



# A Novel Framework on Abdominal Aortic Aneurysm Analysis Based on Biomedical Simulation Tools

Srinivas Thirumala, Srinivasa Rao Chanamallu

**Abstract:** Nowadays, the mortality rate due to cardiovascular diseases is significant due to noticed critical aneurysm cases. Abnormal swelling at the aorta causes Abdominal Aortic Aneurysm (AAA). They are usually saccular, fusiform according to their shape statistics. Hence it's better to analyze, segment and model them to aid physicians/surgeons in various aspects of nonsurgical and surgical treatments. Morphological study provides approximate dimensions and risk of rupture. The objective of this work is to provide an extensive study on AAA segmentation, modeling and analysis with individual frameworks in sequence using tools like MATrix LABoratory (MATLAB), Materialise's Interactive Medical Image Control System (MIMICS), 3-matic and Finite Element Biomechanics (FEBio). The ultimate goal is to develop a 3D printed aneurysm replica for further evaluation and analysis using Ultimaker Cura Slicer Software. MATLAB is used to segment the Aorta irrespective of intensity/contrast inhomogeneities using Solidity feature. MIMICS software is used for modeling the aneurysms using three types of Axial, Coronal, and Saggital views. 3-matic provides an easy interface to do the dimensional analysis using imported aneurysm morphology. FEBio with PreView, PostView plugins is a nonlinear finite element solver which offers a chance to study it and to predict the future regions of rupture to some extent via Computational Fluid Dynamics (CFD) features. 3D printing of aneurysm offers the flexibility of knowing their epithelial characteristics and hands-on experience. The main merit of this novel and efficient framework is non-invasive studies of Aneurysm Segmentation, Analysis, and Modeling using five tools which addresses the complete study of AAA.

**Index Terms:** Aneurysm, Biomedical Simulation tools, Modeling, 3D Printing.

## I. INTRODUCTION

In Global Scenario, Cardiovascular diseases mortality rate is very high as all these critical cases involve abnormal blood flow in the arteries with various haemodynamics. Due to dilatation, blood vessel wall bulge in the form of a balloon or a sac at the aorta premises is identified as an Aortic Aneurysm. Another kind of Aneurysms occurs at carotid, femoral, iliac, popliteal, and renal, splenic arteries

Abdominal Aortic Aneurysm is a critical case of aortic aneurysms as its enlargement is beyond 50 % than normal aorta (diameter is 3 cm larger than the normal). It causes low blood pressure, pain in back, abdomen and leg if ruptures. Usually, people who crossed the age of 50 years especially in men suffer from inherited cardiovascular diseases, Marfan, Ehlers-Danlos genetic syndromes. Chain-smoking, and high blood pressure which increases the risk of rupture in AAA cases [24]. Majority of the AAA cases found below the kidneys rather than above it. United States of America (USA), United Kingdom (UK), Sweden and in many other countries, regular ultrasound diagnosis is made at an average age of 55 years for men. Hence, the analysis of aneurysms is vital in diagnosis & treatment.

The subsequent part of the paper is arranged as follows: Literature survey is discussed in Section II, followed by How to identify the aorta from the Computed Tomography (CT) images using Solidity phenomena is given in Section III. Section IV describes how an Aneurysm prone Blood vessel is designed using MIMICS tool based on the Region of interest (ROI) identification i.e., location of the aorta. Various dimensional performance metrics of aneurysm morphology are discussed using 3-matic in the subsequent part of the Section. Rupture status of Aneurysm via CFD using FEBio suites is provided in Section V. 3D Printing replica of the Blood vessel with Aneurysm using UltiMaker Cura slicer & Hydra FDM Printer is discussed in Section VI, Results and Discussions using MATLAB, MIMICS, 3-matic, FEBio, and Cura Ultimaker slicer are presented in Section VII. Conclusion is given in Section VIII followed by discussion on future work in Section IX.

## II. LITERATURE REVIEW

Because of the risk and mortality rate due to blood vessel abnormalities, especially aneurysms will become a compulsory study in the neuro and vascular medicine. Hence many researchers are studying, analyzing, and formulating different research methodologies in this arena as a primitive (fundamental), analytic, preventive, and rehabilitative research.

The motivation towards this work is the issues & shortcomings addressed in [1-3], [18], [19]. In all these manuscripts, only one or two tools are used to perform only one type of analysis, such as 2D Segmentation, 3D Modeling, Dimensional analysis, Finite Element Analysis (FEA) and Prototyping.

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In 2009, Dehmeshki, J., Amin, H et al developed a threshold segmentation procedure to detect the AAA from Computed Tomography 2D Digital images. But it cannot detect lumen & aneurysm accurately in all cases [19].

In 2010 John Brennan's project dissertation called Production of Anatomical Models from CT scan data discussed the multiple modality based Rapid Prototyping & Post processing. This work is carried out using MIMICS on Brain CT Scans. Phantom construction is complicated in specific ultrasound, Magnetic Resonance Imaging (MRI) imagery using this work [2].

In 2012, Steve A. Maas, Benjamin J. Elis et al. provides a frame work on CFD tool FEBio features to deal with applications of large deformation and contact of solid and biphasic materials [3].

In 2014 H. Girija Bai, K. B. Naidu et al. developed a CFD Analysis for Aortic Aneurysms on the basis of mathematical simulation using MIMICS, Fluent, and Gambit with a methodology called Finite Volume Method on CT AAA data. It establishes a relation between hemodynamics and risk of rupture with dynamic pressure, velocity magnitude, wall strain, Wall Shear Stress (WSS). But its main shortcoming is more dependence of flow parameters on the aneurysm geometry for multiple aneurysm prone cases & lack of calculation of morphological parameters [1].

In 2018 Gerard A., Ateshian et al.'s paper entitled Finite Element Framework for Computational Fluid Dynamics in FEBio provides a new frame work using Sim Vascular (SV), Fluent and FEBio. But it needs Special Boundary Conditions in few critical cases to show WSS distribution. Its main short coming is unable to know the dimensional parameters of the aneurysm [18].

