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Aortic Arch Aneurysm Represented by a 3D Printing and Simulation of Fluid Movement through It

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Degeneration of the human aorta can occur in the thoracic, abdominal and arch region. Rarely this kind of disease happen in the arch region of aorta closer to the semilunar valve. By definition, an aneurysm is a localized dilation of an artery with a diameter at least 50% greater than normal size. The main objective of the study is to recreate the 3D model of the heart with real aortic arch aneurysm and successive simulation of fluid movement in it and demonstrate a difficulty in the conductivity of the vessel.
Successful testing of a 3D model based on real data of aneurism and achieved with great precision through 3D printing. A satisfactory result has been obtained demonstrating the degree of functional predicament of the aorta in this rare type of aneurysm.

Key words: aortic arch aneurysm, 3D print models, heart anatomy, vascular disorders

Introduction

By definition, an aneurysm is a localized dilation of an artery with a diameter at least fifty percent greater than normal size. This often occurs at human aorta in thoracic, abdominal and arch regions. Relatively more rare the aneurysm affects arch region closer to the semilunar valve. However, it is important condition because ascending aortic aneurysm may be fatal due to its liability to dissect or rupture due to intense blood pressure [5].

3D anatomical models are used like educational method and clinical training of medical students while they study anatomy, physiology and surgery. Simulation based training with 3D models are useful and help recognize the morphology and symptoms of the specific disease such as aneurysm [3]. 3D anatomical models can be computer-generated images from medical data by Computed Tomography (CT), or Magnetic Resonance Imaging (MRI). Another source of 3D anatomical models are 3D surface scanners, printers, skeletal collections, etc.

The main goal of this investigation is: to model the fluid dynamics during aortic arch aneurysm and compare it to normal condition by building realistic 3D model of heart with and without ascending aortic aneurysm and compare model results from simulation of fluid dynamics [1]. We hypothesize that fluid flow measured entering left atrium will differ dramatically by means of speed and pressure between aneurysmal and normal heart models.

Materials and Methods

Tubing model.Two flexible plastic hearts in norm and pathology were digitally rendered and 3D printed. Those were attached to blood flow simulator made by flexible silicone tubes. Fluid flow parameters at specific locations before and after aneurim were measured by flow sensors and were recorded by Arduino Uno-based computer [3]. The three-dimensional heart models are 3D printed with a precision monochrome 3D printer of the Kossel Delta Mini type, using Flexible PLA representing viscoelastic biodegradable plastic material. A melting temperature of the filament is 205 °C, as a print speed of 20 mm/s is used. The experimental set is composed of the 3D printed plastic models of the hearth with normal aortic arch and of the hearth with aortic arch aneurysm, water pump, water flow sensor, water preassure sensor, flexible silicon tubes and plastic tube connectors.

Numerical model. Fluid pressure and particle velocity were measured accordingly. The numerical simulation of fluid gives information about the severity of the impairment of circulatory flow in the arch caused by vortices [5]. This was performed by fluid flow simulation in the software Abaqus 6.1 using surface mesh models of the 3D hearts and computational fluid dynamics module.

Results

Precisely 3D printed models, based on real arch aneurism data,which were the subject of the test, showed increased turbulence in the pathology as compared to normal conditions. It can be seen from the diagram shown on **Fig. 1**. Additionally, a concept of proof for numerical modeling was established.Tubing model represents innterplay bettween physics, anatomy and physiology, focused in particular in fluid- and hemodynamics resistance in large circle of blood circulation in norm and pathology. In this investigation we use a realistic 3D model based on printed medical data from MRI, as it can be seen on **Fig. 2** and **Fig. 3.** The model was useful for medical students, helping them imagine the pathology of the area of aorta arch.

