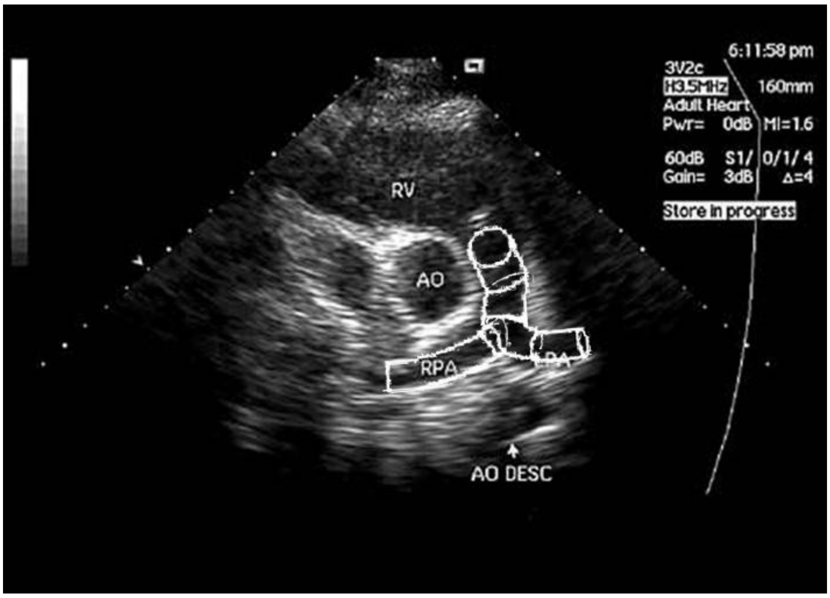


Fig.3 Model's validation: the shape of projected pulmonary vessels (white solid line) and pulmonary vessels ultrasound projection [8]

The previous study and clinical non-invasive patients' examination by ultrasonic Doppler method allowed to estimate blood velocity wave in the pulmonary trunk - its maximal value reached 1.2 m/s. By calculating the Reynolds number (Eq. 1) the level of turbulence was estimated [9].

$$Re = \frac{\rho_B \cdot v \cdot D}{\mu} \approx 9000 \qquad \text{(Eq. 1)}$$

$$Re > 2300$$

Legend: ρ_b-specific mass of blood; μ-velocity; ν-viscosity of blood; D-vessel diameter

Indeed, for typical the pulmonary trunk diameter (20mm), the value of Reynolds number at the blood flow's pick exceeded critical value of 2300, but it should be assumed, that it took place only at flow picks. In other phases the turbulence level was low. It determined the applied types of viscous models: k-ε, k-ω and Reynolds's stress. The simulation were performed for all mentioned types of solvers, taking into consideration the blood viscosity and density (ν=0.0035 kg/m·s, ρ_b=1055kg/m^3). The blood was treated as a Newtonian liquid. The simulations were performed for continuous blood flow with velocity of 1.2 m/s.

3. RESULTS OF NUMERICAL ANALYSES

The convergence of solutions was obtained for all applied solver types. The flow profiles (velocity magnitude) were depicted of Fig. 3. For various types of turbulence models the total volumetric fluxes (FV) in all vessels were calculated and the FV_{RPA}/FV_{LPA} were computed (refer to Table 1). For all viscid models the blood flow through RPA was grater than through LPA.

VISCOUS MODEL	FV_{RPA}/FV_{LPA}
k-ε	1.175
k-ω	1.252
Reynolds's stress	1.169

Table1 The RPA/LPA volumetric flow vs. various viscid models

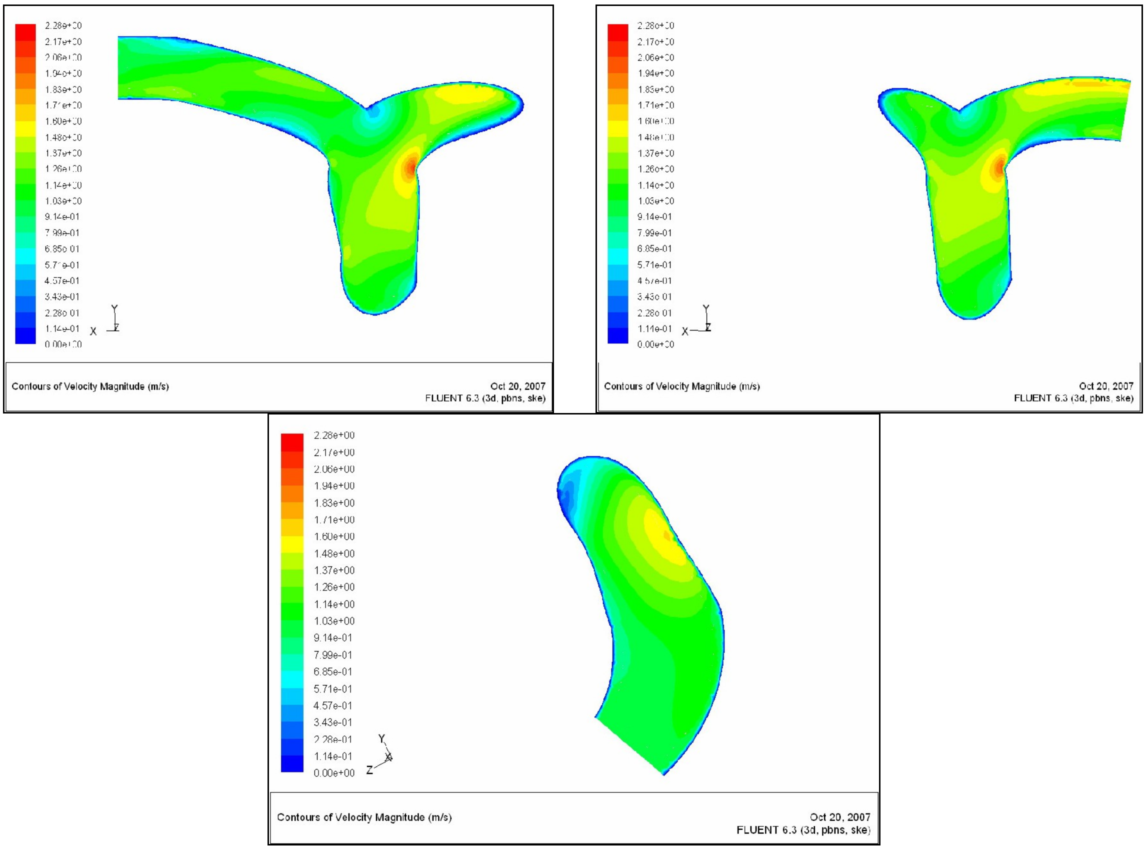


Fig. 3 The velocity flow profiles in specific vessels

4. CONCLUSIONS

Clinical examination revealed strongly variability of pulmonary vessels diameters, depending on individual anatomical features. Performed numerical analyses revealed asymmetric volumetric flow through the considered vessels, regardless of utilized blood viscosity model.

This conjecture should be proved by experiments on physical model of pulmonary circulation which investigations are in progress [10].

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