The proposed framework of this current manuscript addresses all these studies.

### III. AORTA IDENTIFICATION

This subsection discusses the process of delineation of the aorta using image processing. Aneurysm segmentation means identification of aneurysm and locating the aneurysm in the patient CT AAA image using an image processing algorithm.

The algorithm for aneurysm detection uses the solidity phenomena. It is defined as the ratio area of an object to the area of a convex hull of the object [20]. Usually it is a density measure [21].

If solidity value is unity, it indicates it is a solid object. If its value is less than one, it indicates the presence of holes or irregular boundaries in the object.

Obviously, the solidity of abnormality is greater than the solidity of the remaining image. The framework steps are as follows.

#### A. Algorithm for Abnormality (AAA) detection

- Load the CT or MRI image of abdominal scan.
- Convert the image to double data type and binary image for further analysis.
- Label all the connected components in the image in the form of a matrix.
- Measure the solidity of all the labels.
- Select the label having maximum solidity as the aneurysm part has more solidity.
- Calculate the boundaries of the label, which has

maximum solidity to delineate the boundaries or any other abnormality.

MATLAB GUI is used for detection of aneurysm prone aorta from the DICOM files.

#### B. Procedure to create a GUI

1. Open MATLAB and type "GUIDE" in the terminal to start the GUI Development Environment [5]. It is a development environment for creating GUI applications in MATLAB.
2. It opens GUIDE Quick Start window and select Blank GUI and click on OK. It opens a blank GUI window.
3. The Side menu has all the UI options like Buttons, Static Text, Edit Text, and Axis for plotting graphs and showing images. Select "Axis" and draw in the empty grid area.
4. From the side menu, select "Static Text" and draw in the grid area. To edit the text right click on the static text and select "Property Inspector" from the dropdown menu. In the property Inspector, click on the string.
5. It opens a String window. Edit the text and click OK.
6. From the side menu, select "Push Button" and draw in the grid area. To edit the text on the button, go to THE Property Inspector and change the string. From the side menu, Select "Edit Text" to add a text input field.

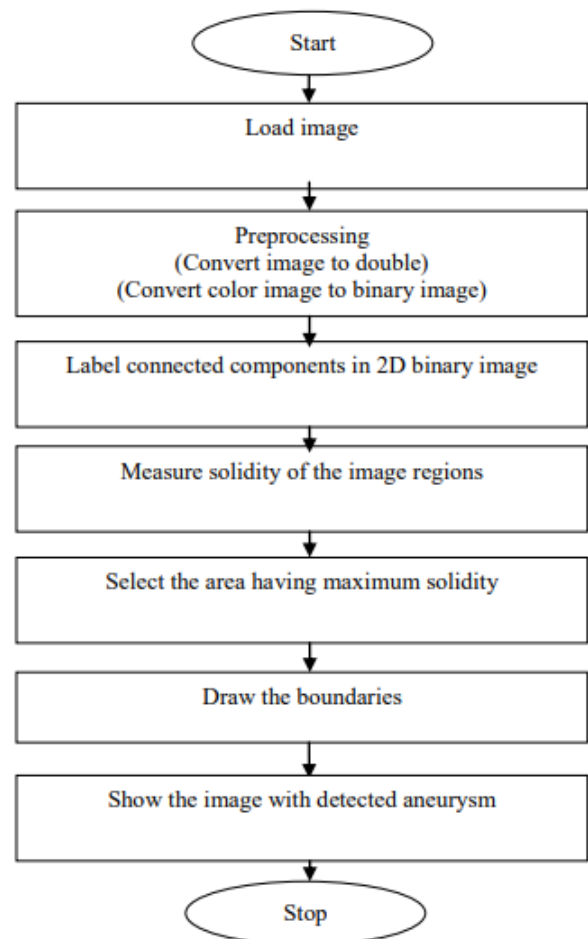


Fig 1. Flow Chart of Aneurysm Detection Method

#### IV. MODELLING & MORPHOLOGICAL ANALYSIS OF VESSELS

In this Section, the framework of vessel modeling (using MIMICS), isolation of the desired aneurysm part from vessel and calculating its dimensions (via 3-matic) are discussed.

##### A. Modelling of the blood vessel with aneurysm

Producing anatomical model from CT Data is a typical work [2]. Space and time constraints always demands an efficient framework. MIMICS is a suite for developing three-dimensional anatomical models from 2D cross-sectional CT/ MRI Images. All these models imported to Computer Aided Design (CAD), Rapid prototyping, and Surgical simulation [1]. It allows advanced manipulation and design on an STL (Stereolithography) file.

Segmentation method such as dynamic region grow provides a chance to grow a mask from a selected point without the need of thresholding it first. It is beneficial for vessels, nerves, and arteries. Hence, One can segment the aorta from the CT scan.



