2011

Cerebral aneurysm morphometrics from 2D biplane angiograms

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CEREBRAL ANEURYSM MORPHOMETRICS FROM 2D BIPLANE ANGIOGRAMS

by

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A thesis submitted in partial fulfillment
of the requirements for the Master of
Science degree in Electrical and Computer Engineering
in the Graduate College of
The University of Iowa

December 2011

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Electrical and Computer Engineering at the December 2011 graduation.

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I would like to dedicate my thesis to my Parents, Professors, Relatives and Friends, every single being who have helped me and encouraged at every stage of my life.

ACKNOWLEDGMENTS

I am very grateful to my academic advisor, Dr. Madhavan Raghavan, who gave me an opportunity to be a part of his wonderful team at BioMOST laboratory, University of Iowa. I really appreciate his help, guidance throughout every step of my research without which I would not have been able to do the work that I have. I learnt a lot from him. Appreciate his patience and understanding. It has been an honor working with you.

I am thankful to Dr. Punam Saha, who suggested us the approach which we took in the research and that turned out to be a success. I appreciate his valuable inputs in the research. I would like to thank Dr. John Huston, who provided us support with aneurysm traces from Mayo Clinic, Rochester. I am grateful to Dr. Jim Torner without whose support the project would not have even started. I am very thankful to Dr. Xiaodong Wu, who became a part of my research committee at such a short notice.

I am also very grateful to my lab mates at BioMOST for their help and support. I am very thankful to all the staff and faculty members of Electrical and Computer Engineering for providing a wonderful support throughout my stay here.

I would also like to show my gratitude to Dharmsinh Desai University, through which I was able to explore this opportunity at The University of Iowa under the B.E – M.S joint program. A special thanks to Dr. V.C.Patel, Dr. H.M.Desai and Dr. P. Barry Butler who made this joint program possible. I am grateful to Dr. Nikhil Kothari and the entire faculty of Electrical and Computer Engineering Department at Dharmsinh Desai University for their help and support.

Last but not the least; I would like to thank my parents, family members and all my friends for their love and encouragement throughout.

ABSTRACT

Cerebral aneurysm is a local dilation in a blood vessel in brain that can rupture and cause hemorrhagic stroke. A study by International Study of Unruptured Intracranial Aneurysms (ISUIA) has collected a large database of bi-plane cerebral angiograms from patients who were followed longitudinally. This unique data may be mined for testing hypotheses on the role of morphology metrics in rupture risk. A method of reconstructing an approximate 3D geometry of aneurysms from bi-plane angiograms was developed using techniques in curve morphing. Aneurysms from a pilot population of 150 patients were reconstructed to assess the effectiveness of the proposed method. The aim of the research is to develop a methodology for 3D reconstruction of aneurysm surface from biplane angiograms, estimate size & shape characteristics, validate the method for 3D morphometric and compare these metric against the ones estimates based on radiologic measurements.

The 3D methodology was developed and validated for the correctness of the developed method of surface reconstruction from biplane angiograms with good correlation coefficient values using a 10 patient data set. Then this method was applied on the 150 patient population studies for calculation of morphologic metric. The results showed that this method was better able to capture the shape characteristics of the aneurysm than the radiologists' way of approximating aneurysm as an ellipsoid formed from the three anatomical dimensions.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Severity of Intracranial Aneurysms

An aneurysm is a weak area in the wall of a blood vessel that causes the blood vessel to bulge or balloon out. When an aneurysm occurs in a blood vessel of the brain, it is called a cerebral aneurysm or intracranial aneurysm (Figure1). It is a cerebrovascular disorder in which the weakness in the wall of a cerebral artery or vein causes a localized dilation or ballooning of the blood vessel. A small, unchanging aneurysm will produce little, if any, symptoms. Before a larger aneurysm ruptures, the individual may experience such symptoms as a sudden and unusually severe headache, nausea, vision impairment, vomiting, and loss of consciousness or the individual may be asymptomatic, experiencing no symptoms at all. Possible complications include increased pressure inside the skull, loss of movement in one or more parts, loss of sensation of any part of the face, seizures, stroke and subarachnoid hemorrhage. There is no known way to prevent the formation of a berry aneurysm. Treating high blood pressure may reduce the chance that an existing aneurysm will rupture. Controlling risk factors for atherosclerosis may reduce the likelihood of some types of aneurysms. If unruptured aneurysms are discovered in time, they can be treated before causing problems. The decision to repair an unruptured cerebral aneurysm is based on the size and location of the aneurysm, and the patient's age and general health. The risks involved in both operating and watchful waiting must be carefully considered [1].

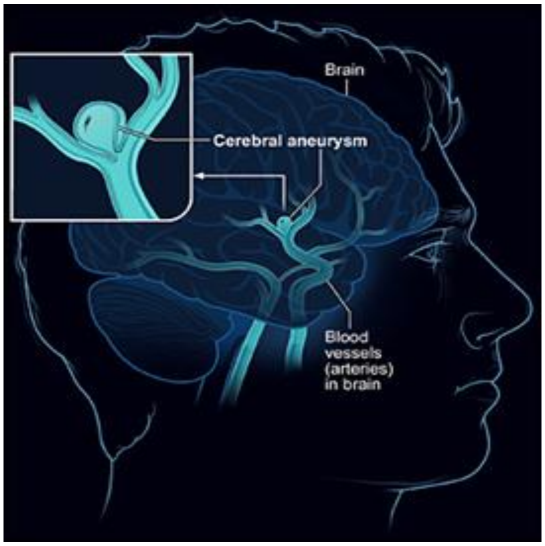

Figure 1 Typical location of a cerebral (berry) aneurysm in the arteries supplying blood to the brain. The inset image shows a close-up of the sac-like aneurysm [2].

