Neuroscience and Neurosurgery

New methods for controlling cerebral aneurysms with Reynolds Numberand Shear stress: Literary review

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Summary

An aneurysm is a pathology where a blood vessel dilates abnormally due to a weakness in the vessel's wall. Brain aneurysms result in swelling in the form of a sac, usually in the most fragile arteries. Ruptured brain aneurysms are the most common cause of subarachnoid hemorrhage, a stroke less common than ischemic strokes. This study aims to study the Reynolds number and shear stress for blood flow, as fluid flow is characterized by these parameters. The Reynolds number can identify the region where the flow is laminar, transient, or turbulent, while the shear stress measures the force exerted at the artery wall level.

Blood flow is classified into laminar flow and turbulent flow based on the Reynolds number value. Laminar flow admits symmetrical and parallel current lines, while turbulent flow is characterized by spatiotemporal fluctuations of current lines leading to vortic-like phenomena. The results indicate that blood flow is transient before and after an aneurysm and becomes turbulent inside the aneurysm. Shear stresses are equal to the pressure, which varies little compared to the patient's pressure but increases as blood pressure increases.

Keywords: Brain aneurysm, Reynolds number, Shear stress

1-Introduction

An aneurysm is a pathology not always symptomatic in which a blood vessel dilates abnormally. In this sense, it is a situation in which an artery or vein widens abnormally due to a weakness in the wall of the blood vessel in question. A cerebral aneurysm occurs when the wall of an intracranial artery expands abnormally under the influence of various factors. A sac is then created, more fragile than the carrier artery, where blood circulates under pressure, since this sac communicates with the vessel through a collar.

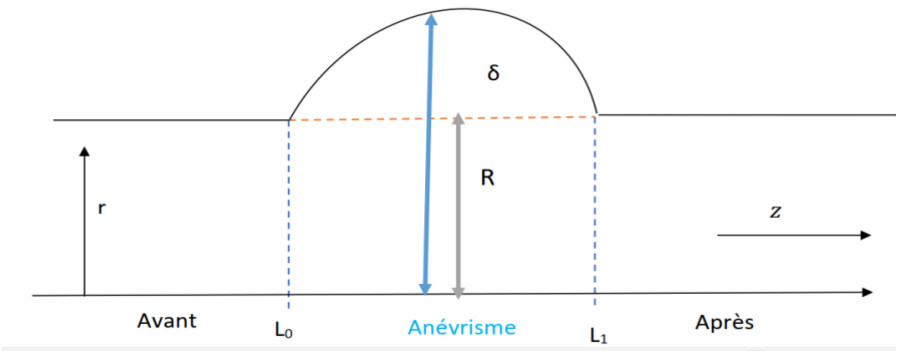
This aneurysm can rupture and cause subarachnoid hemorrhage. The Location, shape, course and mode of discovery of the aneurysm depend on the etiology. The evolution of intercranial aneurysms is towards an increase in their volume under the influence of hemodynamic factors. This increase in volume leads to a weakening of their wall. This is why a ruptured aneurysm is the “The most” frequent and also the most dramatic mode of discovery.

- One of the preferred sites of intracranial aneurysms is the anterior communicating artery (30 to 37%) it is an anastomotic artery connecting the two anterior cerebral arteries in front of the chiasma. It participates in the constitution of the arterial circle of the brain.
- It provides: anteromedial central arteries, suprachiasmatic artery, median commissural artery, median callous artery.

2-Purpose of the study

The study of the Reynolds number and the shear stress for a blood flow is very important because any fluid flow is characterized by these parameters. Through the Reynolds number we will be able to identify the region or regions where the flow is laminar, transient or turbulent; The shear stress will allow us to measure the force exerted on the artery wall

3-Mathematical method



Blood flow is considered in anterior communicating artery of length L and radius R, δ is the maximum swelling of the aneurysm. The equation of conservation of mass will be represented by the conservation of the mass flow rate and the continuity equation will be governed by the compressibility of the blood.