Discussion

We experienced a number of difficulties during the experiment. In the construction of the heart shows that the internal heart morphology does not correspond to the true structure, but the external is realistic and credible. The model has been enforced with a pump in order to stimulate fluid movements without the presence of heart valves.The model of the aortic artery aneurysm is from anactualpatient and allows to create realistic 3D model. The scan we used had the data of the external morphology of the heart and the characteristic pathology of the aorta arch. There is no complete data collected from the main vessels. That was the reason we decided to use the aortic arch as well as a few centimeters of the data available on the cava veins, lung veins and pulmonary trunk.

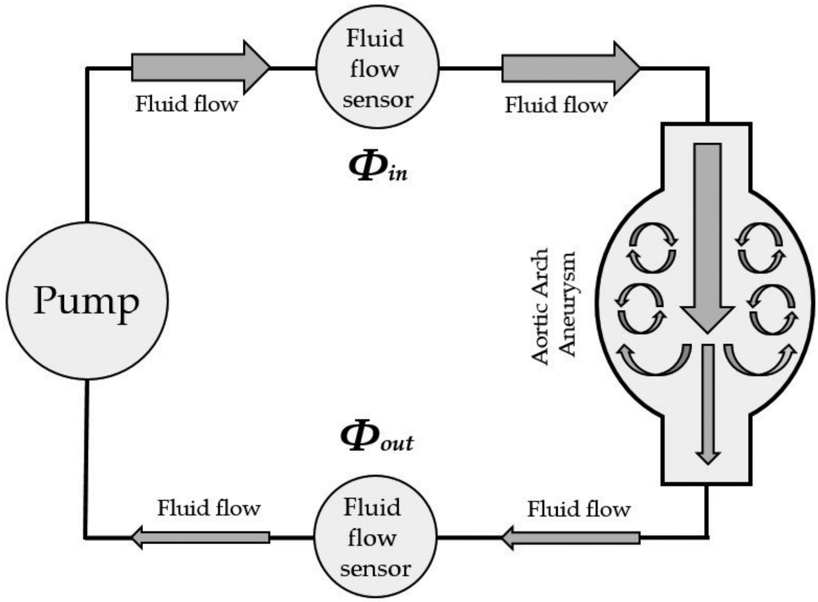

Fig. 1. Diagram of the principle circuit for fluid flow rate measuring in aortic arch

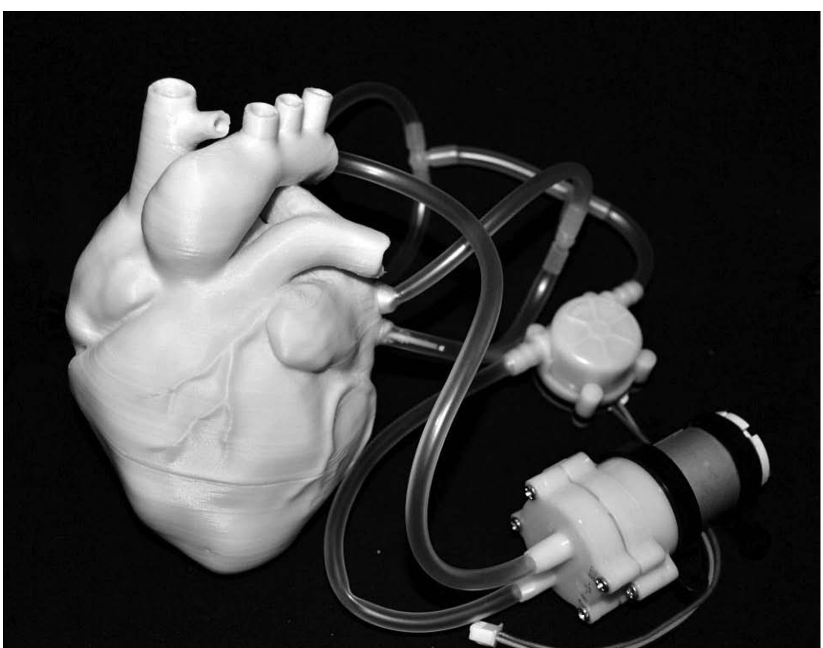

Fig. 2. 3D model of a circuit for fluid flow rate measuring in aortic arch aneurysm

