Modeling and Reconstruction of Blood Vessels Based on CT & MR Images

Sepehr Sadeghian, Soheil Sadeghian, Reza Molaei

***Abstract*—Research on fluid dynamics of the blood vessels and solving the governing equations on fluid flow and extracting comprehensive information from patterns and flow specifications such as velocity distribution and wall shear stress distribution are important subjects in diagnose and evaluation of artery diseases . Fundamental condition for having right evaluation is to have an appropriate three dimensional view from related artery. With more care on this issue and if artery reconstruction becomes more realistic, better results will be gained. In this research a new simple method for artery reconstruction presented. CT images adapted and Matlab and Gambit soft wares are used. Verifying of achieved data described and in the end practical case has been considered.**

***Index Terms*—Coronary, CT images, Matlab, Vessels Reconstruction**

I. Introduction

Published reports of world health organization (WHO) declare that vascular diseases, is the reason of significant portion of human mortality in all over the world.

Researches on 3D geometry and fluid dynamic of human vessels are great importance issue in diagnosis and evaluation of vascular diseases.

Since all vessels have noticeable geometrical differences with each other, to have more efficient and precise consideration, use of more realistic models is necessary. Also presenting proper models for vessels will help us to solving the governing equations of fluid flow throughout the cardiac cycle, have better understanding of inner environment of vessels and prepare key information of mechanical characteristics of fluid flow and by means of these, we can control the environment more precisely and do better prevention, treatment and care for vascular diseases.

In light of recent developments in CT-SCAN systems and high quality images from them and also having special tools to show these images & to help having more accurate calculation for achieving requirement information to reconstruction; simulation of the vessels geometry can be possible. Different studies have been done in this field specifically in recent decade, which the most important ones are as follows:

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Sepehr Sadeghian. Faculty of mechanic & biomechanics engineering , University of IRAN Science & Technology Narmak, Tehran, 16846_13114 IRAN (phone: +98 21 88713566) fax : +98 21 88702196, Sepehr_111 @yahoo.com)
Soheil Sadeghian. Faculty of biomedical engineering, Azad university, IRAN (soheil_s @yahoo.com)
Reza Molaei. Faculty of mechanic & biomechanics engineering, University of IRAN Science & Technology (r_molaei@mecheng.iust.ac.ir)

Coronary reconstruction by biplane angiograms by Ernst wellnhofer , 2006 from Germany [1].

3D geometric reconstruction of thoracic aortic aneurysms by Alessandro Borghi,2006 from England [2].

3D models of blood flow in the cerebral vascular by S. Moore, 2005 from New Zealand [3].

Reconstruction and meshing of blood vessels from MR & angiography by Luca Antiga , 2003 from Italy [4].

Cyclic flow patterns in human coronary arteries by S.Corney, 2001 from Australia [5].

In many of old methods, for each types of vessels, general models were used; in order to reconstruct the vessels more realistically some procedures have been used like:

Chosen feature from two non-planar tomographic images & identify the center line & edge of the chosen artery separately, then calculate the radii and obtain the geometry.

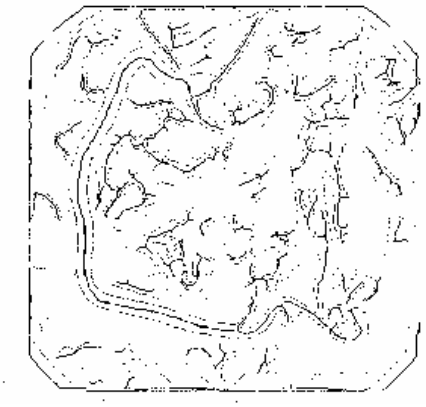

Fig 1.using edge detector for reconstruction

In another method 3 images on mutually orthogonal were taken from single time flight scan & imported in to AutoCAD software.