Fig 2. Dynamic region growing window

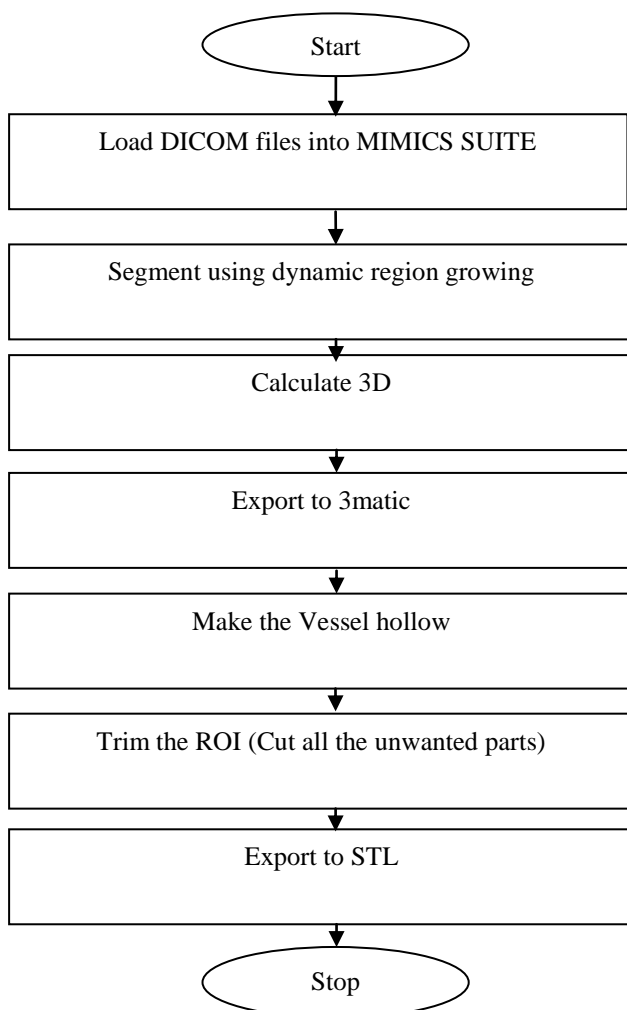


Fig 3. Flow Chart of Vessel Modeling using MIMICS

The vessel is modelled using two software suites developed by Materialise called MIMICS and 3-matic. Vessel modeling methodology & steps are available in Fig 3.

##### Procedure for vessel modelling in MIMICS

1. Open the MIMICS suite and go to file menu and click on a new project.
2. It opens a new project wizard and then choose the folder containing the DICOM dataset.
3. It converts the data and shows the data of the patient.
4. Click on convert, and it opens a window showing the Coronal, Axial, and Saggital views and loads these views into a window.
5. Go to Segment menu and select dynamic region growing.
6. Select Fill Cavities and Multiple layer, as shown in Fig 2. Then click on the aorta part in the axial view. So that it generates a mask.
7. Calculate the part from the mask created from Dynamic Region Growing.
8. Export the part to 3-matic. It opens the part in 3matic.
9. Go to design menu and click on Hollow to make the vessel hollow.
10. Select the part and click on apply.
11. Go to Finish and select Trim.
12. Select the model and Select Remove outer and draw a box on the model to remove the vessel outer the box. Click on Apply. This generates the 3D model. Export this 3D model to STL for performing FEA.

##### B. Dimensional Analysis of Aneurysm

Based on morphological analysis, AAA analysis is more comfortable for a physician in case of AAA patients. In the past works of aneurysm's dimensional parameters calculation of Posterior Communicating artery (PCoA) involves complex procedures of morphology are adopted using MATLAB (MathWorks Inc., Natick, MA, USA) and GEOMAGIC STUDIO 9.0 software (Geomagic, Morrisville, North Carolina).

In this paper dimensional parameters are found with 3-matic tool rather than above complex and proprietary tools [22]. Usage of 3matic is simple via trim, line, distance, and angle tools [6].

##### Procedure for dimensional analysis

The simple four-step process to do dimensional analysis is discussed as the aneurysm is symmetric or asymmetric. Aspect ratio, dome to neck ratio, inflow Angle ( $\beta$ ), and size ratio, bottle neck factor are calculated using this process.

1. Open the STL file in the 3 – matic. Make the aneurysm into half using the trim tool.
2. Draw line using line tool in the analyze menu.
3. Measure the distance using the Distance tool in the Measurement menu.
4. Measure angle using the Angle tool.



### Dimensional parameters

#### Aspect Ratio (AR):

It is the perpendicular height (H) and neck diameter's ( $N_D$ ) ratio as an aneurysm can be either symmetrical or asymmetrical aneurysm [6], [9], [10].

$$\text{Aspect Ratio} = \frac{\text{Perpendicular Height (H)}}{\text{Neck Diameter (ND)}} \quad (1)$$

#### Dome to Neck Ratio:

It is the ratio of Dome diameter (D) to Neck diameter ( $N_D$ ). It is also known as Bottle Neck factor [6], [8], [9], [10].

$$\text{Dome to Neck Ratio} = \frac{\text{Dome Diameter (D)}}{\text{Neck diameter (ND)}} \quad (2)$$

#### Angle of Asymmetry ( $\beta$ ):

$\beta$  is the angle between flow line height ( $H_f$ ) and perpendicular height (H) for an aneurysm which is either symmetrical or asymmetrical aneurysm [9], [10].

#### Size Ratio (SR):

The ratio of maximum perpendicular height ( $H_{\max}$ ) to the average diameter ( $D_{\text{avg}}$ ) is said to be Size ratio [7], [9], [10].

$$D_{\text{avg}} = \frac{D_1 + D_2 + D_3}{3} \quad (3)$$

$$\text{Size Ratio} = \frac{H_{\max}}{D_{\text{avg}}} \quad (4)$$

### V. FEA OF ANEURYSM

Computational biomechanics are useful in studying the mechanics of the biological systems, i.e. Developing computational models via simulations. The main merit of computational biomechanics is to obtain the endo-anatomical response without any ethical restrictions [14].

BioPhysics & Bio Chemistry provides an opportunity to choose what kind of material (Elastic, Viscoelastic, and Multiphase) is suitable for a particular organ morphology and sufficient boundary condition while creating a virtual model of it [15]. For instance, Finite Element Model (FEM) is a numerical method used in medicine to study vivo over the past two decades. FEM's main advantages include an easy way of computation of multiple parameters and their interdependence without any experimentation, time and cost resources optimization etc. It computes the optimum solution with minimum error function using variational calculus methods [19]. It supports both quasi-static and dynamic analyses of 3D multiphysics models which undergoes large deformations. The risk of rupture is predicted by using FEA through FEBio. It has three plugins called Preview, FEBio and Post view [3], [16].

