# Vessel Deformation Modeling- Cerebral Arteriovenous Malformation

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**Abstract** Cerebrovascular abnormalities are extremely complex, due to the multitude of factors acting simultaneously on cerebral hemodynamics. Cerebral Arterio Venous Malformation (CAVM) hemodynamic in one of the vascular abnormality condition results changes in the flow and pressure level in blood vessels. This can cause rupture or decreased blood supply to the tissue through capillary causing infarct. Measuring flow and pressure without intervention along the vessel is big challenge due to occlusion, bending and thinning of the vessel in Arteriovenous Malformation patients. In this paper, we proposed a lumped model for the Vessels Deformation in CAVM Structures that will help clinicians to find the pressure and velocity measurements non-invasively.

Keywords: Vessel Deformation, AVM, Lumped Model

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#### 1. Introduction

Cerebral Arteriovenous Malformation (CAVM) is an abnormal tangle of brain blood vessels where arteries shunt directly into veins with no intervening capillary bed which causes high pressure and hemorrhage risk. Intracranial Arteriovenous malformations 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 modeling of the Hemodynamics with physical properties of Cerebral AVM 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 and treatment.

The aim of this work is to model the pressure at various vessel deformation of a DSA/3DRA dataset using the Lumped models. The input parameters used for the proposed simulation and for analysis is the clinical parameters. In the present work we have used new modeling approach for the Vessels Deformation from 2D & 3D data.. In the literature analysis, the modeling is based on the fluid dynamics of the vessel. It has some drawbacks on the analysis using various signals. In the lumped modeling, the analysis is based on the electrical circuit analogy using WindKessel models, was used provide a computationally simple way to obtain information about the overall behavior of the Neurovascular system. The authors had proposed electrical parameters and derived a number of lumped

models for blood flow and pressure variances in the Cerebral Arteries Windkessel as well as lumped parameter models are used to simulate pressure and blood flow in the arterial system. In these models, electric potential and current are analogous to the average pressure and flow rate, respectively. A particular vessel (or group of vessels) is described by means of its impedance, which is represented by an appropriate combination of resistors, capacitors and inductors. The vessel deformation modeling is a gap, where very few authors have analyzed on this research due to high complexity behavior of vessels.. The below Figure 1 shows the complexity of CAVM, that indicates the complex anatomy of the Vessel.



Figure 1. Cerebral Arteriovenous Malformation (CAVM)

In this paper, we are proposing to address the above gap, by using the WindKessel model for the vessel deformation modeling using lumped model for the asymmetrical and symmetrical networks that simulates the actual neurovascular complexity. Using this approach, the clinicians can measure the cerebral parameters non-invasively.

# 2. Methodology

The input dataset used for analysis is 3D-Rotational Angiogram dataset, which is obtained from Philips Allure Unit. The following steps are applied to volume image:

- 1. 3D ROI is drawn for the Vessel Deformed region, automatically propagated to all the slices, by applying interpolation technique.
- 2. Preprocessing techniques are applied to the ROI by performing enhanced contrast, smoothing algorithm and edge detection algorithm based on intensity.
- 3. The filtering is applied to remove the noise, we have used various filtering techniques –Mean, Median, Convolve and Gaussian Blur, FFT.
- 4. The input 3D RA image is used as the input volume of the Brain AVM (BAVM).
- 5. 3D ROI is drawn for the NIDUS Portion, automatically propagated to all the slices, by applying interpolation technique.
- 6. Preprocessing techniques are applied to the ROI by performing enhanced contrast, smoothing algorithm and edge detection algorithm based on intensity.
- 7. The filtering is applied to remove the noise, we have used various filtering techniques –Mean, Median, Convolve and Gaussian Blur, FFT. The flow chart 1.0 shows the methodology steps

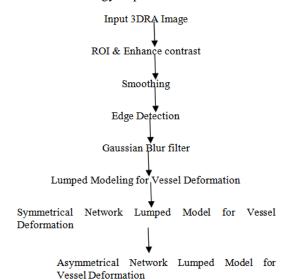


Figure 2. Flowchart of Methodology

#### 2.1. Lumped Model Analysis

Windkessel and 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 equivalent RLC values are calculated using the following equations: Resistance = pressure drop through the channel

/ flow =  $8\eta$  L/  $\pi$  R4 ; 1 its length and  $\mu is$  the fluid viscosity. R is the radius

$$R = \frac{8l\pi\mu}{A^2} \tag{1}$$

Where  $\mu$  is blood viscosity, 1 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.

$$L = \frac{9l\rho}{4A} \tag{2}$$

Where  $\rho$  is blood density.

$$C = \frac{3l\pi r^3}{2Fh} \tag{3}$$

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 [8,9,10].

We have derived the electrical model for the symmetrical and asymmetrical network for vessel deformation. The Figure 3 shows the Vessel deformation model for the symmetrical network.

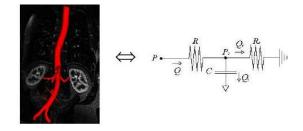


Figure 3. Vessel Deformation Lumped Model

The Figure 4 shows the vessel deformation model for the asymmetrical network, for example a stenoses vessel model for an asymmetry network.

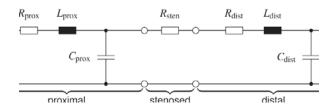


Figure 4. Vesseld Deformation for Asymmetrical Netowrk

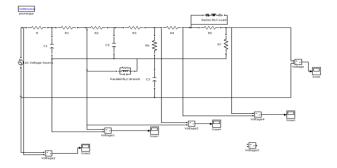


Figure 5. MATLAB Implementation

## 2.2. Statistical Analysis

The statistical analysis for the continuous time varying input signal voltage is measured with mean  $\pm$  standard errors. The hypothesis test is performed for various node voltages at different location of the network. The hypothesis test considers p-values with p-Value < 0.05. The variance and covariance matrix is calculated to show the pattern of the node voltage variation for different input voltages.

## 3. Results and Discussion

The implementation is done using MATLAB Software using 3D-RA dataset. The electrical model is derived for the vessel deformation with symmetric and asymmetric using clinical parameters. The clinical parameters are analyzed and converted in to electrical parameters which help to create a WindKessel model using R, L, C values. The RLC values and its combinations are modified based on the type of network and also type of vessel deformation. This leads to symmetrical network vessel deformation and asymmetrical vessel deformation.

This model is simulated and validated with clinical results and with mechanical outputs. The mechanical simulation is performed using ANSYS software. The Figure 4 shows the MATLAB implementation to simulate the vessel deformation. The effect of vessel deformation shows the clinical significance on the pressure and flow rate variation of the blood flow in AVM patients. Simulations were also performed using the phantoms and also using 2D –DSA images that are varying length with networks of symmetric and asymmetrical. In these simulations for various values of diameters are used to simulate the actual clinical scenario.

## 4. Conclusion

In this paper, we have proposed a neurovascular vessel deformation which indicates the blood vessel movement and other clinical parameters variation. This work helps clinicians to measure hemodynamics parameters non-invasively, which is difficult in real hospital cases using catheter insertion in CATHLAB. This work is based on Lumped Model and it is validated through the Mechanical Model. The simulation is implemented for both

symmetrical and asymmetrical networks. The modeling outputs are used by clinicians for the diagnosis, treatment planning for the AVM Surgery and also for the AVM management.

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