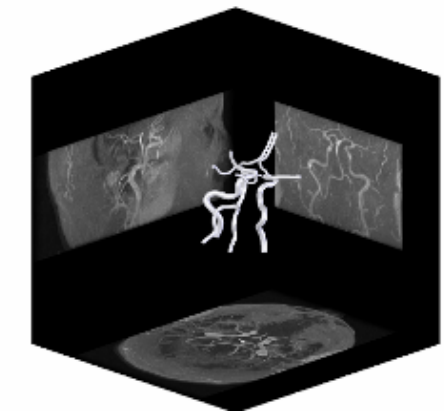

Fig 2.using AutoCAD software for reconstruction

By the way with using these methods in 3D analysis we lose many valuable data. The Approach that has been expressed in this study includes direct use of different segments of images from the arteries that were taken by 64 Slice CT-Scan.

II. Problem Discussion

Nowadays, coronary CT angiography have special place in diagnosing cardiovascular diseases. Multi detector CT Scans with high accuracy in computed tomography images in DICOM format, precise digital measurement tools, freedom of view from all directions on reconstructed vessel and possibility of having top view for each segment, have come to assist us.

As mentioned before, if we want to get valuable information about the conditions and fluid flow inside the vessels, governing equations of fluid flow:

Conservation of mass:

$$\frac{\partial u_i}{\partial x_j} = 0 \qquad (1)$$

Navier-stocks equations:

$$\mu\left[\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j}\right] = \frac{\partial p}{\partial x_i} + \nabla^2 \mu(J) u_i + \frac{\partial \mu(J)}{\partial x_j}\left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right] \qquad (2)$$

should be solved.

(P = pressure, t = time, U= Velocity, μ = Viscosity)

For solving the equations, the shape of vessel should be available; therefore the equations could be solved by one of the numerical solution methods (e.g. CFD in the science of mechanics).

By means of intermediate software (e.g. Gambit) the geometry should be defined for one of the commercial packages of CFD (e.g. Fluent).

Generally, base of the analysis that has been considering is to send the necessary information from scanned images to the CFD software packages.

Results of imaging devices are mostly in pixel format but the mentioned software just accepts the data in vector format to determine the figure! And this is the main problem.

III. Method

This approach presents a simple executive idea which has acceptable accuracy.

Strategy of geometry reconstruction is obtaining 3D components (x, y, z) of some proper and necessary points on each segment of the vessel, then transfer these points to Gambit software and get a string of circles and substantial points on vessel structure. By connecting these points the vessel shape is reconstructed. All the mentioned procedure is done semi automatically.

Before everything, we should notice, taking appropriate assumptions into consideration will assist us reaching the results easier. But utilizing each of these assumptions, results in losing some data and decreasing accuracy.

In this method:

All vessel segments are assumed circular, (Dehong Zeng 2003).

Side branches of vessels are ignored, (Krams et al., 1997; Berthier et al., 2002).

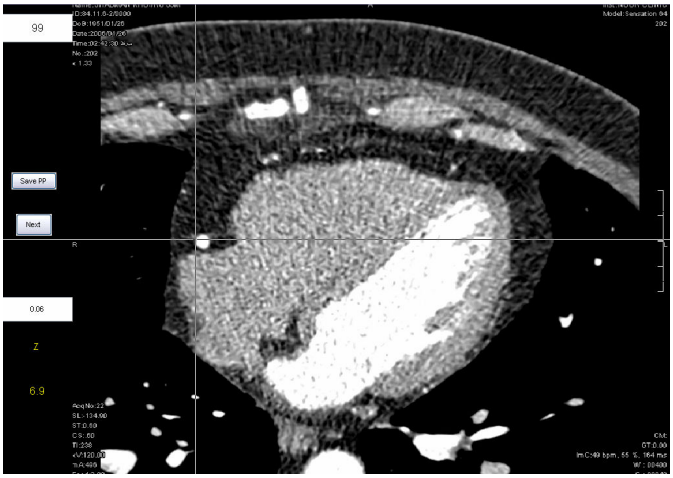

Fig 3.Obtaining 3D components on the segments of vessel in Matlab software

To do this method the specific Dicom player for 64 Slice CT and the special program that written in Matlab software are used. By giving the images of vessel segments as an input, selecting appropriate points on vessel boundaries a, file including the required components of each segment will prepared.

