

Classification of normal and anomalous regions in 3D human cerebrovascular phantom

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Abstract— Detection of anomaly in cerebrovasculature is a vital job as it can lead to predict and assess the cerebrovascular diseases. Classification of anomalous part in human cerebrovascular phantom can help to detect some of the vascular diseases. Disease like aneurysm causes a number of deaths worldwide and so it is very crucial for clinicians to predict or assess it. Hemodynamics is commonly thought to play an important role in the mechanisms of development, progression, and rupture of aneurysm. It is reasonable to assume that rupture risk assessment can be improved by incorporating hemodynamic analysis on the parameter like wall shear stress(wss), velocity, static pressure information. So to compare the hemodynamic parameters on different cerebrovascular phantoms with and without aneurysm and to find some features from that for pattern classification, carries a significant role in prediction of occurrence of aneurysm and subsequently rupture risk of the same.

Index Terms— Aneurysm, hemodynamic analysis, cerebrovascular phantoms, wall shear stress, classification, feature, rupture risk.

1 INTRODUCTION

Classification of anomalous part and normal part of the cerebrovasculature is a vital job because disease like aneurysm which is caused by some anomaly in structural form and hemodynamic parameter form.

Aneurysms, basically are some outpouch which is filled with blood and formed in the wall of a blood vessel. This disease is responsible for nearly 500,000 deaths a year worldwide if they burst before being treated. Various hemodynamic parameters are suspected to be major factors related to the genesis and progression of aneurysm. So it is of immense importance for treatment to understand the hemodynamic factors that play a role in the formation and development of disease like aneurysms[1]. The flow pattern will be changed in the vascular structure if there exists an aneurysm and also the hemodynamic parameter values differ from the one without aneurysm. So to classify the aneurysm part and normal part of the vascular structure, it is very crucial to analyze hemodynamics there in and select features from that analysis.

In this work, we focus on the major arterial structure present in the human carotid region because carotid vasculature is the one of the major part of the human vasculature. To do the hemodynamic analysis and to select feature from that analysis, it is important to understand the carotid blood flow patterns and so structural analysis of carotid arteries are needed for determination of abnormal out pouching. Detection of possible shrinkage or blockage in the blood flow determines the causes of malformation. To describe the network of carotid arteries, knowledge about the structure of the Circle of Willis which is present at the base of the brain, is very much necessary. This is a circular vasculature formed by the left and right Anterior cerebral artery (left and right), Internal Carotid Arteries (ICA), Anterior Communicating Artery (ACA), Internal Carotid Artery (left and right) or ICA, Posterior cerebral

artery (left and right), Posterior communicating artery (left and right). The basilar artery and middle cerebral arteries, which supplies the oxygen rich blood to the brain, are also considered as part of the circle of willis [2].

Collecting the medical image is really a difficult job. *In vivo* or *ex vivo* analysis of carotid arterial system is a vital job and need to be taken care very minutely by the experts. Patient permission and participation is equally important to capture and collect the in-vivo images. So construction of synthetic structures or phantoms are very necessary and important as it is important to analyze real medical data. Therefore generation of the synthetic structures or phantoms are often valuable for evaluation and application of new computational techniques [4], [5], [12] at the laboratories. It also helps the patients to avoid repeated harmful cerebral scans. Due to the apparent simplicity of the design, phantom based simulation experiments are most popular. In general, there are two aspects of the study; 1) using physical vascular phantoms with and without aneurysm, generated by casting a replica of the actual vasculature, and 2) digital modeling of the vasculature, using mathematical models.

Weakness of the arterial wall is the major cause of development and progress of aneurysm. If it becomes large enough, it can be ruptured to spill blood into the surrounding tissue. Cerebral aneurysm is a bulge in the vessel wall of an artery located in the brain. There are three types of cerebral aneurysms which can be separated geometrically. A saccular aneurysm is the most common type of aneurysm. It is of rounded shape that is attached to an artery by a neck. As the shape is like berry it is also called berry aneurysm. Another less common type of aneurysm is a fusiform aneurysm. It is of spindle-shape. It is due to the widening of the vessel wall. Another type of aneurysm is a giant aneurysm which is a ber-

ry aneurysm but is large. It occurs mainly at the bifurcation of an artery.

