Loop Modeling Forward and Feedback Analysis in Cerebral Arteriovenous Malformation

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Abstract*—Cerebral Arteriovenous Malformation (CAVM) hemodynamic in disease condition results changes in the flow and pressure level in blood vessels. 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. This paper is focus on the creation of a new electrical model for spiral loop structures that will simulate the pressure at various locations of the CAVM Complex blood vessels. The proposed model helps Doctors to take diagnostic and treatment planning for treatment by non-invasive measurement.. 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 loop structures of feedback and forward flows in Arteriovenous Malformation patients. In this paper, we proposed a lumped model for the spiral loop in CAVM Structures that will help doctors to find the pressure and velocity measurements non-invasively.

***Keywords*—Vessel Loops; AVM; Lumped Model**

I. 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 he morrhage risk. 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 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 loops analysis of a MRA/3DRA dataset using the Lumped models. The input parameters used for the proposed simulation and for analysis is the clinical parameters [1-3]. In the present work we have used new modeling approach for the Vessels Loops from 2D & 3D data and also proposed the modeling for the forward loop and feedback loop in any vessel structure .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 loop analysis and modeling is a gap, where very few authors have analyzed on this research due to high complexity behavior of vessels [4-7]. . The below figure 1.0, shows the complexity of CAVM, that indicates the complex anatomy of the Vessel.

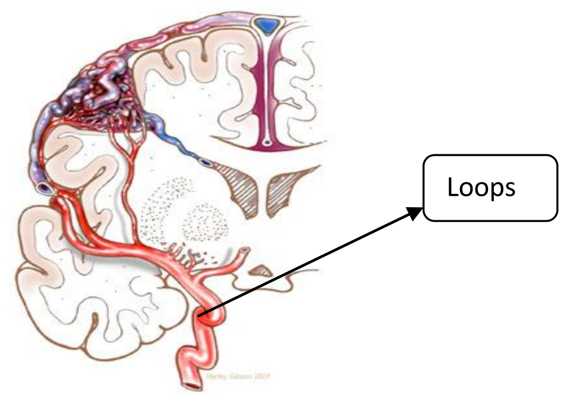

Fig. 1. Cerebral Arteriovenous Malformation (CAVM)

The problem statement we are targeting in the proposed work is to address the above gap, by using the WindKessel model for the vessel Loops types like forward and feedback loop modeling using lumped model for the asymmetrical and symmetrical networks that simulates the actual neurovascular complexity.

II. METHODOLOGY

The proposed methodology is based on the 3DRA dataset, which is obtained from Philips Allure Unit. The input 3DRA image is used as the input volume of the Brain AVM (BAVM). The following steps are applied to volume image:

1) Acquisition of 3DRA/MRA dataset of AVM.

2) Segmentation and Preprocessing techniques are applied to the dataset and enhanced contrast, smoothing algorithm and edge detection algorithm based on intensity.

3) The filtering is applied to remove the noise using wavelet transform.

4) 3D ROI is drawn for the Vessel loop region, which automatically propagated to all the slices, by applying interpolation technique.

5) The modeling is constructed for the loop region for the segmented 3D-ROI. Depending on the clinical scenario of the patient, the loop is separated in to feedback /forward loop of blood flow.

The flow chart

Input MRA/3DRA Image

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PreProcessing and Segmentation

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ROI analysis

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Wavelet filtering

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Lumped Modeling for Vessel Loops

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Forward loop modeling of Vessel

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Feedback loop modeling for Vessel

A. Lumped Model Analysis:

Windkessel and lumped models are often used to represent blood flow and pressure in the arterial system. 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 and further developed by Otto Frank in 1899 [8-10]. , the equivalent RLC values are calculated using the following equations:

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

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.

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

Where ρ is blood density.

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

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 [8-10].