First Plugin PreView is a GUI based finite-element pre-processor which is responsible for the generation of meshes, choice of proper material, selection of adequate boundary conditions, other auxiliary contact/load conditions and further analysis settings. Then generated models are exported to the next plugin FEBio. It is Extended Mark-Up Language (XML) formatted and it further provides novel

constitutive models, different finite element solvers, nonlinear constraints, boundary/body load conditions and results in the XPLT format. The last plugin postview is used to monitor, visualise and analyse the results. It provides different plots for flow visualisation viz. contour, isosurface, particle flows, plane cuts, slice, streamlines and vector plots [11]. The Process for FEA using FEBio is explained below with 18 steps & Fig 4 (Flow chart).

#### Procedure for dimensional analysis

1. Go to file menu → Import → .STL file.
2. Select the STL file of AAA generated from 3Matic. Hence STL file imported to PreView.
3. Complex structures have shells with zero thickness. It leads to Negative jacobian error. Next assign a thickness to the shell. The Shell Thickness is set to 10 (arbitrary value by trial and error).

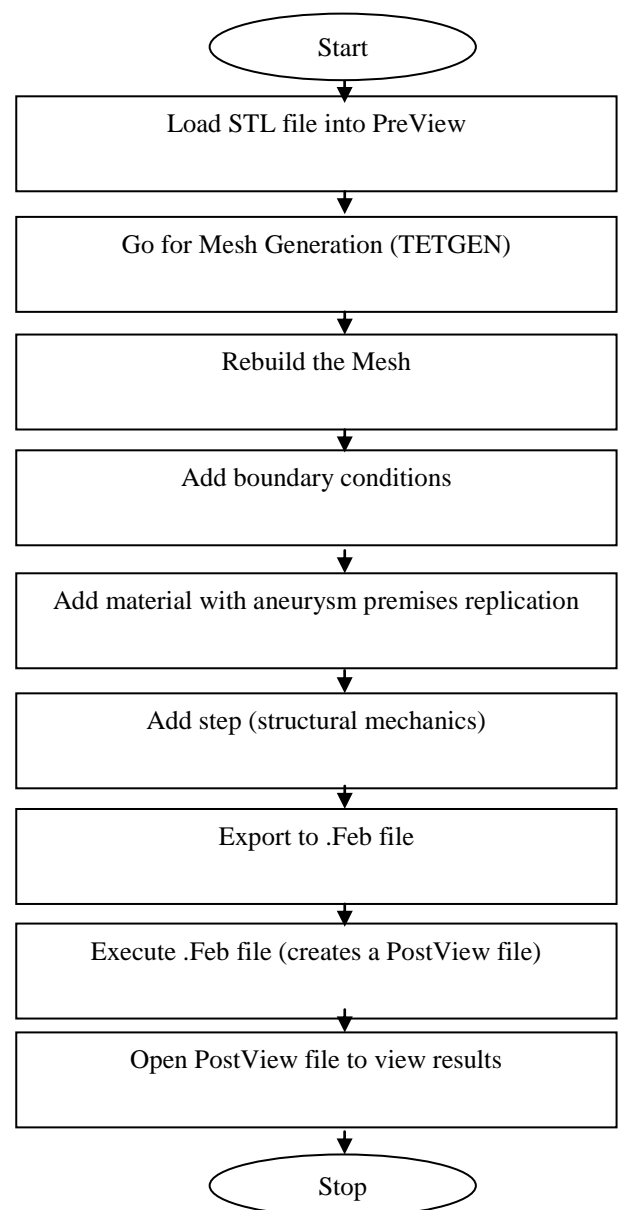


Fig 4. Flow chart of FEBio Analysis Process

4. tetrahedral mesh of element using Tetgen (Refine). These meshes possess isotropically shaped tetrahedral elements with no special boundary clustering. The main merit of using these meshes is no need for any special elements near the wall surfaces using inviscid Euler flow simulations.
5. Tetrahedral mesh generation chosen using Tetgen to generate tetrahedral mesh for analysis.
6. Rebuild the mesh to replace the original mesh with a tetrahedral mesh made.
7. Add Boundary condition → Zero Displacement. To perform FEA boundary conditions are to be added.
8. Select x, y, z to keep the object constant in all the three axes.
9. Add zero displacement boundary condition to all the openings faces. Add boundary load → Pressure Load
10. Set the load scale factor to Mean Aortic Pressure (MAP) and chose its value as 100 mm Hg. The value in newton meter square is  $0.13332268 \text{ N/mm}^2$ .
11. Select the inner surface of the model.
12. Add material Mooney Rivlin to the model. Mooney Rivlin is a hyper elastic material having the same characteristics of epithelial tissue of nerve.
13. Select the model to add material.
14. Add step → Structural Mechanics
15. Give step properties
16. Export to .feb file
17. Open .feb file using FEBio. It opens a command prompt executing non linear solver and creates a Postview file.
18. PostView shows FEA result. It shows a colour map for differentiating the pressure at different points on the model.

## VI. ANEURYSM REPLICA CONSTRUCTION USING 3D PRINTING

STL file is required to generate the 3D model. For making mechanical model, dimensions are required to create STL file. Axial, coronal and sagittal view images are necessary for medical anatomic model STL file generation. For aerospace, art, civil, mechanical and vehicle applications, STL file is generated usually using tools like DS Solid Works, CATIA, ANSYS and Hyper mesh. In medical modeling and prototyping STL file is generated using different views via tools such as MIMIC, Blender, etc. Leading 3D printer technologies are Digital Light Processing (DLP), Fused Deposition Modeling (FDM), PolyJet, Stereo Lithography (SLA), Selective Laser Sintering (SLS).

Acrylonitrile Butadiene Styrene (ABS), Bio Fila (a Biodegradable 3D printed filament material) Nylon, PolyCarbonates (PC), Poly Ethylene Teraphthalate (PET), Poly Lactic Acid (PLA), Poly Vinyl Alcohol (PVC), Tango Plus, Thermo Plastic Elastomers (TPE) are different 3D printing Spool materials. During 3D printing, first STL file of the desired model is created, and later it is forwarded to a slicer tool in which each layer of 3D model is interpreted in a feasible manner using machine code. Hence, it got the name of slicer as each layer is a slice [12], [13].