Unruptured intracranial aneurysms constitute a significant public health problem in the United States [3]. Approximately 10,000 patients are hospitalized annually in the United States with a diagnosis of unruptured intracranial aneurysm (UIA), and many others are diagnosed and followed as outpatients. In addition to the obvious impact on society in terms of disability and loss of life, the economic impact of these lesions is considerable. The estimated lifetime cost of annual cases of UIA patients hospitalized in the United States--including the cost of hospitalization, surgery, morbidity, and mortality--is approximately $522.5 million compared to an analogous figure of $1,755 million per year for subarachnoid hemorrhage (SAH). These estimates include only hospitalized patients in nonfederal hospitals and, consequently, they are likely to be underestimates of the magnitude of the problem, particularly among UIA patients. The management of patients with UIA still remains controversial. It is absolutely necessary to understand the rupturing phenomenon and the factors affecting rupture. Given the lack of consensus about managing these patients and the substantial and increasing magnitude of the problem, a new study group was formed called the International Study of Unruptured Intracranial Aneurysms (ISUIA). This group has undertaken an initial epidemiologic project to address the major issues involved in clinical decision making regarding patients with UIA [4].

1.2 Need of Research

The International Study of Unruptured Intracranial Aneurysms (ISUIA) Study Group undertook an initial epidemiological project on September 1, 1991, to obtain a better understanding of the natural history of unruptured intracranial aneurysms (UIAs) and the risks associated with surgical and endovascular repair of UIAs to help define the optimal management of patients with these lesions. Over the next 7½ years, 5,500 patients were entered into the study and followed until 2001 as outlined in the research protocol. As planned, the overall patient group from Phase I of the study included approximately 1,500 retrospectively identified patients who were un-operated and approximately 4,000 prospectively entered patients including approximately 1,700 who were conservatively managed, 1,900 who had surgical treatment and 450 who underwent initial endovascular ISUIA I and II was published in The Lancet in July 2003 [5].

During this study, they formed a large database of biplane cerebral aneurysms from these patients who were followed longitudinally. This unique data may be mined for testing hypotheses on the role of morphology metrics in rupture risk. This is a legacy data – gold data. It contains data of the patients followed over a very long period of time, with inconsistent time gaps. It has a very large number of patients set as well. The only disadvantage with this data is the lesser quality as these are angiogram data and have been collected during the 90’s at various centers over the world with various inconsistencies.

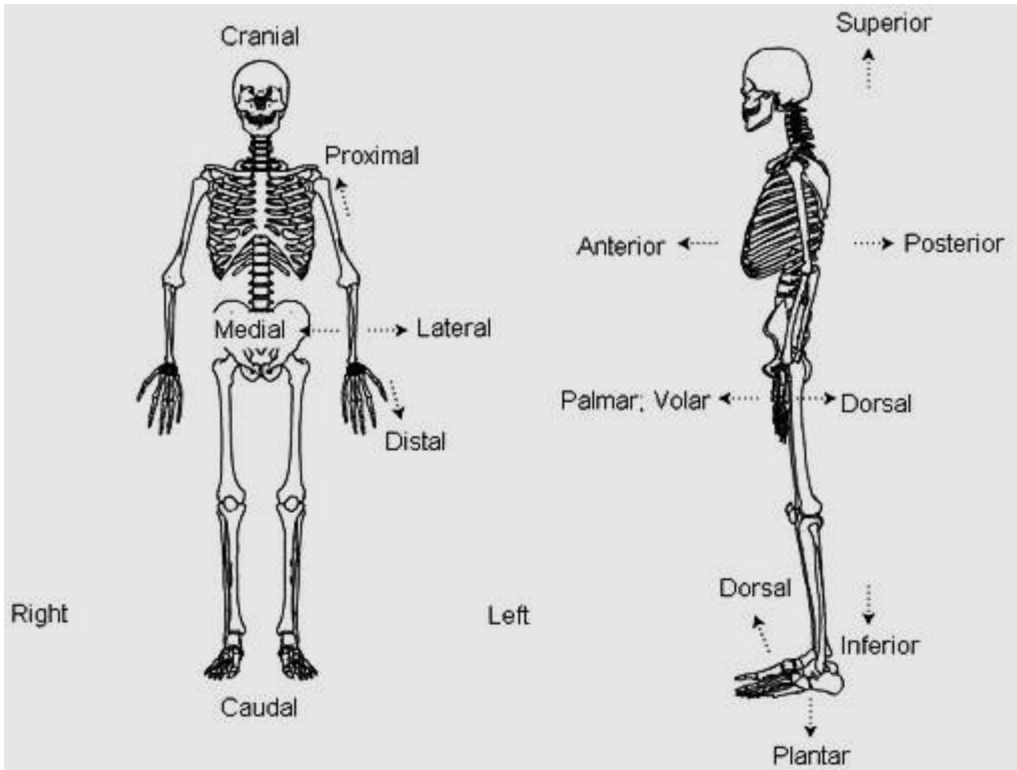

Figure 2 Standard Anatomical Directions [6].

