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LUMPED PARAMETER MODELING FOR CEREBRAL VESSELS – A NOVEL APPROACH

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Abstract:

Intracranial Arteriovenous malformations (AVM) constitute usually congenital vascular anomalies of the brain. AVMs are composed of complex connections between the arteries and veins that lack an intervening capillary bed. A brain AVM (BAVM) is a set of abnormal vessels comprising feeding arteries; draining veins and a collection of arterialized veins called the Nidus. The AVM model with vessel dilation is more similar to clinical observations than those without vessel dilation. The invention we proposing is the various combination of RLC circuits for each diameter and measuring voltage /pressure at each location of vessel by non-invasive, that will help radiologist to determine hemodynamic of the cerebral circulation.

Cerebral Arteriovenous Malformation (CAVM) is an abnormal shunting of vessels between arteries and veins. It is one of the common Brain disorder. In general, the blood flows of cerebral region are from arteries to veins through capillary bed. But due to shunting more pressure is flow from arteries to veins causes the rupture of blood vessels causes' death to the patient. Our focus in this research work to create a new electrical model using lumped parameter that will simulate the pressure at various locations of the blood vessels, which helps Doctors to take diagnostic and Treatment planning for treatment. The modeling using Zero-D models provide a concise way to evaluate the hemodynamic interactions among the Cerebral Vessels Modeling.

Introduction:

The proposed method address the issues such as - measurement of pressure and velocity at any location of vessel by invasive and also patient care and patient safety is given high priority.

The following g methodology used for the modeling of the Cerebral AVM:

- Segmentation of Vessels
- Lumped mathematical model for blood flow in Cerebral Arteries.
- Validation of Model

The electrical stimulation of the each part of vessel for the small length variation is of new concept, where the measurement of voltage or pressure is not possible in the current clinical environment, hence a simulation is required to measure the pressure at various locations in a single vessel to take a clinical decision for the treatment planning. As of now the only option to measure pressure is by the catheter insertion to the corresponding location, which is invasive, this method proposes a non-invasive method

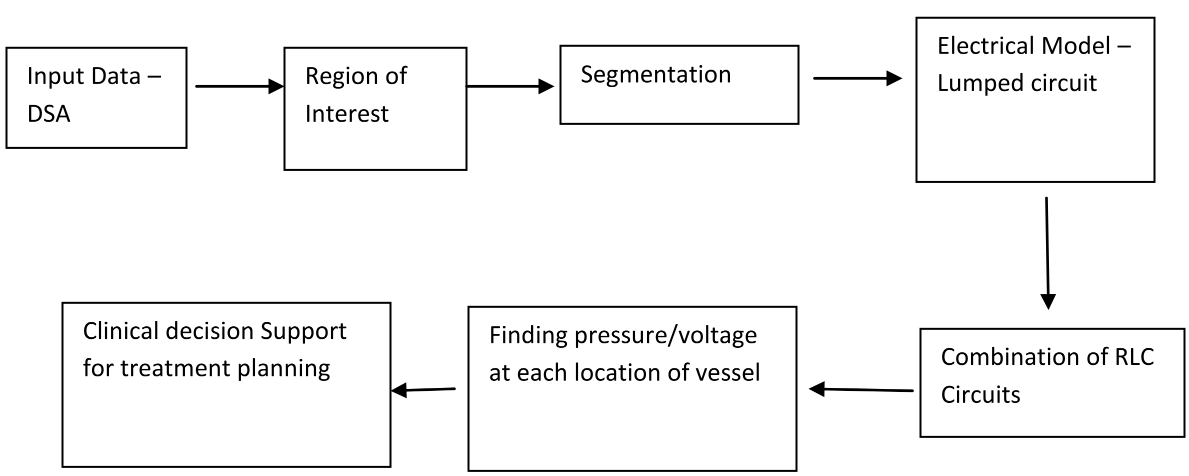
Modeling of the physical properties of Cerebral arterial systems is important in understanding the dynamics of pressure flow relationships and implications of alterations in these properties with respect to, pressure monitoring, and logical approach to therapy [1]. Because overall arterial system properties are presently impossible or impractical to measure directly, they must be estimated indirectly from clinical measurements like pressure, flow, volume.

