Heart rate effects on intracranial aneurysm hemodynamic.

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Abstract: The hemodynamic is an important biomechanical factor influencing the development of different forms of vascular diseases, especially intracranial aneurysms, in where hemodynamic environment influences strongly their genesis, growth and rupture. The purpose of this study is to assess the influence of the Inlet frequency variation on different hemodynamic parameters inside intra-aneurysmal circulation, using computational fluid dynamics combined to patient specific MRI images. By the variation of the heart rate we observed disturbance of the overall hemodynamic parameters assessed on the geometry. The increase of the heart rate, allowed observing de disturbance of the association between flow and pressure inside the aneurysmal sac. The intra-aneurysmal flow is highly influenced by the feeding inlet frequency, which may cause growth or in the extreme case, the rupture of the aneurysm.

Keywords: Intracranial aneurysms, Hemodynamics, flow, pressure.

1. Introduction (10 point, bold)

Intracranial aneurysms (IA) are abnormal bulging or a focal dilatation located on cerebral arteries, frequently found in the bifurcations of the circle of willis (CoW). The rupture of IA causes subarachnoid hemorrhage (SAH), which is associated to a high morbidity and mortality. The exact mechanism of the IA prevalence is still unknown; however, the physical cause can be described as a decrease of the middle muscular resistance of the artery involving a structural defect and localized weakness of the vessel wall. The hemodynamic is an important biomechanical factor influencing the development of different forms of vascular diseases [1], especially (IAs), in where hemodynamic environment influences strongly their genesis, growth and rupture [2]. Therefore, knowledge of hemodynamic factors becomes very important. The aim of this work is to investigate the effect of the heart rate on hemodynamics parameters inside IA. We focused on two parameters, which are: inlet-intra-aneurysmal delay and pressure-flow shift.

In order to study the heart rate effect on the hemodynamic factors cited above we have performed Time Of Flight (TOF) Magnetic Resonance Angiography (MRA) with GE HDxt system (General Electric Healthcare)using the parameters: repetition time TR=25ms, Echo Time TE=3.2ms, flip Angle: 20°, slice thickness=1.4 mm. The 3D patient-specific aneurysm model is obtained by gathering images of the angiographic, and truncate the aneurysm using open source software 3DSlicer (www.slicer.org). Fig. 1 represents patient specific aneurysm of 52 years female located in the internal carotid artery (ICA). Inside the obtained geometry, the blood flow behaviour can be described by unsteady Navier-Stokes equations for an incompressible fluid with blood density ρ=1060kg/m^3 and a dynamic viscosity μ=4mPas. For the simulations, we used twenty-seven (27) rescaled volumetric flow rate (inlet) and pressure (outlet).further, three pulses were used (or cardiac cycles), where the first is used to examine solution convergence and the second to ensure that numerical stability is reached.

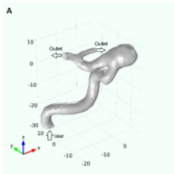

Fig. 1. Patient specific ICA aneurysm.

2. Results and Discussion

Varying heart rate, several phenomena were observed. Among those phenomena we can see a delay between the intra-aneurysmal flow and the inlet flow rate (IFD). This delay can be quantified using the following formula:

$$IFD = \frac{(T_{PS} - T_{Mif})}{CD}$$

Where T_{PS} and T_{Mif} are the temporal positions respectively of the systolic peak and the maximum intra-aneurysmal flow. CD is the cycle duration.

By the variation of the heart rate, the delay between the inlet and the intra-aneurysmal flows at systolic peak varies between 2.87 and 4.21% with a mean delay of $(3.56 \pm 0.42)\%$ (fig 2.a). Furthermore, the IFD increases linearly with the heart rate according the following equation :

$$IFD = 0.049\,.IF - 0.28 \quad with \quad r^2 = 0.86$$

Another phenomenon was observed. A shift between the flow and the pressure in the intra-aneurysmal is noted. The pressure flow shift (PFS) can be calculated by :

$$FPS = \frac{T_{Mip} - T_{Mif}}{CD}$$

Where T_{Mip} is the instant of the maximum of the pressure inside the aneurysmal dome.

By varying the heart rate, the PFS varies from 0.98 to 3.25% with a mean shift of $(1.71 \pm 0.55)\%$. The PFS presents a linear increasing with the inlet frequency (fig 2.b). These variations are given by the following equation:

$$PSF = 0.048\,IF - 2.13, \quad with\, r^2 = 0.81$$

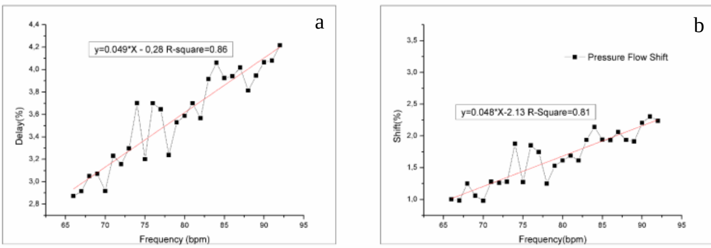

Fig. 2. a) delay between Inlet and the intra-aneurysmal flows. b) intra-aneurysmal pressure flow shift

Inside normal arteries, the blood flow and the pressure are closely associated by a linear relationship. However, the pressure wave reflexion phenomenon inside the vessel, disturbs the coupling Flow-pressure. Therefore, the relation between the pressure and the flow waves, taking into account the reflected pressure waves, is opposite [3]. The presence of aneurysm can affect the hemodynamic factors inside the vessel. A. Sorteberg et al. [4] have found a pessure-flow shift in the aneurysmal dome by varying the frequency of the inlet pressure. However, this can causes an alteration of the pressure inside the vessel and creates a new pressure of stability [5,6]. Our results, obtained by the heart rate variation, show that pressure values disturbance is a sign of a loss of the pressure-flow equilibrium, causing fluctuations of pressure inside the aneurysmal dome and the feeding vessels. In addition, the numerical simulations of blood flow inside the aneurysm allowed the quantification of the pressure-flow shift and revealed its linear dependence to the feeding frequency.

The flow structure inside the IA not only depends on the size and the shape of the aneurysmal dome, but also on how the aneurysm is feed [6]. Therefore, increasing inlet frequency may cause unfavourable blood circulation inside the aneurysm. The increase of the blood stagnation disturbs the flow inside the aneurysm and affects the different hemodynamic factors inside the aneurysmal dome and the parent arteries.

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