The radiologists have been using these biplane angiograms for prediction of the aneurysm rupture. They measure the three dimensions medial-lateral (M-L), anterior-posterior (A-P) and cephalic-caudal (C-C) from these biplane views (medial-lateral and anterior-posterior views). Using these dimensions, they determine the shape and size characteristics of the aneurysm and predict rupture risk associated with the aneurysm.

ISUIA used aneurysm size as a factor to predict the aneurysm rupture. They used the A-P, M-L and C-C dimensions to predict the aneurysm rupture risk. Is just the size as a parameter enough to predict the rupture risk? They viewed aneurysm as an ellipsoid constructed from these three dimensions. It does not capture the entire aneurysm characteristics such as daughter sacs, irregular surfaces etc. Hence, there is a need for developing the accurate 3D reconstruction methodology which captures the real aneurysm geometry from biplane angiograms.

1.3 Specific Objective

1) Develop a methodology for estimating 3D morphometric indices from biplane angiograms.
    a) Develop a method for 3D reconstruction of aneurysm surface from biplane angiograms.
    b) Estimate the size and shape metrics of aneurysm and validate the developed methodology for 3D morphometric.
2) Compare the metrics of the aneurysm shape estimated from reconstructed 3D surfaces with estimates based on radiologists' measurements in a study population of 150 patients.

CHAPTER 2

METHOD

2.1 Introduction

This section discusses the procedure for 3D reconstruction of cerebral aneurysm from biplane angiograms provided by ISUIA. From the biplane angiogram traces, the two views are registered in the 3D space and a 3D geometry is constructed using the "Curve Morphing" approach. This 3D method was validated for the correctness and efficiency of this method. The logic of this method was validated. Then, this method was applied on the study population of 150 patients for the 3D surface reconstruction and calculation of morphometric indices for comparison with the measures from radiologists' ellipsoid approximation of aneurysm from three dimensions.

2.2 Development of Methodology

2.2.1 Developing a methodology for 3D reconstruction of aneurysm surface from biplane angiograms

2.2.1.1 Data Acquisition from ISUIA

Biplane angiograms of the patients which were followed longitudinally from ISUIA were provided. These were in the form of paper copies as well as electronic image data in dicom format. Initially, we got the paper copy of biplane angiograms with aneurysm traced by the radiologist. Ideally the medial-lateral (M-L) and the anterior-

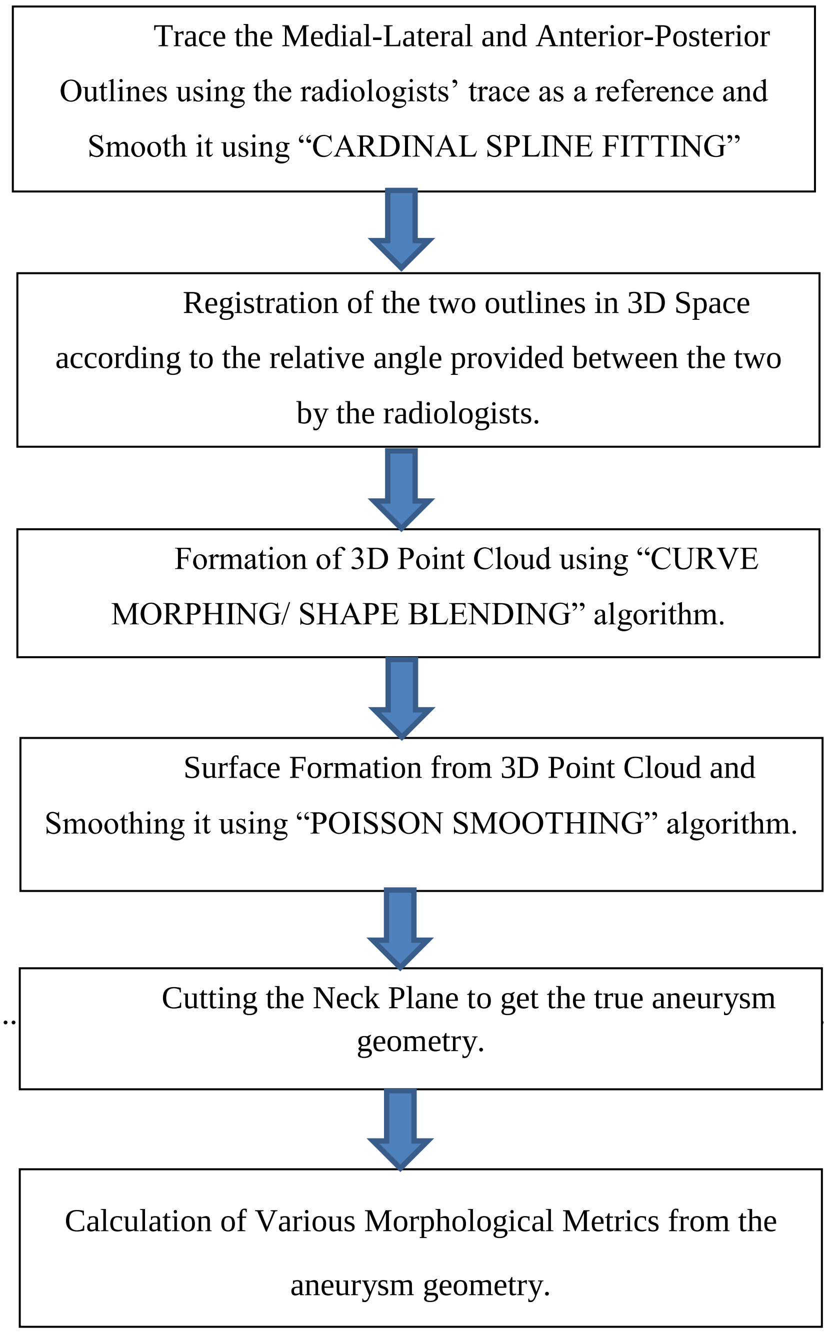

Figure 3 Flow diagram depicting methodology of 3D reconstruction from biplane angiograms

posterior (A-P) views of the skull should be orthogonal to each other. But it is not necessarily the case. The paper copies provide us with a line on the lateral view indicating the relative angle between the M-L and the A-P view. The outline of the aneurysm is also provided on the paper copy which was used as a reference for aneurysm tracing in the electronic data.