Currently, an engine is used, which is a combination of user interface/control software, STL processing/editing tools and slicer. i.e. control software allows a user to send a machine

code file from the computer to the 3D printer, change flow, speed, and temperature parameters dynamically, and correspondingly move the print head manually around the three axes (x,y,z). Astropoint, Craftware, Cura, 3D Printer OS, etc. are available slicers [15].

Proposed prototype models are made with Cura [14]. Upload the G-Code from this slicer into a 3D printer which interprets the G-Code and adds material according to the coordinates. Model is printed slice by slice [13].

## VII. RESULTS & DISCUSSIONS

In this section, the analysis of AAA is discussed via five phases i.e. Segmentation using MATLAB & its 3D reconstruction using MIMICS, dimensionality analysis using 3-matic, prediction of risk of rupture via FEA using FEBio, and specific phantoms fabrication using 3D printing respectively.

Initially, the results of identification of aorta or abnormal aorta (bulged aorta or aneurysm) boundaries (for six 2D image case studies from Radiopedia site) via segmentation using MATLAB are shown in Fig 6. by column-wise [4]. Image (A) is an Image of AAA with an indication of intramural haematoma with rupture. Image (B) is a case of appendicitis and AAA abnormality. Image (C) is an example of a Chronic contained rupture of AAA. Image (D) is an indication of AAA. Image (E) is an illustration of Infrarenal Aortic Aneurysm. Image (F) is an inference of ruptured AAA. Images (G) – (L) are the aorta identified images of images (A) – (F) respectively in which aorta boundaries are highlighted with red colour.

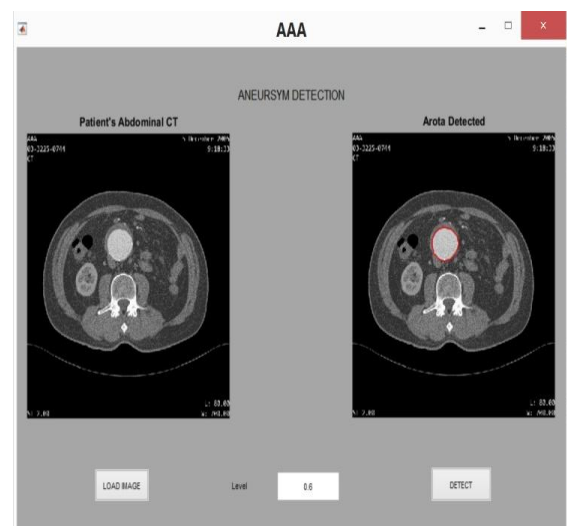
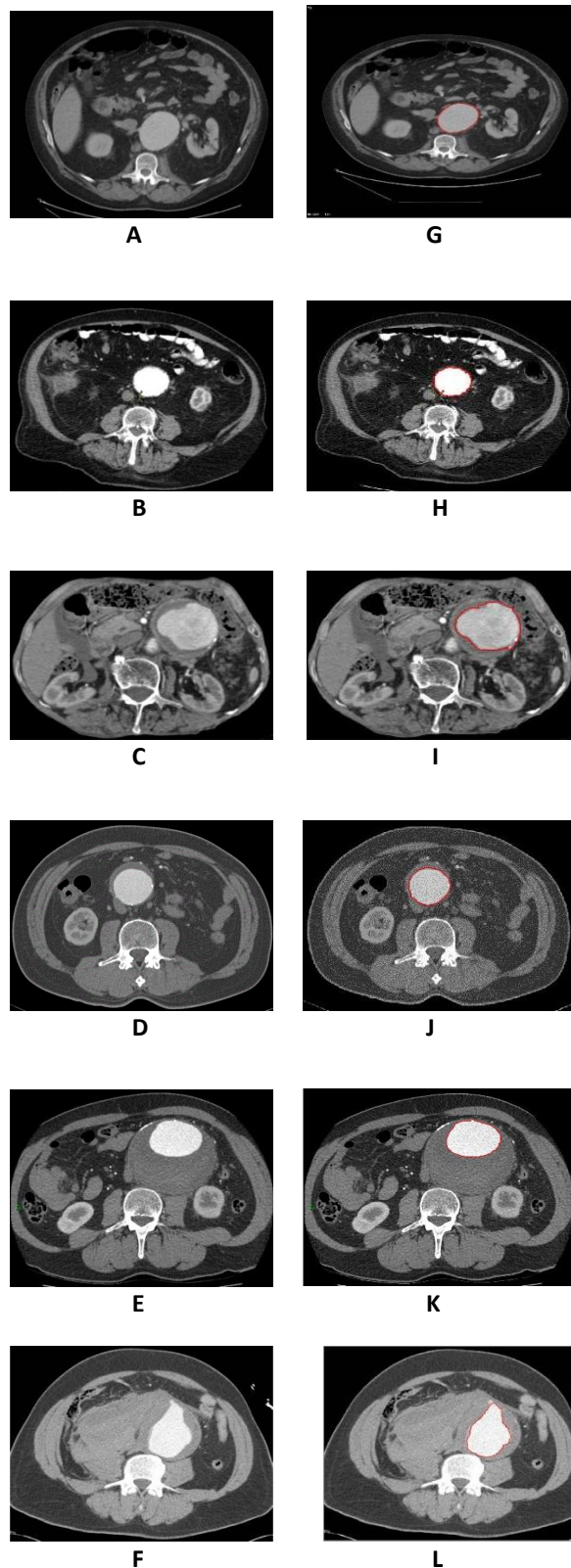
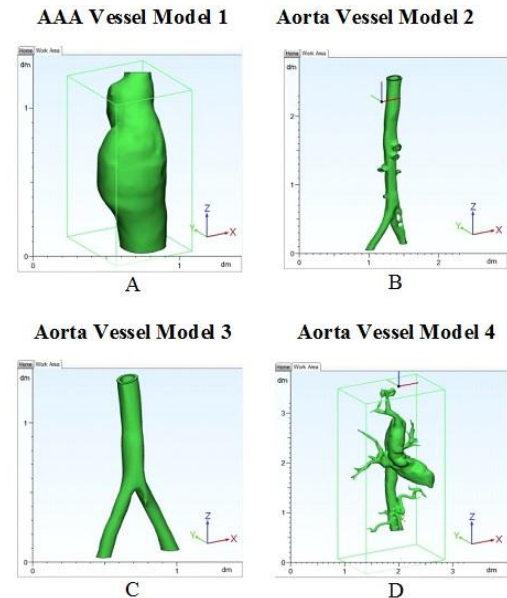