Table1. Samples of driven components

Z	X1	Y1	X2	Y2	X3	Y3
5.64	4.79	9.35	5.23	9.38	4.89	9.26
5.70	4.74	9.40	5.21	9.46	4.76	9.26
5.76	4.71	9.43	5.18	9.40	4.86	9.17
5.82	4.69	9.49	5.18	9.38	4.86	9.17
5.88	4.66	9.40	5.18	9.40	4.76	9.23
5.94	4.64	9.40	5.11	9.40	4.79	9.17
6.00	4.61	9.49	5.11	9.40	4.74	9.23
6.06	4.59	9.43	5.06	9.46	4.84	9.17
6.12	4.56	9.46	5.09	9.46	4.84	9.20
6.18	4.56	9.46	5.04	9.46	4.74	9.17
6.24	4.54	9.46	5.01	9.49	4.69	9.23
6.30	4.54	9.55	4.99	9.49	4.64	9.29
6.36	4.51	9.52	4.99	9.55	4.64	9.26
6.42	4.49	9.46	4.96	9.46	4.66	9.26
6.48	4.46	9.58	4.94	9.58	4.51	9.38
6.54	4.46	9.61	4.96	9.55	4.56	9.32

Point's selection is done by hand in Matlab software and the edge detector soft wares are not used. This regards to the colors of these images that noisy and this can misguide the software; so when we select the points by hand, the error is decreased. To increase the precision and avoiding to making mistake, the selection of points on edge's boundaries & choosing the points is done by multiple people and multiple times, the best choice between populations is used for further discussion.

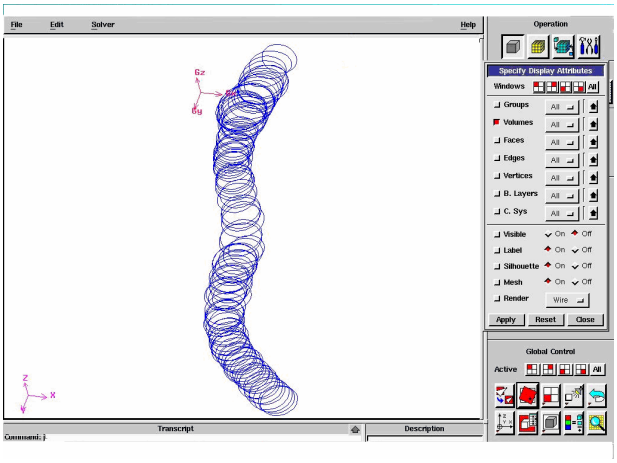

Fig 4. String of circles

IV. Result Validation

With aid of statistics science, the diameters calculated by different related specialist are considered for each of the circles. By using the comparison theory test of statistical societies, the convergence level of measurement accuracy of specialists on vessel diameter, has been considered.

Because of existing, random or regular error in measurement, assessment about determines the real interval is difficult or even impossible without statistical tests.

To reach this goal we use the comparison theory test "student T" between two populations with statistic:

$$T = \frac{(\bar{x}_1 - \bar{x}_2)}{SP\left(\frac{1}{n_1} + \frac{1}{n_2}\right)} \qquad (3)$$

Where:

$$Sp = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}} \qquad (4)$$

In which S^2 represents error variance, x is sample average, n is iteration counts and Sp represents the variances' integrated rule.

Can be used in error area of $\alpha = 0.01$ and degree of freedom: $df = n_1 + n_2 - 2$

To analyze the convergence of accuracy of more than 2 specialists, variance analysis can be utilized. All this procedure is done by (Mini tab) or (SPSS) software packages.