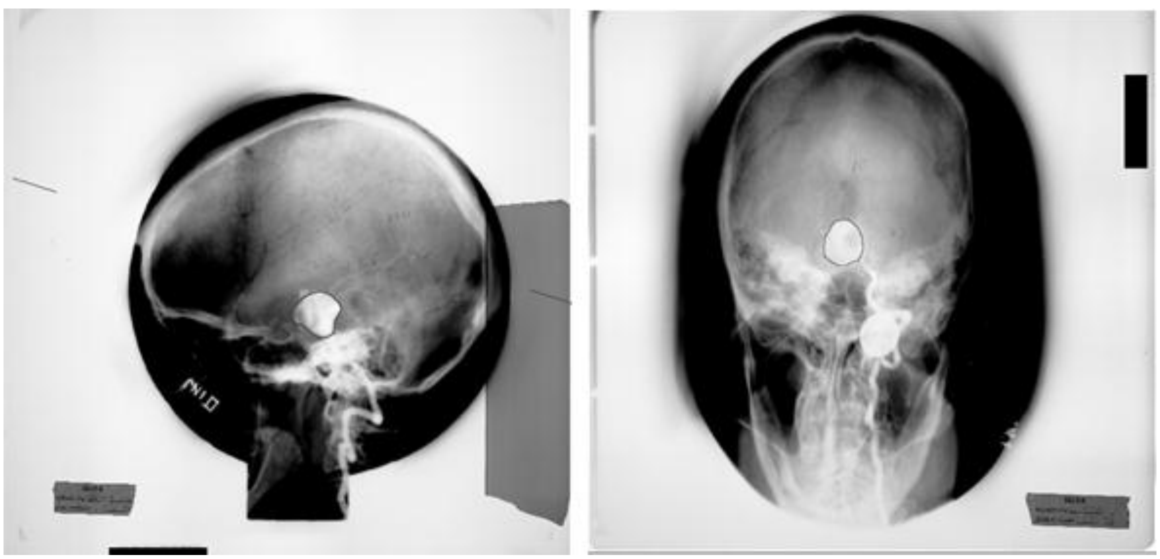

Figure 4 The left image shows the M-L paper trace. The line across the page indicates its orientation with reference to the A-P view of the skull. The right image shows the A-P paper trace. The aneurysms are marked with pencil in both the images which is used as a reference for Computer Model Calculations.

2.2.1.2 Manual Tracing of Aneurysm

The lateral view was rotated as per the angle provided by the radiologist on the lateral view in paper copy. The result of this was that the two views were orthogonal to each other.

We found the matching point between the two views. This was based on the user discretion. Ideally this point was chosen near the aneurysm neck. Also, the maximum height of both views should match between the two views. Based on this criterion a matching point was selected.

The A-P view is scaled according to the maximum height of the aneurysm in the M-L view. The final result of this step is that the two aneurysms are orthogonal to each other and scaled appropriately.

Then the manual tracing was carried out using imaging software ImageJ [7] and using the aneurysm outlined by radiologist as a reference.

2.2.1.3 Smoothing of aneurysm outline

After the manual tracing was carried out, the outlines were smoothed using "Cardinal Spline" curve fitting technique [8]. A spline curve is a mathematical device allowing us to easily build an interface that will allow the user to design and control the shape of complex curves and surfaces. The general approach is that the user enters a sequence of points, and a curve is constructed that generally follows this sequence. The points are called control points. A curve that actually passes through each control point is called an interpolating curve; a curve that passes near to the control points but not necessarily through them is called an approximating curve (smooth curve). Cardinal spline is a C1 continuous curve. Cardinal spline interpolates piecewise cubic with specified endpoint tangents for each segment.

Cubic Cardinal spline is a *C*1 continuous curve. Cardinal spline interpolates piecewise cubics with specified endpoint tangents for each segment. A Cardinal spline segment, as shown in figure, is defined by four control points, i.e., P_{j-1}, P_j , P_{j+1} and P_{j+2}. The *jth* segment of Cardinal spline interpolates between two *middle control points*, i.e., P_j and P_{j+1}. The *end control points*, i.e., P_{j-1} and P_{j+2} are used to calculate the tangent of P_j and P_{j+1}.