There is no known prevention method for this vascular disease as the initiation of aneurysm is not well understood. If it is not taken care of in right time it can be ruptured and consequently patient may die. So the classification of the part which is with aneurysm from the normal vascular part is very necessary. Numerous studies have been performed to provide the detailed hemodynamic information of the artery. Many studies have attempted to identify appropriate hemodynamic properties related to the aneurysm initiation, progress and growth. Hemodynamic parameters such as the blood pressure, velocity of blood flow and the wall shear stress are performed to be linked to the progression of the aneurysm [14], [15]. Wall shear stress is considered to be highly associated with the development of the cerebral aneurysm. Furthermore, high wall shear stress magnitude or high spatial and temporal variation of wall shear stress may damage the inner wall artery [16], [17].

In this connection, the purpose of the work presented here is to classify the normal and anomalous voxel through features extracted from the study of the flow analysis on the cerebrovascular phantoms with and without aneurysm and the comparison of the hemodynamic parameters therein. Digital topology is used for some studies related to this [6], [7], [8], [9], [10], [11].

2 PHANTOM DESIGN

Some cerebrovascular structure like ICA, circle of willis, complex bifurcation without aneurysm are shown in Fig.1. In Fig.2 we have shown some cerebrovascular phantom with aneurysm.

In first step original CT image is taken as input and converted into fuzzy distance transform(FDT) image. One can find a vast and rich literature on FDT and its application [6],[7], [8], [9], [10], [11]. Recently Guha et al. proposed a FDT based geodesic path propagation algorithm for reconstruction of cerebrovascular phantom which required least user interaction [12].

In next step start and end input seed points are taken from user and geodesic path is found between those two points. Next sphere is drawn at each point on the geodesic path with radius equal to the FDT value of that point. If generated phantom needs further modification user can give more seed points and followed same steps described before.

Fluid dynamics of blood flow which is referred to as hemodynamics explains the physical laws that govern the flow of blood in the blood vessels. Hemodynamic response continuously monitors and adjusts to conditions in the body and its environment. Due to viscosity, flow of blood engenders on the luminal vessel wall a frictional force per unit area known as hemodynamic shear stress.

To do the hemodynamic analysis through the finite element modeling we need synthetic 3-D phantom which will resemble human carotid arteries. Here we have designed 3 cerebrovascular phantom with and without aneurysm which are (1) complex bifurcation structure with and without aneurysm

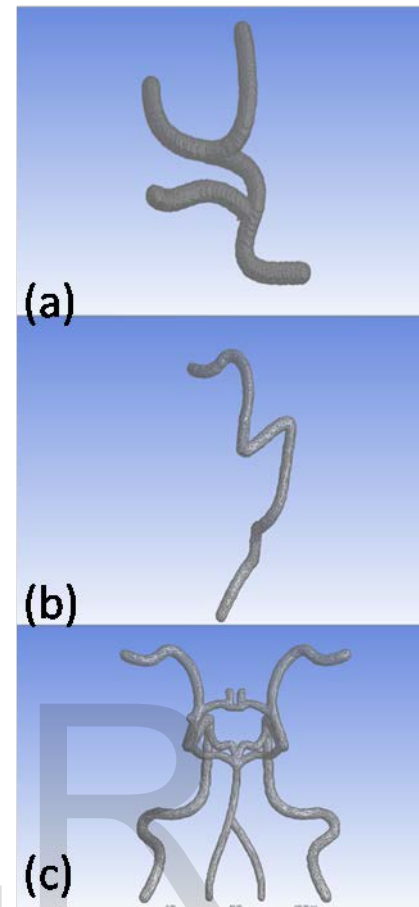


Fig.1. (a) Complex bifurcation without aneurysm (b) ICA without aneurysm (c) circle of willis without aneurysm

(2) ICA (internal carotid artery) with and without aneurysm (3) circle of willis with and without aneurysm which are shown in Fig1 and Fig2. It is informative to note that for 3-D reconstruction during the first phase, we have designed a cerebrovascular phantom [4], [5] and then get a 3-D surface reconstruction for hemodynamic analysis. During the second phase of the 3-D reconstruction process 3-D surface is converted to a 3-D solid mesh.

In case of complex structures a series of pre-processing methods are applied to discard spurious edges and vertices. MeshLab_64bit_v1.3.4BETA [18] has been used for generation of the initial surface mesh and for the rendering purpose. Rhinoceros 5.0 [19] has been used to convert the surface mesh to solid mesh. Another approach of hemodynamic analysis which we applied here uses digital topology. In Fig.2 all the vascular structure are with aneurysm. All these phantoms of Fig.1 and Fig.2 are designed for flow analysis or very specifically for hemodynamic analysis. And from those analysis some important features for classification are to be extracted.