Fig 5. Proposed MATLAB GUI of AAA Segmentation

The first phase is developing the MATLAB GUI for aorta segmentation. The proposed GUI consists of an input button, to load an image, and an output button to detect the aorta in the loaded image, as shown in Fig 5 for Cybernet Systems I-NTAGE Realia CT image [25]. It consists of a level field in between Input and output fields, to set the level value based on solidity phenomena. In Fig 6, the First column shown images (A) - (F) are input loaded images and the second column displayed images (G) – (L) are output images obtained from the GUI.



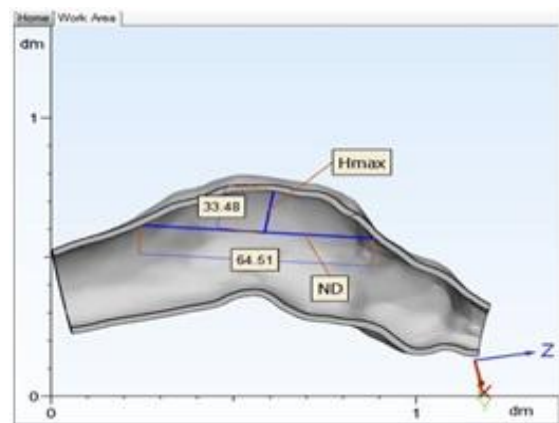
**Fig 6. Aorta identification image results of MATLAB**  
(A to F) – Input Images; (G-L) – Aorta Identified Images



**Fig 7. AAA and Normal Aorta blood vessels reconstruction using MIMICS**

After identifying the aorta boundary from MATLAB GUI, use MIMICS tool to create the 3D model of the normal or abnormal aorta with aneurysm and other issues is the second phase as shown in Fig 7. In this fig, image (A) is AAA created from Cybernet Systems INTAGE Realia CT database, image (B), (C) and (D) are Normal aorta generated from Hope International Hospital, Kakinada, A.P., India.

Next third phase is to find the morphological analysis parameters by importing the hollow vessel file of MIMICS, i.e. by using the measured dimensions & angles from the 3-matic tool. Calculate the angle of asymmetry ( $\beta$ ), aspect ratio, dome to neck ratio, and size ratio for further diagnosis. The formulae for these calculations are available in section IV (dimensions required for estimates of parameters plotted in 3-matic tool of Intage Realia) are shown as fig's 8, 9, 10, and 11.



**Fig 8. Dimensions required for Aspect ratio calculation of Intage Realia AAA**



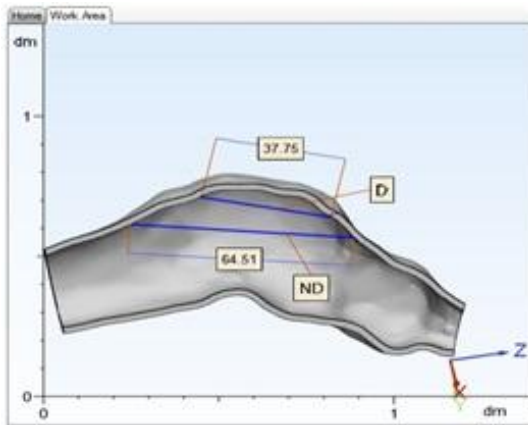


Fig 9. Dimensions required for Dome to Neck ratio calculation of Intage Realia AAA

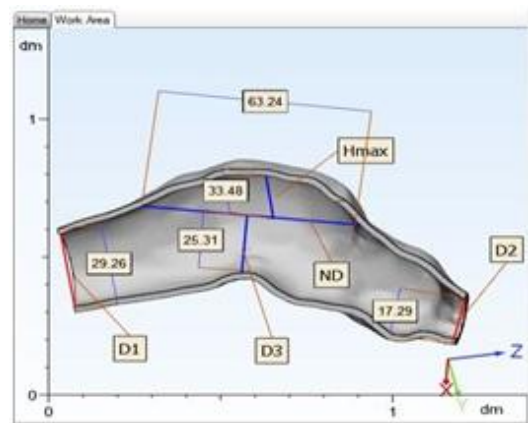


Fig 10. Dimensions required for Size Ratio Calculation of Intage Realia AAA

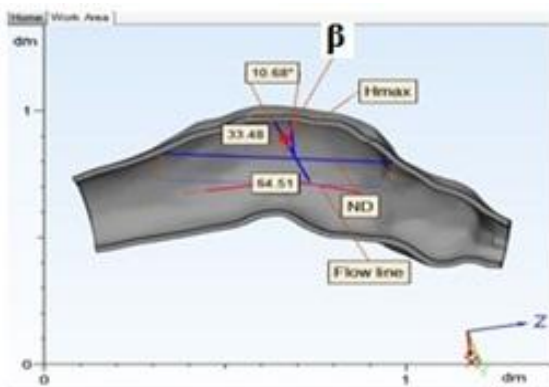


Fig 11. Dimensions required for In flow angle ( $\beta$ ) calculation of Intage Realia

From the Fig's 8, 9, 10, and 11,  $\beta$  is directly known as  $10.68^\circ$  and remaining parameters calculated as follows:

$$\text{Aspect Ratio} = \frac{H}{ND} = \frac{33.48 \text{ mm}}{64.51 \text{ mm}} = 0.5$$

$$\text{Dome to Neck Ratio} = \frac{D}{ND} = \frac{37.75 \text{ mm}}{64.51} = 0.6$$

$$\text{Size Ratio (SR)} = \frac{H_{\max}}{D_{\text{avg}}} = \frac{33.48 \text{ mm}}{23.6 \text{ mm}} = 1.41$$

The dimensions of MIMIC demo AAA are shown in Fig 12 at a glance to calculate four parameters. With the help of Fig's 13, 14, 15 and Table I, relative comparison of two AAA is made.