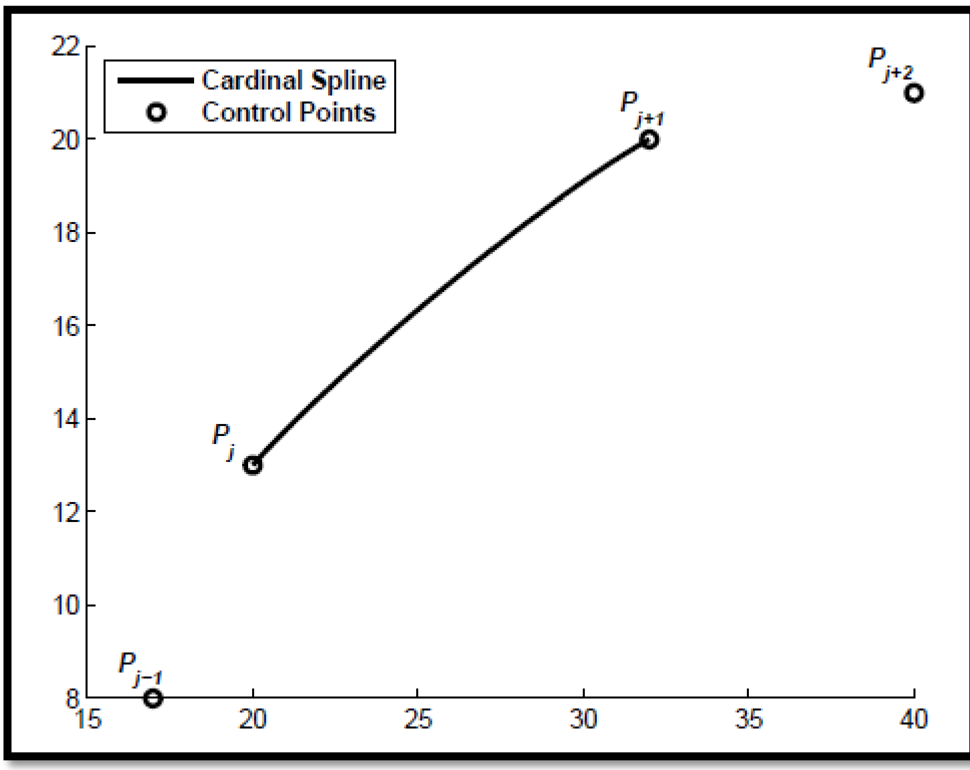

Figure 5 The jth Cardinal spline segment, T = 0 [8].

Equations for boundary conditions of *jth* segment is written as:

$$P_j' = \frac{1}{2}(1 - T)(P_{j+1} - P_{j-1}) \quad 0.1$$

$$P'_{j+1} = \frac{1}{2}(1 - T)(P_{j+2} - P_j)$$

0.2

where parameter *T* is *Tension* and it controls looseness/tightness of spline. For *l* joined segments, there are 2(l −1) conditions for continuity of functions and 2(l −1) conditions for continuity of slopes. Finally the equation of Cardinal spline for *jth* segment is written as follows:

$$Q(t_i) = (-st_i^3 + 2st_i^2 - st_i)P_{j-1} + [(2 - s)t_i^3 + (s - 3)t_i^2 + 1]P_j + [(s - 2)t_i^3 + (3 - 2s)t_i^2 + st_i]P_{j+1} + (st_i^3 - st_i^2)P_{j+2}$$

0.3

where *ti* is parameter of interpolation , 0 ≤ *ti* ≤ 1, and *s* is related to *Tension* by *s*= (1−*T*)/2 . In order to generate *n* points between *Pj* and *Pj*+1 inclusive, the parameter *ti* is divided into (*n*–1) intervals between 0 and 1 inclusive, and *Q*(*ti*) is evaluated (interpolated) at *n* values of *ti*.

The Cardinal Spline fitting algorithm was applied on the M-L and A-P aneurysm traces. It resulted in the smoothing of the sharp edges of the aneurysm outlines traced. The tension parameter was kept as 0. As the tension parameter increases the amount of smoothing decreases. The curve becomes tighter.