The advantage of the proposed methodology is as follows:

1. Non invasive method of measurement of pressure, velocity for each branch of vessel

2. Clinical decision support systems suggesting analysis to perform treatment planning

Methodology:



Segmentation of Vessels: The first step of the Electrical Modeling is to segment the cerebral arterial vessel and using the segmented output, the clinical parameters like radius of vessel, Length, area of the vessels can be calculated. The following are the various techniques used for the automatic segmentation of the cerebral arterial vessels [4] - OTSU, Threshold based, and Region Growing. We have used OTSU segmentation, as the results are better visible than other techniques of Segmentation as shown below:

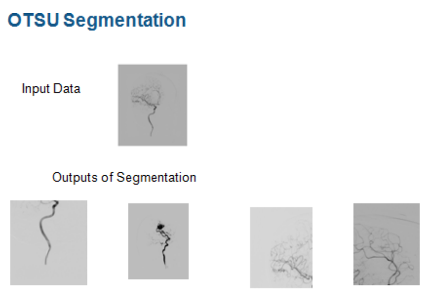


Figure 1: OTSU Segmentation

Lumped mathematical model for blood flow in Cerebral Arteries: Windkessel and similar lumped models are often used to represent blood flow and pressure in the arterial system [5]. These lumped models can be derived from electrical circuit analogies where current represents arterial blood flow and voltage represents arterial pressure. Resistances represent arterial and peripheral resistance that occur as a result of viscous dissipation inside the vessels, capacitors represent volume compliance of the vessels that allows them to store large amounts of blood, and inductors represent inertia of the blood. The windkessel model was originally put forward by Stephen Hales in 1733 [6] and further developed by Otto Frank in 1899 [7].

The model is constructed by converting the clinical parameters to the electrical equivalence [8]. For any segmented arterial vessel, the equivalent RLC values are calculated using the following equations: Resistance = pressure drop through the channel / flow $= 8\eta L/ \pi R4$; l its length and μis the fluid viscosity. R is the radius

$$R = \frac{8l\pi\mu}{A^2} \qquad (1)$$

Where μ is blood viscosity, l and A are in respect length and cross section area of each arterial segment. Blood viscosity is a measure of the resistance of blood to flow, which is being deformed by either shear stress or extensional stress. This simulation has considered because blood viscosity will cause resistance against Blood flow crossing.

$$L = \frac{9l\rho}{4A} \qquad (2)$$

Where ρ is blood density.

$$C = \frac{3l\pi r^3}{2Eh} \qquad (3)$$

Where r, E, h are in respect artery radius, Elasticity module and thickness of arteries. The arterial radius and thickness are calculated from the segmented vessel, which is used for calculating the R, L, C values to generate electrical Model [8-10].

Results & Discussion:

The following figures [1-5], shows the input image, Segmentation output , length of the segmented vessel and diameter variations at different locations. The figure 6,7 shows the electrical modeling circuits and table 1.0 shows the results of the modeling output.

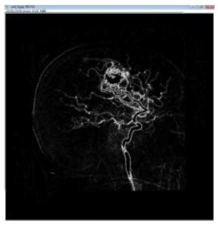


Figure 1: Input Image:

Figure 2: ROI – Segmentation:

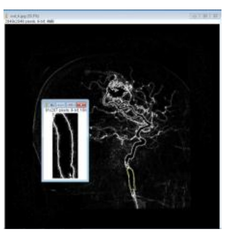
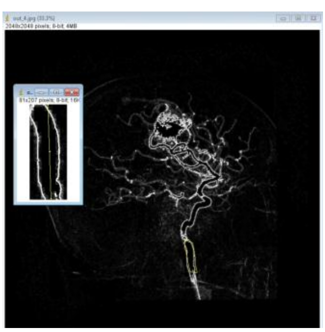


Figure 3: Length of Segmented Vessel:



Diameter of Vessel at different locations:

Figure 4: Diameter – 32 units =1.1cm

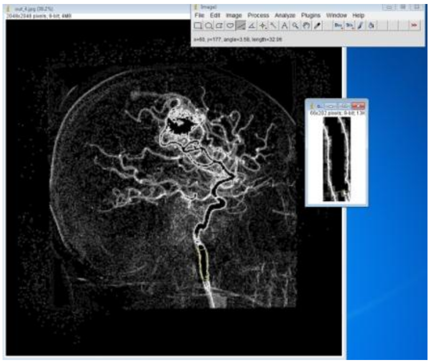


Figure 5: Diameter – 41 units = 1.416cm

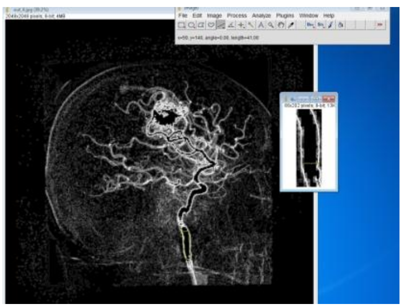
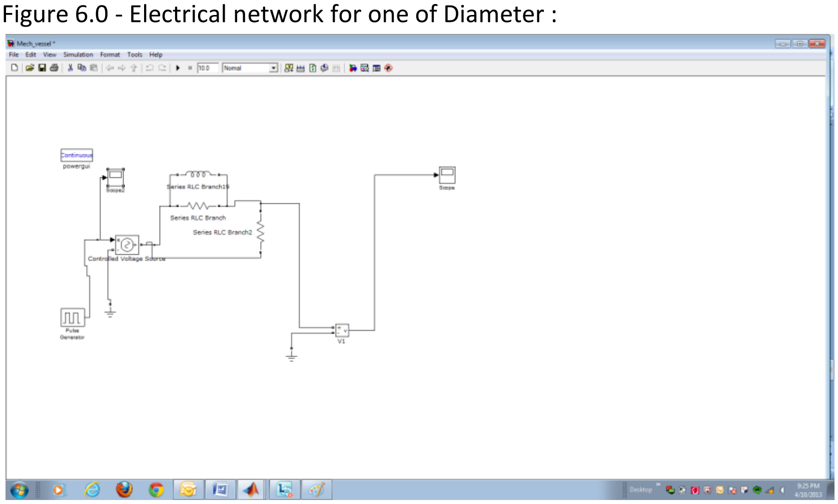