The geometrical parameters are usually used to determine the category and characteristic of aneurysms for making treatment decisions. These parameters include aneurysm size, aspect ratio and vessel curvature. Study area are Before, after aneurysm and the region of aneurysm.

In order to model this pathology, we will use the Navier Stokes equations in the directions (r, θ, z), the equation of continuity and this by applying the following assumptions

- Permanent regime: $\frac{\partial}{\partial t} = 0$
- Flow along the axis of revolution z: $v_r = v_\theta = 0$ and $v_z \neq 0$
- Symmetry with respect to the axis so we have no influence according to θ, the flow is axisymmetric $\frac{\partial}{\partial \theta} = 0$
- The anterior communicating artery is horizontal with a small diameter so following all directions $\rho g = 0$

We also apply approximations such as:

- Cylindrical the anterior communicating artery so the blood flow is everywhere parallel to the walls (Lubrication approximation)

- Friction at the walls (non-slip condition) implies that the speed is zero
- The pressure does not vary (lubrication approximation)
- The velocity is parallel to the axis of the anterior communicating artery (z) $\vec{v} = v\,\vec{u_z}$

We will introduce Young's relationship [1] for stenosy but we have modified it for aneurysm

$$r(z) = R + \frac{\delta_{math}}{2R}\left(1 - cos\,\frac{2\pi z}{L_0}\right)$$

In order to calculate the radius of the aneurysm as a function of position and this for different possible deformations with $\delta_{math} = \delta_{cli} - 1$

Now let's move on to the formula of speed

$$v_z(r) = \frac{A}{4\mu}\left[r^2 - \frac{1}{2}(R^2 + r^2(z))\right]$$

with $A = \frac{dP}{dz}$, that will allow us to have the pressure at the level of the aneurysm according to the deformation of the artery and the pressure of the patient.

Reynolds number

$$Re = 2\,\rho_{sang}\,v_m r(z)/\mu_{sang}$$

$\mu_{sang} = 3{,}3\ \times 10^{-3} Kg/ms$

$\rho_{sang} = 1060\ Kg/m^3$

$$v_m = \frac{Q_V}{S} = \frac{Q_V}{\pi r^2} = 4\ m/s$$

Shear stresses and pressure

$$\sigma_{\theta\theta} = -p + 2\mu\left(\frac{1}{r}\frac{\partial v_\theta}{\partial \theta} + \frac{v_r}{r}\right) = -p$$

$$\sigma_{rr} = -p + 2\mu\frac{\partial v_r}{\partial r} = -p \qquad \sigma_{zz} = -p + 2\mu\frac{\partial v_z}{\partial z} = -p$$

Using the continuity equation: $\frac{\partial v_z}{\partial z} = 0$; We obtain $\sigma_{r\theta} = \sigma_{\theta r} = 0$ and $\sigma_{rz} = \sigma_{zr} = 0$(z)

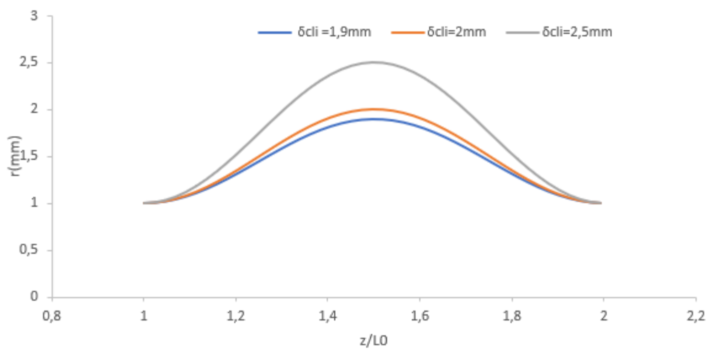
The pressure at any position (z) is:

$$P_z = \frac{4\,\mu_{sang} v_m L_0}{r^2(z)}\left(\frac{z}{L_0} - 1\right) - \frac{8\mu_{sang} v_m L_0}{R^2} + P_0$$