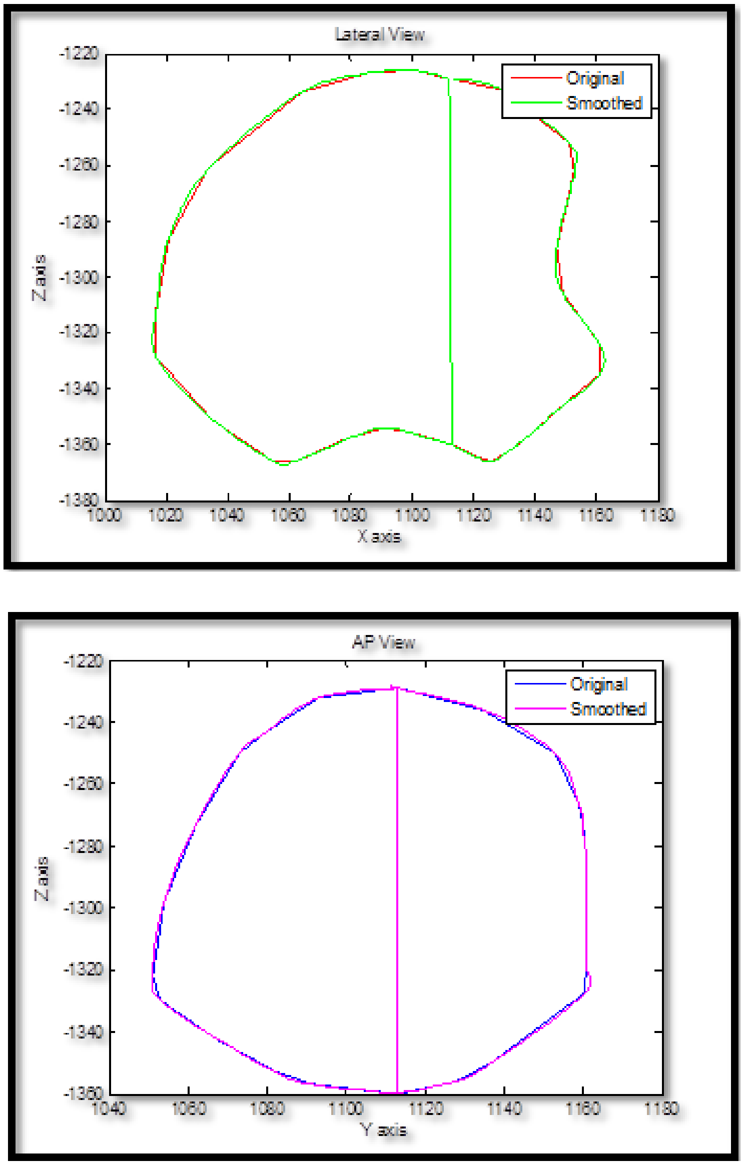

Figure 6 The Top image shows the M-L trace of the aneurysm. Red color shows the outline of the original aneurysm trace whereas green one shows the Smooth trace after the Cardinal spline fitting algorithm application.
The bottom image shows the A-P trace of the aneurysm. Blue color shows the outline of the original aneurysm trace whereas pinkish one shows the Smooth trace after the Cardinal spline fitting algorithm application.

2.2.1.4 Registration in 3D space

The two views are then placed in the 3D space in accordance to the matching point found earlier. A MATLAB code was written for this purpose.

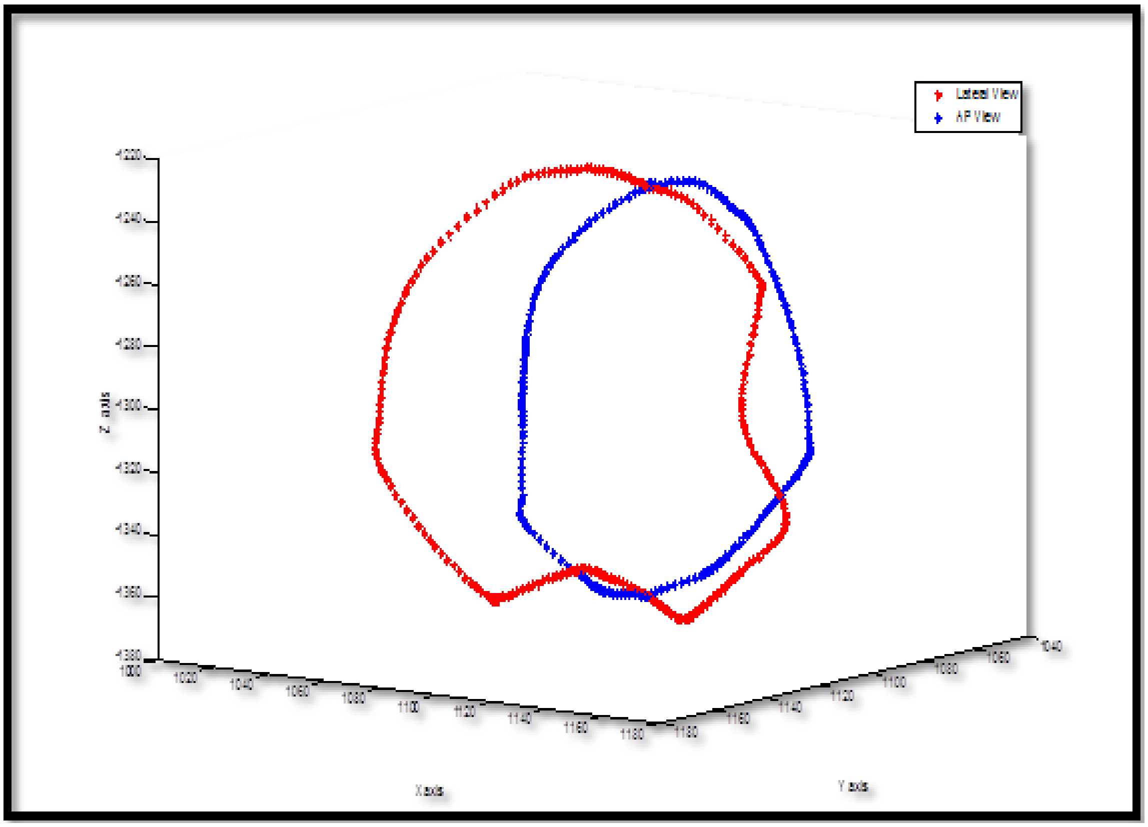

Figure 7 MATLAB image showing the placement of two views in 3-D. This shows that the two views are properly registered in the 3D-space. Red color depicts the M -L trace of the aneurysm whereas Blue depicts the A-P trace.

