Biomechanical evaluation of the walls of abdominal aortic aneurysms

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1. Introduction

The development of an abdominal aortic aneurysm (AAA) is a long-lasting, gradual and, usually, asymptomatic process. Thus, the diagnostics of the aneurysm poses some difficulties and most cases are diagnosed by accident. An untreated aneurysm results in death when its walls are destroyed. The mortality rate in the case of the abdominal aortic aneurysms’ rupture ranges from 80% to 90% [1, 2]. A surgical repair of AAA (an aneurysmectomy) is the only effective way to treat aneurysm and prevent it rupture. This procedure, which includes inserting an artificial prosthesis of a vessel, is highly invasive and rather dangerous [1, 3]. Patients with an aneurysm with the diameter of approximately 55 mm or more are scheduled for a planned surgery in order to remove the aneurysm, as it is believed that the larger the diameter the higher the risk of a rupture [4, 5]. However, the „maximum diameter criterion” seems unjustified in the case of estimating the risk and the stage of an aneurysm development because AAA may rupture even in the vessels of a 40 mm or less diameter, in which cases the hypothetical risk is the lowest [6], whereas other aneurysms grow and reach the size of (80÷100) mm without any signs of rupturing [7]. This implies that searching for other indicators of the severity of AAA and its degree of development is essential. Recently, there has been a rise of interest in the possibilities of using the mechanical properties of abdominal aortic aneurysm’s walls in order to estimate the probability of a rupture and to assess the degree of an aneurysm development.

2. Methods

The purpose of this paper was to determine the influence of the elastin and collagen fibres degradation in a vessel wall on its mechanical properties, as well as to prepare an identifying description of an abdominal aortic aneurysm development, basing on the assessment of the mechanical properties of blood vessels walls. Multiaspect experimental research was carried out, the results of which formed the basis to evaluate the mechanical properties and the microscopic structure of the walls of different preparations of healthy abdominal aortas and aneurysms. The mechanical properties were determined on the basis of a uniaxial tensile test, with the use of MTS Synergie 100 loading system, and on the real time analysis of the changes in the geometric dimensions of the scrutinized specimen, which was feasible owing to the videoextensometer system (ME 46-350, Messphysik), employed in such tests for the first time. Three measurement techniques were applied to analyze the microscopic structure, i.e. classic histology, pictures obtained in scanning electron microscopy and chemical composition analysis, based on X-ray microanalysis.

3. Results

Basing on the mechanical properties tests a stress-strain characteristic, which is a highly non-linear curve, was determined for each case analyzed. They were described fairly precisely by an essential equation derived from a hyperelastic model, founded on the neo-Hookean generalized model. The model was used with the assumption of the isotropy and incompressibility of the aortic aneurysms walls. The equation applied is a phenomenological model and may be called quasi-structural because of its conformity to the Holzapfel’s and Weizsacker’s postulate [8], which talks about the additive split of the isochoric strain-energy function into parts connected with the different deformation of a structure. Two distinct coefficients were determined due to the division of the curve into two areas – the first was related to the structure deformation at low deformation values and the second at high deformation values. On the basis of this data, the results of structural and mechanical research were quantitatively correlated for the first time. The description of the influence of the structural transformations on vessel walls stiffness and strength was particularized. It was shown that there is a high degree of correlation for the connection between the parameters determined for the first range of the stress-strain curve and the amount of elastin fibres, as well as between the values determined for the second range of the deformations characteristics and the amount of collagen fibres. The strength and the amount of collagen fibres also demonstrated a very good correlation.
4. Discussion

The research done on a numerous and diversified population, using advanced analytical techniques (data clustering), allowed to suggest an aneurysm development’s three-stage description, which took into consideration the changes of its walls’ mechanical properties. It was revealed that during the process of an aneurysm developing, there is a reduction of the vessel walls strength. On the other hand, the walls stiffness in the range of low strains (connected with elastin fibres) is gradually increasing and in the range of substantial deformations (connected with collagen fibres) it is growing at first but then suddenly starts decreasing in proportion to the reduction of fibres. The problem of changes of the mechanical properties taking place in the development of an abdominal aortic aneurysm was treated as the key criterion to estimate the progression of the illness.

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References