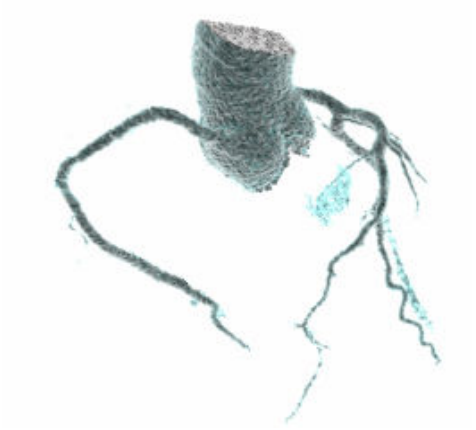

Fig 5 (a). Image of Coronary vessels, captured by CT

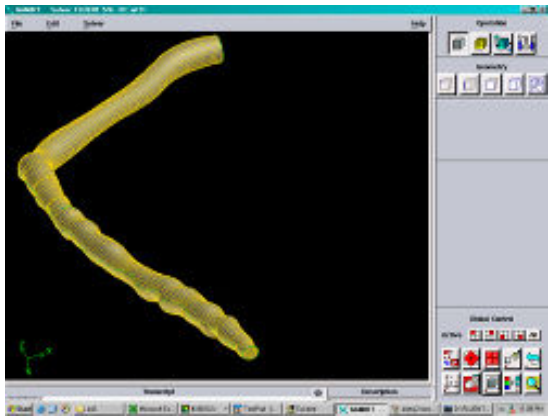

Fig 5 (b). Reconstruction of right coronary

After reaching the geometry of reconstructed vessel, solving the mentioned equations and data analysis will benefit us to find key factors for:

Study and design (e.g. velocity distribution &…)

Get the information which is the sign of atherogenesis (e.g. WSS (wall shear stress) changes)

In order to understand the importance of WSS analysis, the results of the paper done by Starry H.C [6] can be considered:

Flow patterns and wall structure are the only two which might relate to position of atheroma. the conditions of blood flow at the arterial wall are bound by the rate of change of velocity from the wall in to the stream & wall shear stress .Both high and low shear stress have been proposed to cause arterial damage.

V. Results

At the end has been taken a glance at some of results of flow analysis in reconstructed vessels.

An example regards to the 3D reconstruction of two normal right coronaries of 2 men who have been CT scanned in one of Tehran medical centers [7].

Study determined:

There is an inverse relation ship between vessel radius and WSS magnitude.

All the figures and pictures shows that WSS forms have complicated patterns which have meaningful changes during heart cycle.

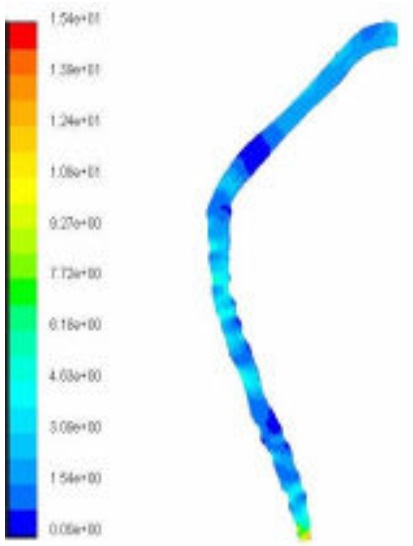

Fig6.WSS distribution for entering velocity 0.2 m/s
Into vessel in Carreau model

In the vessels examined, low WSS was seen at the beginning of vessel for a large part of heart cycle and high WSS was detected at the distal end and also in the curvature and narrowing area of vessel.

Sudden expansion has low WSS for most heart cycles.

With Evaluating different suggested models for blood viscosity, resulted that in comparison with non-Newton models considering the strain rate changes, Newtonian model was chosen as the best approximate model in most cases.

All these conclusions are in good agreement with B.Johnston's researches in 2005 & 2003 papers [8], [9].

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