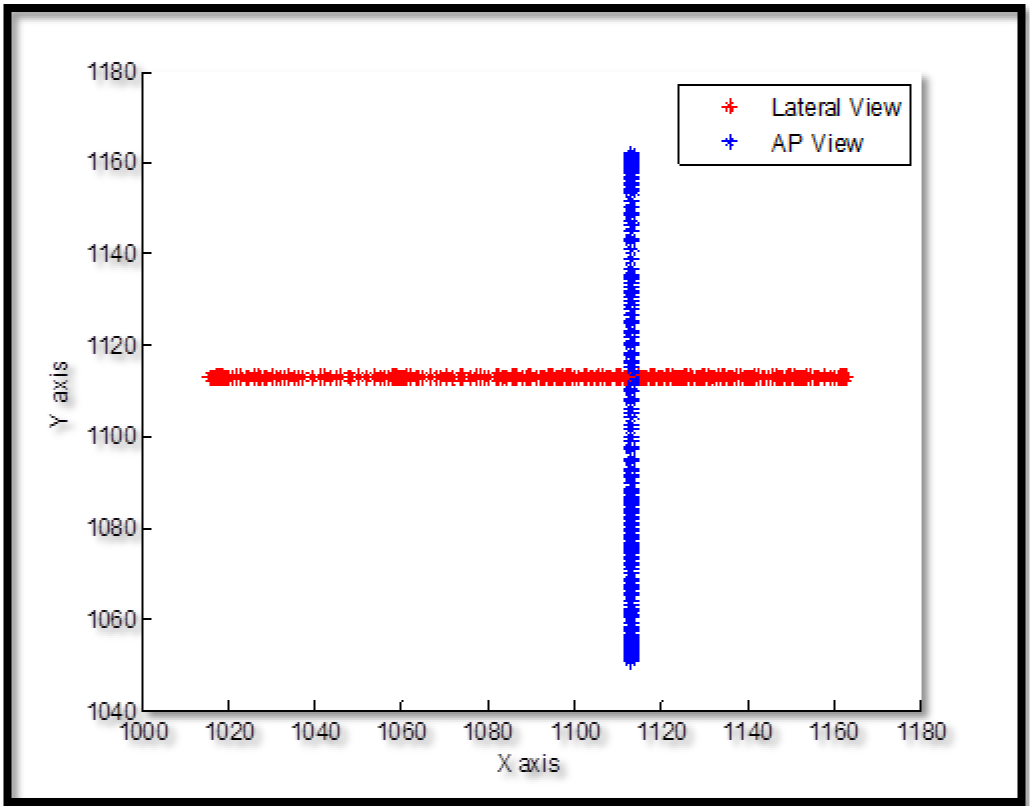

Figure 8 Top view of the two traces in the 3D space.

2.2.1.5 Shape blending and formation of 3D point cloud

Shape blending is the process addressing how to transform between two 2-D shapes which are defined using piecewise curves.

Shape blending consists of two distinct sub problems: the correspondence problem, and the path problem [9].

2.2.1.5.1 Correspondence problem

The heart of the algorithm is to insert knots into the two B-splines so that they have the same number of knots in their respective knot vectors. The resulting knot vectors define the correspondence between the two curves. The knots are inserted in such a way that the work to bend and stretch one shape into the other is minimized.

Essentially it is interpolation of each of the two curves between which transformation is to be done using B-splines.

A MATLAB function is created which does this point to point correspondence task.

$$function\ pt = interparc(t, p_x, p_y, 'spline') \tag{0.4}$$

Function ‘interparc’ interpolates new points at any fractional point along the curve defined by a list of points in 2 or more dimensions. The curve may be defined by any sequence of non-replicated points.

Argument ‘t’ is vector of numbers, 0 <= t <= 1, that define the fractional distance along the curve to interpolate the curve at. t = 0 will generate the very first point in the point list, and t = 1 yields the last point in that list. Similarly, t = 0.5 will yield the mid-point on the curve in terms of arc length as the curve is interpolated by a parametric spline. If t is a scalar integer, at least 2, then it specifies the number of equally spaced points in arclength to be generated along the curve.

Arguments ‘px’, ‘py’ and ‘pz’ are vectors of length n, defining points along the curve. n must be at least 2. Exact Replicate points should not be present in the curve, although there is no constraint that the curve has replicate independent variables.

Method is the optional string flag which denotes the method used to compute the points along the curve. It may be any of 'linear', 'spline', or 'pchip', or any simple contraction thereof, such as 'lin', 'sp', or even 'p'.

Output ‘pt’ is interpolated points at the specified fractional distance (in arc length) along the curve. Here px and py are the x and y co-ordinate of a curve,‘t’ indicates the number of points, 'pt' is the interpolated outcome for the curve. Here, a point to point correspondence between the curves is established.

2.2.1.5.2 Path problem

Intermediate B-splines in the blend can then be defined by linearly interpolating the control points and knot vectors of the two terminal B-splines.

$$M(t) = (1 - t)P + tQ \qquad 0.5$$

P and Q are the two B-spline curves. Here P is morphed into Q. 't' controls the number of morphed transition between the two curves. Curve M represents the morphed intermediate curves