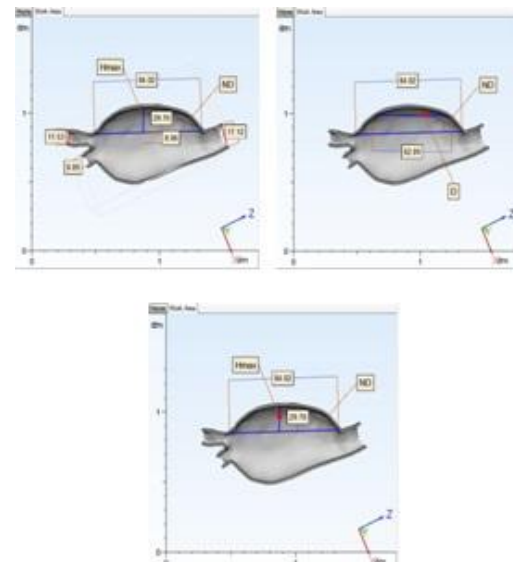


Fig 12. Dimensions Analysis of MIMIC demo AAA

Table I. Relative comparison of Dimension parameters

Parameter	Value of Intage Realia AAA	Value of MIMICS Demo AAA
Aspect Ratio	0.5	0.35
Dome to Neck ratio	0.6	0.74
Inflow Angle	10.68	3.23
Size Ratio	1.41	2.605

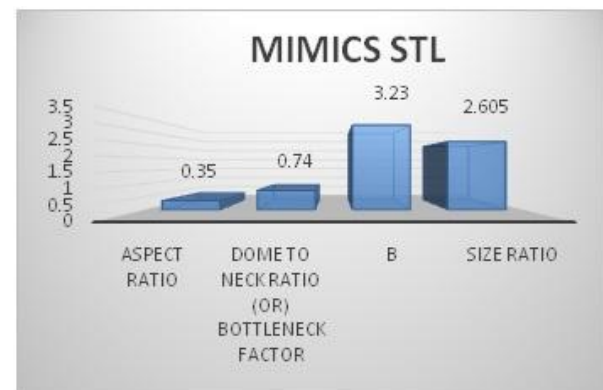


Fig 13. Dimension Analysis Statistics plot of MIMIC Demo

STL file of AAA

The MIMICS, Intage Realia AAA results are differentiated by light blue and red colour respectively in Fig 15.

The fourth phase is to analyse them with FEA via FEBio tool to know MAP's and Rupture prone areas identification [17]. For this analysis follow the procedure given in Section V. Fig 16 shows the results for Normal aorta (Hope Hospital aorta) and Fig's 17 and 18 shows abnormal aorta (Intage Realia & MIMIC Demo AAA). In all the three figures, Red and Pale yellow areas usually indicate High MAP values and report the high degree of risk of rupture.

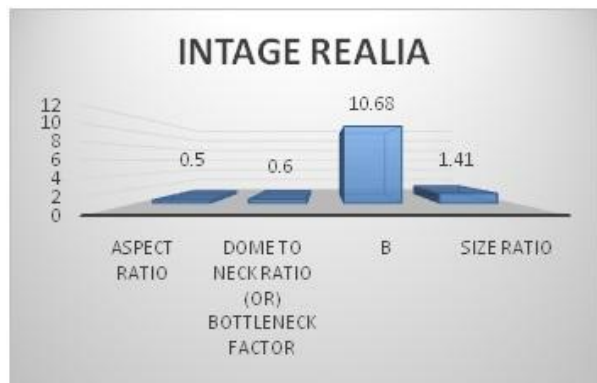


Fig 14. Dimension analysis statistics plot of CYBERNET SYSTEMS INTAGE Realia's STL file of AAA

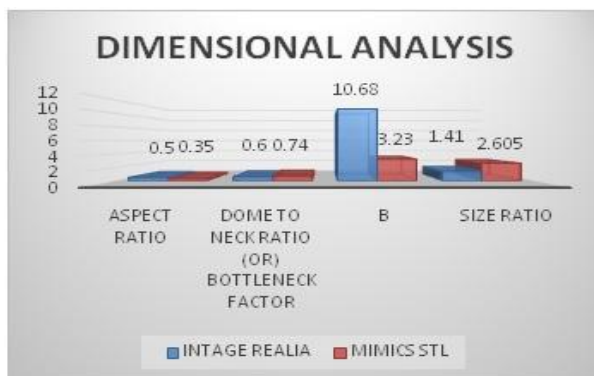


Fig 15. Relative comparison of the Dimensional Parameters

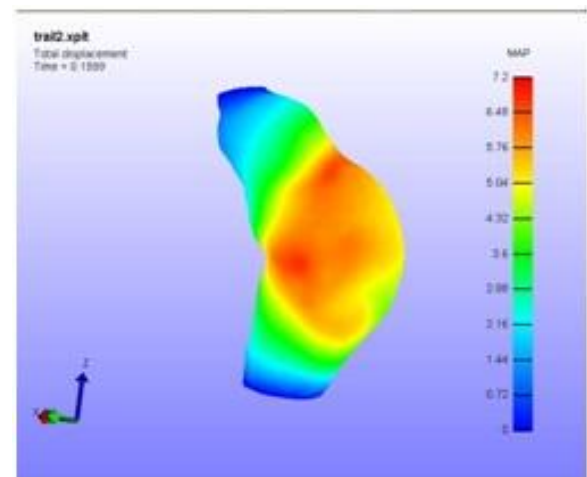


Fig 17. FEA output of Intage Realia aorta with aneurysm.