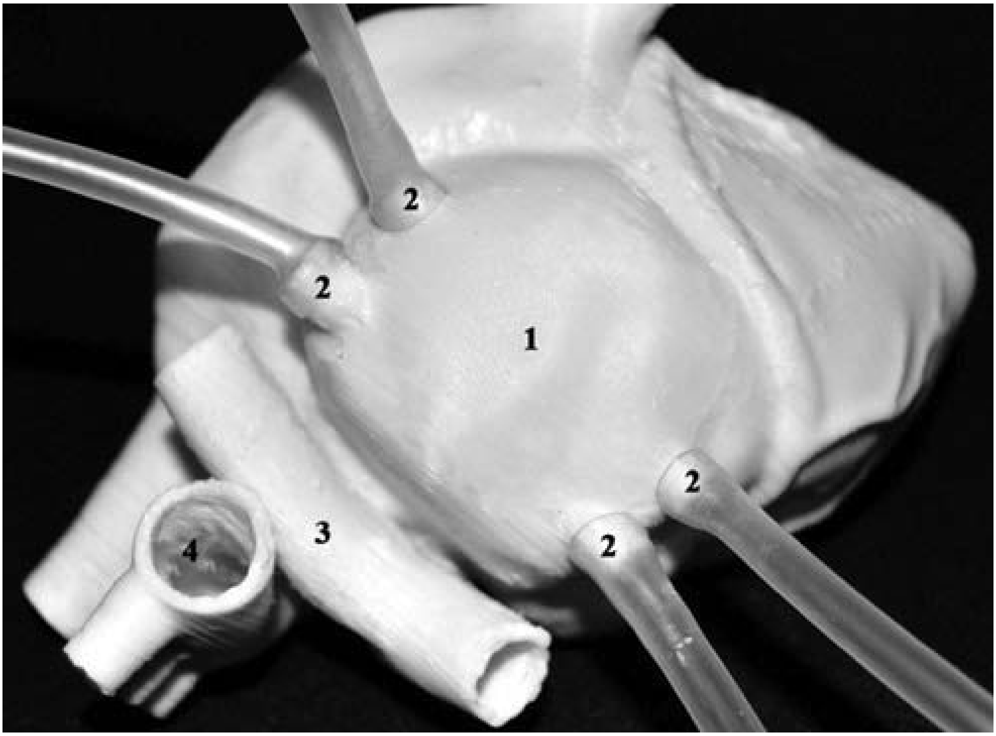

Fig. 3. Connection of the silicon tubes with 3D printed human heart. 1- left atrium, 2 - pulmonary veins, 3 - pulmonary trunk, 4 - aorta.

Another problem occurred while choosing the printing material for the heart and, respectively, the blood vessels. We used not transparent and less elastic material. The model was equipped with an electrical motor, silicone tubes and flow sensor. For fluid we used saline. We used computer program to change the problematic part of the aorta creating second model in order to study the differences in the fluid dynamics of the saline. The fluid model shows reduced blood flow passing through the aorta. The main reason for that is the creation of the vortex fluid movements, which are fed primarily by the kinetic energy of the main fluid flow. A major consequence of this, is a reduction of the velocity and blood flow rate through the aorta. To compensate this shortage the cardiac muscle contractions becomes more powerful and needs more energy consumption. The long term effect of this disease leads to overloading of the heart muscle and causes disruption of the normal function.

The results apparently showed "vortexing" and slowing down the fluid's rate in the area of aortic aneurysm. The deviation of the norm in the movements of the fluid and the reasons for its delay can be observed macroscopic. In our opinion, these models, although without the characteristic of internal heart morphology, can improve motivation and knowledge of medical students related to vascular diseases. Each fluid dynamic model has better training potential than schemes and images and allows to open a new chapter in the scientific research. The 3D modeling of blood vessels could be used in different anatomical areas. This will help to study and actually visualize the presence of thrombosis of varicose disease. The model described in this manuscript could be used together with color duplex of the blood and Doppler check of the blood velocity.

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