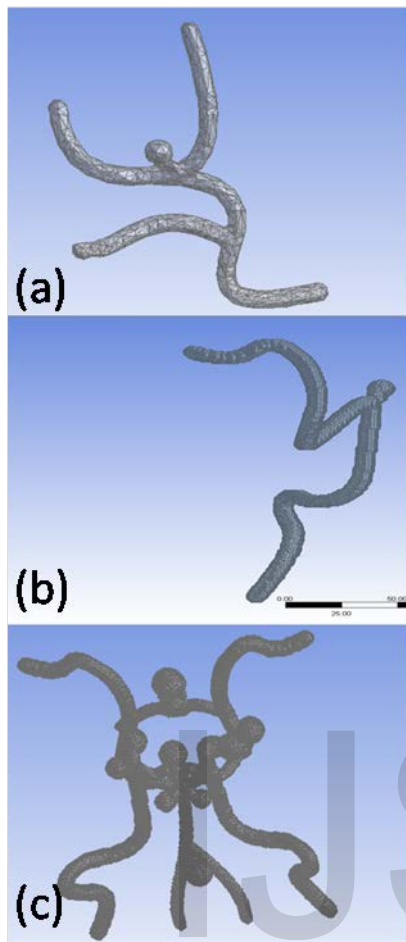


Fig.2. (a) Complex bifurcation with aneurysm (b) ICA with aneurysm (c) circle of willis with aneurysm

3 HEMODYNAMIC ANALYSIS

For hemodynamic analysis we have used two approaches; 1) digital topology, 2) computational fluid dynamics. ANSYS [20] is a well-known computational fluid dynamics software and here it is used for hemodynamic analysis on some cerebrovascular phantoms. To analyze different hemodynamic parameters through flow analysis. The Fluent module of ANSYS Workbench 16.0 is used. Velocity and wall shear stress, pressure are the major hemodynamic parameter which are analyzed and some features are extracted from the flow analysis.

In the present work, we have classified the anomalous part specifically aneurysm part from the normal arterial structure using some flow based and hemodynamic parameter based feature.

4 CLASSIFICATION

Classification of normal and anomalous voxel in 3D vascular structure is the main work to be done. The feature vector which I have generated here for the classification, is obtained from digital flow based model. The features are- number of flow in each direction (Xpositive, Xnegative, Ypositive, Ynegative, Zpositive, Znegative) in 5X5 neighbourhood voxel, velocity, wall shear stress etc.

Training for the classification is done through back-propagation algorithm. Number of hidden neuron is 20. Training is done through 8287 samples whereas validation and testing is done using 1775 samples each. Training and testing for classification is done through Matlab R2013a.

5 RESULTS AND DISCUSSION

Table 1

Test Confusion Matrix			
Output Class	0	1	
	125 7.0%	8 0.4%	94.0% 6.0%
	12 0.7%	1630 91.8%	99.3% 0.7%
		0	1
		91.2% 8.7%	99.5% 0.5%
		92.9% 7.1%	
		Target Class	

From the above confusion matrix we can say that 7% of total test sample is anomalous. 91.8% of total test sample is normal voxel. 8 number of test samples are incorrectly classified as anomalous which is 0.4% of total samples. Out of 133 prediction of anomalous voxel 94% are correct and 6% are incorrect. Out of 1642 prediction of normal voxel 99.3% are correct and 0.7% are incorrect. Out of 137 anomalous voxel, 91.2% are correctly predicted as anomalous and 8.7% are predicted as normal voxel. Out of 1638 normal voxel 99.5% are correctly predicted as normal voxel and 0.5% are misclassified as anomalous voxel. Overall 92.9% prediction are correct and 7.1% prediction are wrong.

$$\text{Accuracy (ACC)} = \frac{\sum \text{True positive} + \sum \text{True negative}}{\sum \text{Total}}$$

population

Accuracy=(125+1630)/1775=.9887

So accuracy of the classification model is 98.87%.

6 CONCLUSION

In this present work we have classified the abnormal and normal voxel of the cerebrovascular phantom. This classification emphasized on the comparison of cerebrovascular phantom with and without aneurysm and hemodynamics therein.

In the flow analysis of the phantom with aneurysm we have found that there is a turbulent nature in the flow which differs from the flow in the phantom without aneurysm. These results are useful for extracting feature from understanding of fluid flows through cerebral vasculature with and without aneurysm. More computational studies on digital flows on phantom with and without aneurysm are important future research directions for the current work. 2-D digital flows have already been used successfully for the study of structural/plastic changes in hippocampal dendritic spines [3]. The classification accuracy of the present work is 98.87%. The work presented may be included in the future study on the 3-D digital flow based hemodynamic analysis in both patients' CTA images with and without aneurysm as well as on complex mathematical phantoms.

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