Figure 6.0 - Electrical network for one of Diameter :



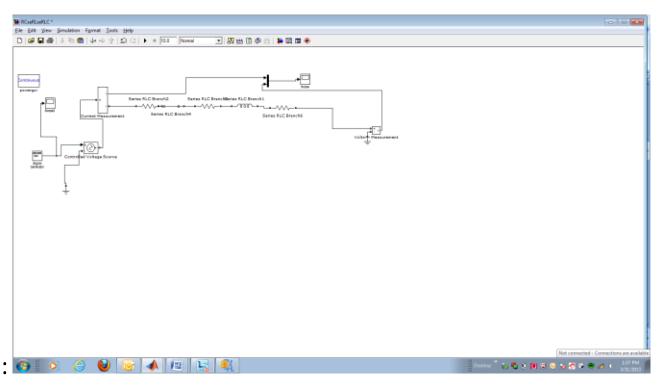


Figure 7.0 - Electrical Model for the complete vessel:

Table 1.0 : Electrical Modeling output

V-IN	V-OUT
1	0.9
0.8	0.7
1.2	1.1

Validation with Equivalent circuit

The validation of the above segmented outputs and electrical circuits are validated with equivalent network by combinations of various segmented vessel network. The figure 8.0 is the equivalent network of the above outputs and it is validated with results of Table 1.0. The results are matching with results of the validated circuit as per the table 2.0.

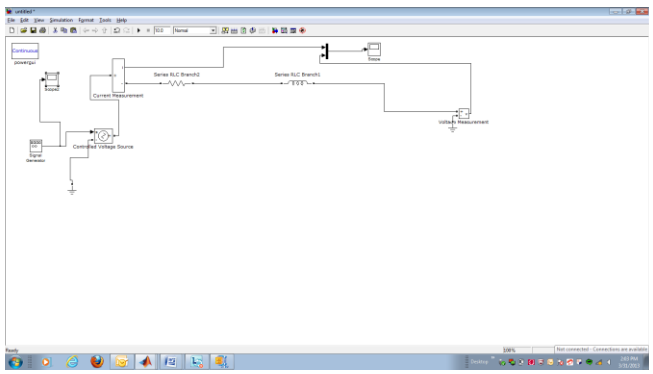


Figure 8.0 Equivalent Electrical Circuit

Table 2.0 : Equivalent Modeling Output:

V-IN	V-OUT
1	0.9
0.8	0.7
1.2	1.1

Mechanical Output Validation: We also performed the validation of our model with the Mechanical simulation using PiPeFlow Expert software and simulated the exact conditions of the electrical network with mechanical inputs and achieved the equivalent results of electrical. The figure 9.0 shows the mechanical output are as follows:

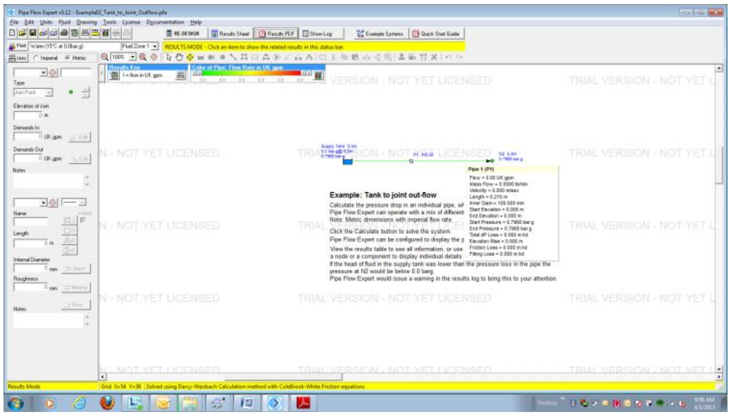


Figure 9.0 : Mechanical Simulation

Conclusion:

The proposed approach for the mathematical modeling of the AVM vessels is unique as it helps to find the pressure values non-invasive , which will help doctors to take clinical decision and treatment planning. This work is in progress to perform more complex segmentation and complex modeling**.**

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