MODELING OF HUMAN CIRCLE OF WILLIS WITH AND WITHOUT ANEURISMS

Ivanov D. V., Dol A. V., Pavlova O. E., Aristambekova A. V.
Saratov State University named after N. G. Chernyshevsky
ivanovdv@gmail.com, dzero@pisem.net,
pavlovaoe@yandex.ru, aristambekovaav@mail.ru

Cerebral aneurysms don't have pronounced and stable clinic symptoms, but quickly lead to dramatic consequences in case of development of complications. Despite the social and economic value and a long history of studying the issue from the medicine point of view the mechanism of aneurysm development and factors affecting their appearance are not yet fully understood. In accordance with the clinical data up to 80–90% of non-traumatic subarachnoid hemorrhage in Russia are due to rupture of intracranial aneurysms. Aneurysm rupture leads to neurological disorders of varying severity caused by damage of the brain tissue or to death. Especially important is the fact that the subarachnoid haemorrhage disables the working age population (40–60 years).

Aneurysms can be acquired or congenital. Recent studies show that the majority of aneurysms develop as a result of hemodynamic and degenerative lesions of the vascular wall. Obviously, such wall damage can be studied using the methods of continuum mechanics and numerical simulations. Biomechanical modelling allows to study hemodynamic parameters and stress-strain state of these arteries in health and disease, and to formulate practical recommendations for the necessity and reasonable selection of a particular type of cerebral arteries aneurysm treatment.

Many researchers believe that aneurysms form due to hemodynamic wall damage and pay attention to the values of shear stresses on the walls of arteries and aneurysms. Authors noted the presence of high values of shear stresses (more than 20 N/m^2) in arterial bifurcations. High shear stresses cause damage to the vessel wall and, consequently, lead to the formation of aneurysms. A series of papers performed under the leadership of the professor G. A. Holzapfel [1–4] and devoted to the study of cerebral aneurisms growth processes from continuum mechanics point of view were published. Authors believe that the development of an aneurysm is accompanied by the loss of media, and the entire load is applied only to the collagen fibers.

Although three-dimensional reconstruction of the arteries today can be performed even in clinic with the help of built in scanners software these images are not three-dimensional models and can only be used for visual examination of the blood vessels geometry. Therefore, the problem of reconstructing a realistic spatial geometry of blood vessels and aneurisms suitable for numerical calculations of their behavior is relevant.

Much attention in the modern scientific community is paid to restoring the geometry from the CT and MRI [5–6]. These authors are trying to work with tomograms of individual patients, allowing escape from generalizations and to compare the results of calculations with the parameters of the specific person blood flow. These models often have realistic geometry of the arteries, but it sometimes leads to certain difficulties in the development of computer simulations and problems with numerical calculations. So it is necessary to correct and optimize the geometry. Many scientists use specialized software Mimics TM for the initial work with tomograms. Further work with geometric images is performed in the third-party programs and grid generators, which requires additional steps often in manual mode, and that greatly complicates the process.

Some attention in current literature is paid to numerical methods for the recovery of the geometry. For example, the Monte Carlo method, calibrated in a certain way was used to simulate the human brain based on MRI. However, this approach is quite complex and labor intensive. Obviously, the three-dimensional realistic model of vessels allows to describe their behavior more accurately and make more adequate conclusions on the arising, growth and rupture of aneurysms. However, some authors still use one-dimensional models.

In our view, it is necessary to find a «middle ground» among the proposed methods of constructing geometric models based on tomographic data. It is important not only to create realistic models of vessels. For the numerical computation model should be smooth. It shouldn't have any defects. Model should be covered by a limited number of surfaces. Moreover, the method of constructing such models should not be overly time-consuming.

Researchers paid special attention to boundary conditions, which are set at the inlets and outlets of the vessels during finite-element analysis. Most authors prefer to set inflow velocity at the inlets, but some authors set volume blood flow at the inlet.

If we consider the patient-specific model of the circle of Willis of individual patient, it is necessary to take into account not only the vessels geometry. Blood flow velocity at the inlets as well as mechanical properties of the walls are very important for the computer simulation.

Situation with the first two items is quite simple. We can construct the realistic patient-specific geometry from the CT and MRI data. We can use ultrasound examination of the vessels of the same patient to find out boundary conditions for the velocity and pressure. The problem is to obtain the mechanical characteristics of the individual patient. At present it is not possible to determine the mechanical properties of blood vessels of a living person. So we made the following decision: on the basis of mechanical tests of more than 100 samples of human arteries of the circle of Willis which were conducted in 2008–2009 [7] we obtained an average mechanical characteristics. So the average data corresponding the sex and age group of studied patients were used in the numerical calculations.

Though there are many studies on aneurisms of the arteries of the circle of Willis, we didn't find any work that contains the problem definition of the patient-specific arteries behavior and means to assess mechanical factors leading to formation and evolution of aneurism at the same time and that could be used in clinical practice.

In this paper we introduce the original methods of constructing the 3D patient-specific smooth geometric models of healthy arteries of the circle of Willis and arteries with aneurisms.

In order to define boundary conditions for linear velocity of blood flow at the entries to the circle of Willis we processed ultrasound data for carotid and vertebral arteries.

In the end of the paper the procedure of acquisition of material coefficients in the model of circle of Willis arteries walls based on mechanical experiments data is described.

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INVESTIGATION OF THE STRESS-STRAIN STATE OF THE INTERVERTEBRAL DISK IMPLANT BY THE METHOD OF INTEGRAL EQUATIONS

Karalevich U. V., Medvedev D. G.

Белорусский государственный университет,
Беларусь, 220030, Минск, пр-т Независимости, 4
medvedev@bsu.by

Modern intervertebral disc implants allow us to successfully solve many problems associated with the diseases of the human spinal column. By constructive EC-implementing, they may be metal, polymeric, ceramic or may combine some properties of these materials.

In this paper we study the stress-strain state of the intervertebral disc implant M6, proposed by the orthopedic clinic Vitos in Kassel (Germany). As the Head of the Spine Surgery Department Dr. Ulrich Schmitz-Sieg assures: «the implant is strikingly similar to the natural intervertebral disc with regard to its anatomy and function. A high-elastic core as well as a natural pulposus nucleus of the intervertebral disc withstands heavy loads and is a shock absorber. Instead of the natural fi-