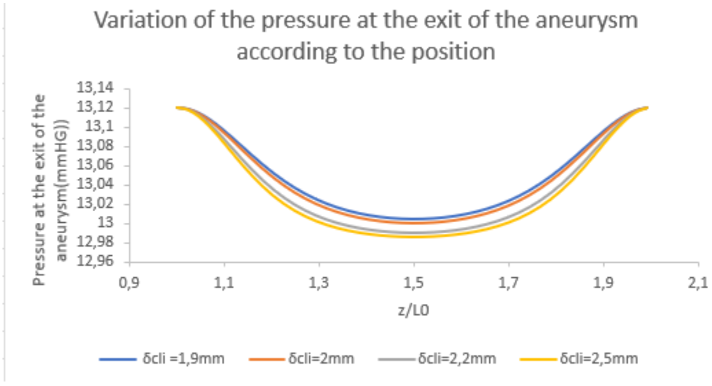
With $L_0 = {}^{L}/_{3}$

So, with this relation, we get the shear stresses as a function of the z position.

4-Results and discussion

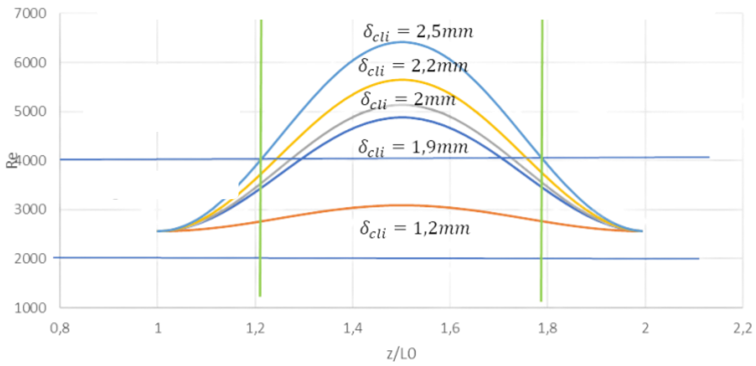


This graph tells us that the position of the aneurysm does not depend on δ_{cli} also that the value of the maximum radius coincides well with δ_{cli}.



This graph tells us that the pressure is minimal at $z/L_0 = 1{,}5$ therefore $z = 2mm$ and $r = 1{,}0054mm$, and the pressure are constant during aneurysm which confirms the hypothesis

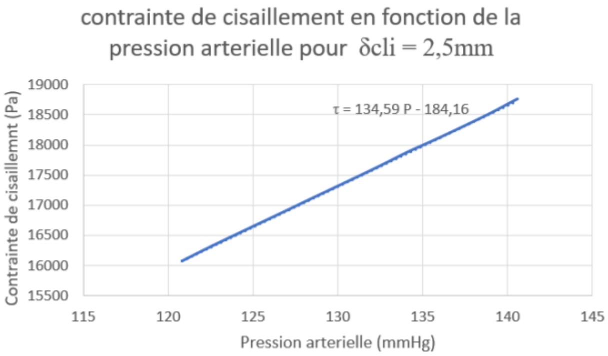
Reynolds number as a function of aneurysm size and size



For $\delta_{cli} = 1{,}2mm$ the regime is always transitory regardless of the position

On the other hand, for $1{,}9mm < \delta_{cli} < 2{,}5mm$ the regime goes from transitional to turbulent such as:

$$\begin{cases} \text{regime transitional for } 1 < \dfrac{z}{L_0} < 1{,}2 \\ \text{regime turbulent for } 1{,}2 < \dfrac{z}{L_0} < 1{,}8 \\ \text{regime transitional for } 1{,}8 < \dfrac{z}{L_0} < 2 \end{cases}$$



This graph shows us that the shear stress increases linearly as a function of arterial pressure and this according to the correlation

5 Conclusion

This work will lead us to early detection of intracranial aneurysm just with the radius and the position of aneurysm and allowed us to use biomechanical parameters in order to apply them to medicine and more specifically to brain aneurysms. The parameters are the Reynolds Re number and the shear stresses

For a low magnification the regime remains transient on the other hand for a magnification of the order of 1.8mm up to 2.5mm the speed becomes turbulent.

The shear stress remains virtually constant along the position but increases linearly depending on the patient's blood pressure.

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