B. Creation of Loop Model:

The below figure 2.0 shows the complex loop of the vessels of the AVM patient. The loop is segmented using threshold based and filtered output is shown in figure 3.0

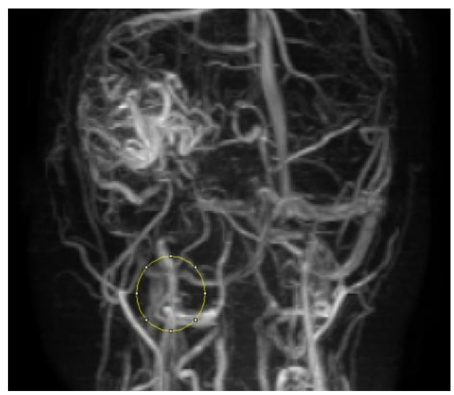

Fig. 2. MRA Dataset

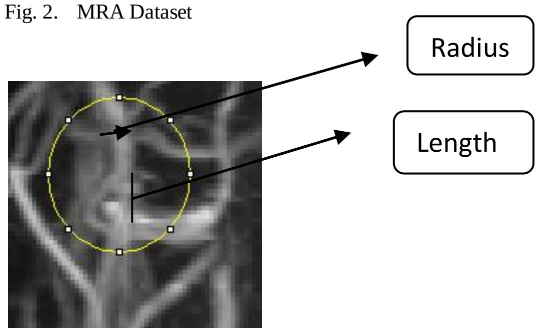

Fig. 3. Preprocessed and Segmented loop

The challenge in the modeling is that it is not direct spiral loop structure, present in the Cerebral vessel, it is the complex structures, which is modeled for the various forward and feedback loop is created using RLC networks, the circuit shows the loop modeling with variation in the inductors and capacitance as shown in figure 4.0 [11-13]:

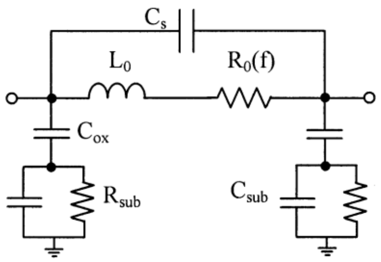

Fig. 4. Modeling Circuit

III. METHODOLOGY

The Loop Modeling is analyzed using various inputs and simulated for various input pressure range /voltage sources. The table 1.0 shows the variations across various inputs.

TABLE I. VARIATIONS ACROSS INPUTS

Input Voltage/ Pressure mmHg/Volts	Output Pressure mmHg/Volts	Clinical results /Application results mmHg/Volts	Mechanical Simulation mmHg/Volts
0.8Volts	0.78	0.8	0.78
1.2 Volts	**1.1**	**1.2**	**1.15**

The statistical analysis is performed for various input voltage range to verify for the stability of the model. The correlation coefficient shows that the results are correlating with mechanical and with actual results from Clinical sites.

TABLE II. STATISTICAL ANALYSIS

Sample size	17
Correlation coefficient r	0.9896
Significance level	P<0.0001
95% Confidence interval for r	0.9705 to 0.9963

IV. RESULTS AND DISCUSSION

The implementation is done using MATLAB Software using 3D-RA and MRA dataset. The electrical model is derived for the vessel loops of forward and feedback propagation of the blood flow based on the symmetric and asymmetrical networks 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 using Electrical Analogy conversion. The RLC values and its combinations are modified based on the type of network and also type of vessel loops.

The figure 5.0 shows the Matlab implementation of the modeling of loops.

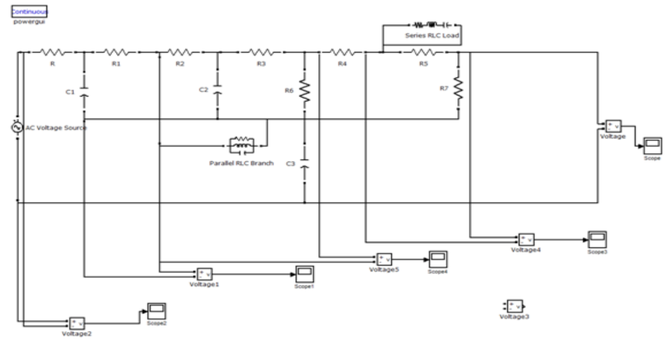

Fig. 5. MATLAB Implementation

This model is simulated and validated with clinical results and with mechanical outputs. The mechanical simulation is performed using ANSYS software. The figure 5.0 shows the MATLAB implementation to simulate the vessel loop structures. The effect of vessel loops analysis 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.

V. CONCLUSION

In this paper, we have proposed a neurovascular vessel loop modeling which indicates the blood vessel movement and other clinical parameters variation. This work is based on Lumped Model and it is validated through the Mechanical Model. The future scope of this work is to analyze all the types of vessel loops for complete brain.The modeling outputs are used by Doctors for the diagnosis, treatment planning for the AVM Surgery and also for the AVM management. This work is in progress for various organs and complex vessels loop analysis.

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