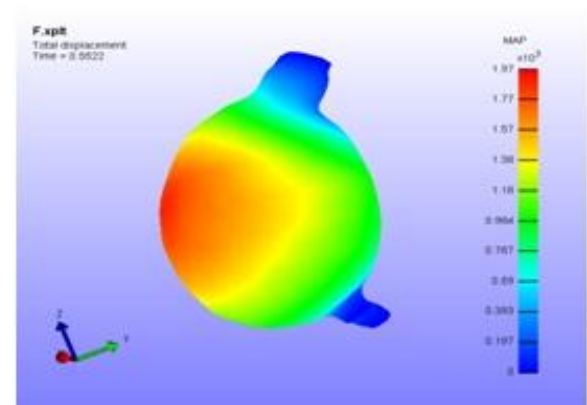


Fig 18. FEA output of MIMICS demo aorta with aneurysm

Final phase is to develop 3D phantom prototype models of the normal and abnormal aorta [23]. These are useful for further and future evaluation by adding sensors, hemodynamic parameters measuring device and control console to know the real situation in vessel and aneurysm premises without surgical intervention and noninvasiveness. The developed prototype 3D printed models are shown in fig's 19, 20 and 21.

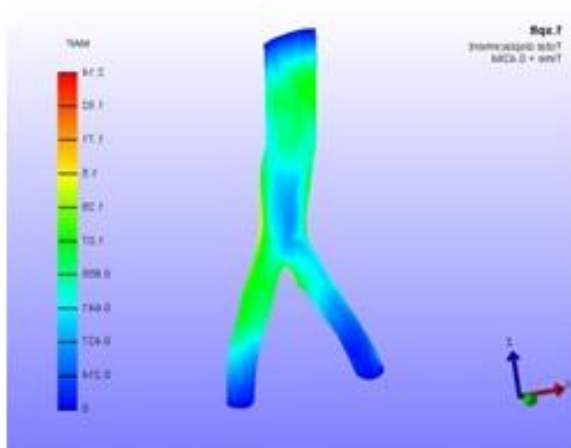


Fig 16. FEA output of normal aorta without aneurysm.



Fig 19. 3D printed model of Normal Aorta of Hope Hospital.



For this 3D printing Hydra 250 3D-printer is used along with Ultimaker Cura slicer [14], [15], [24]. Figure 19 shows the 3D prototype of Normal Abdominal Aorta with femoral (iliac) arteries to know the specific functionality of it in future course with different flow rates and Haemodynamic parameters.

During slicing, Open the ultimaker cura and load STL file. Set the printing temperature to 210° C and bed temperature to 240°C. Select everywhere in support type. Set fill density to 2% and print speed to 50mm/S. Now start printing by loading the G-Code file in SD Card of the Printer.



**Fig 20. 3D printed model of Intage Realia STL AAA.**

For this, the White PLA Spool is used to incorporate the real environment of the aorta. Figure 20 shows the image of the 3D prototype of Intage realia Abdominal Aorta parent vessel with aneurysm, other child vessels at bifurcation using Black PLA spool. Fig 21 is the image of the 3D prototype of MIMIC Demo STL AAA with PLA White Spool.



**Fig 21. 3D printed model of MIMICS Demo AAA.**

The below table II summarizes the advantages of the current paper framework compared to Section II manuscript's frameworks through the type of analysis, tools, and the metrics. The framework is robust as it uses five tools to carry out five kinds of analysis.

Analysis made	Tools used	Metrics
i. Delineation from 2D data ii. 3D model making iii. Morphological analysis iv. FEA v. Prototyping	i. MATLAB ii. MIMICS iii. 3-matic iv. FEBio v. Ultimaker Cura	i. Aspect Ratio ii. Dome to neck ratio iii. Inflow angle iv. Size ratio

**Table II. Merit Summary OF Current frame work**

## VIII. CONCLUSION

This work provides an opportunity to carry out the non-invasive AAA analysis in five phases which resembles to different measures found by the real time studies. Five biomedical simulation tools are applied on various online patient AAA data sets of INTAGE Realia (Cybernet Systems), various AAA abnormalities data sheets of radiopedia.org and normal aorta data sets of Hope International Hospital, Kakinada, A.P., India. Aneurysm prone blood vessel and normal aorta vessel structures physical 3D printing replicas for further analysis are prepared using Hydra 250 3D-printer. The main merits of this work are proposing a novel and sequential AAA analysis frame work by combining individual frame works of each tool and conducting analysis with 3D modelling without any open cut or micro catheter guided conventional procedures.

## IX. FUTURE SCOPE

In the current scenario, Patient Specific replicas of the aneurysm are made from patient CT data using 3D printing. In future, experimentation can be done on these models to find the deformation in real time. Deciding the WSS and pressure on the model by experimentation is the subsequent task. Simulate these parameters in real time by pumping a mixture of water and glycerol (which mimics blood) into the model and use pressure and flow sensors to find the inlet flow and inlet pressure. The deformation can be captured using a digital camera. 4D CT scanning measures the pressure and WSS. This provides further validated phases for blood vessel & aneurysms analysis.

AMIRA software, Optical fluoroscopy / VELScope provide another framework to study characteristics of endothelialization further using MEMS-based Biochips. Developing an extended framework for implant designs in various limbs/parts to support the surgical simulation, for example, Making a stent/graft for aneurysm healing via solid works etc. and artificial jaw making in case of severe trauma patients of an accident are future works. Making of complete demonstration models of vital organs like brain, heart, abdomen, leg for the better exp of various case studies for undergraduate students of medicine and auxiliary sales communities is another possible extension of this work.

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