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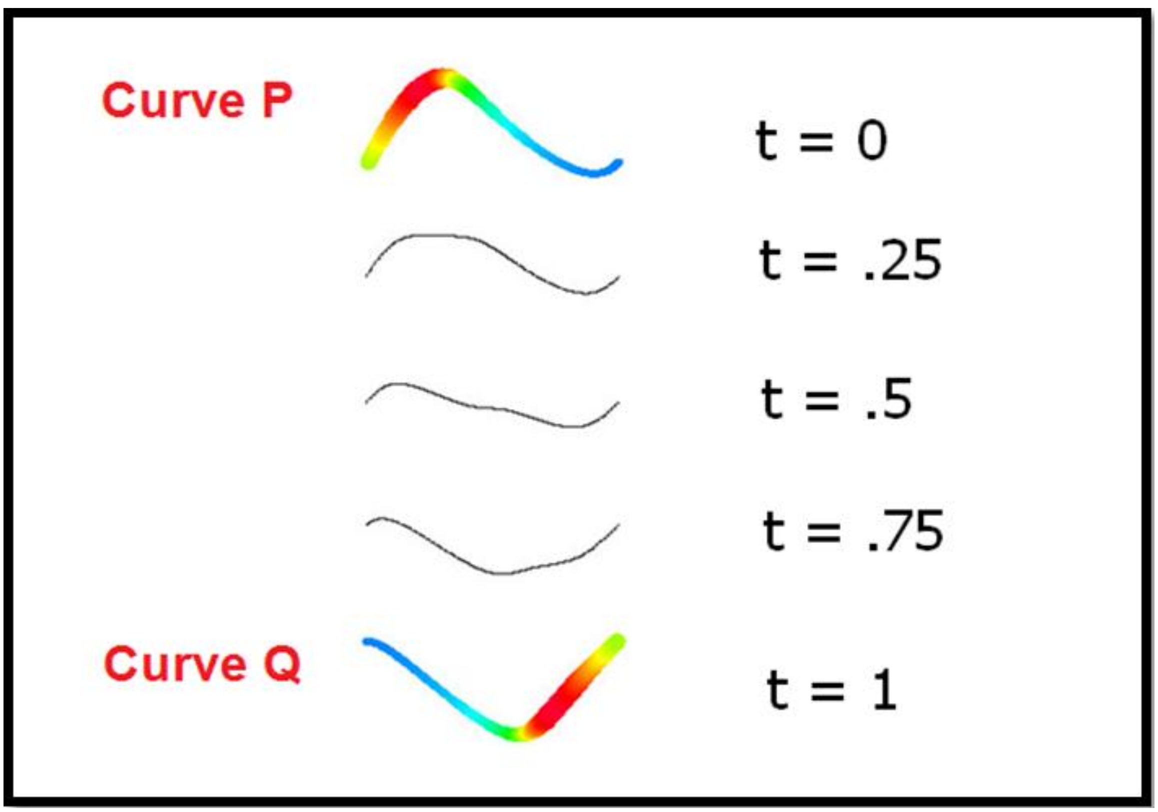

Figure 9 Graduate curve morphing between two curves.

At the end of this step, a 3D point cloud was obtained.

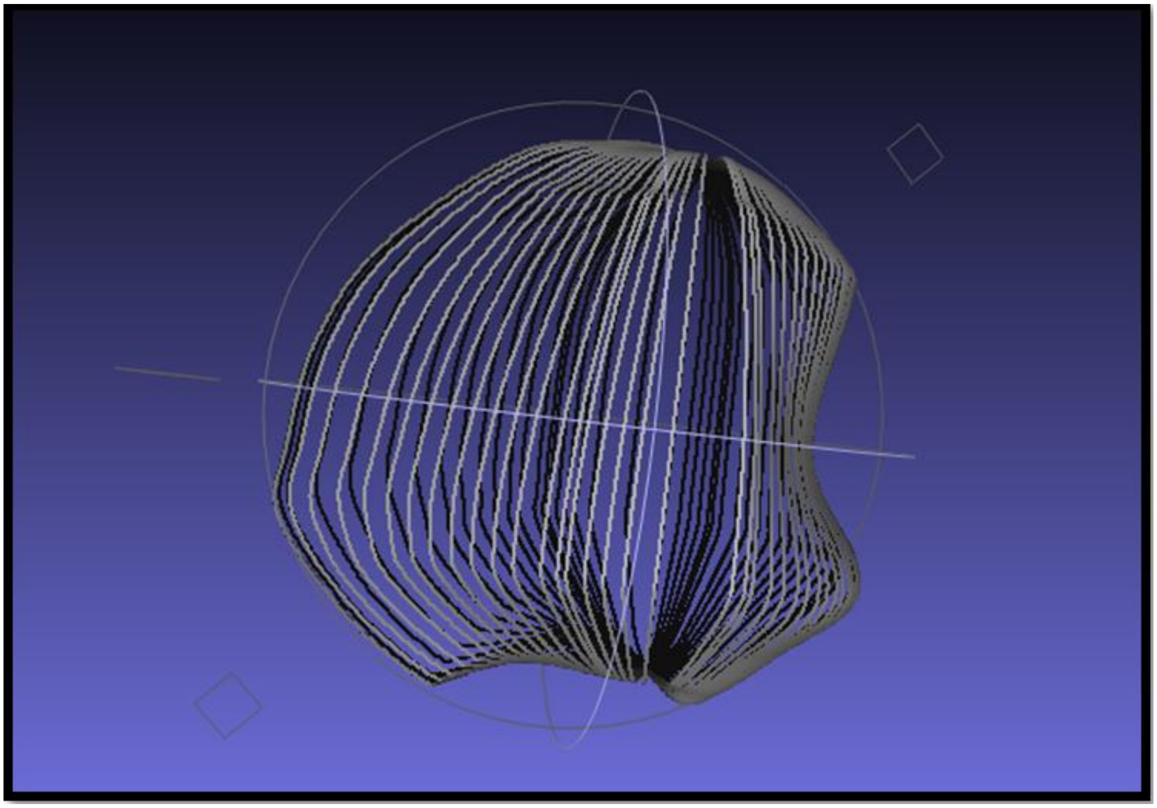

Figure 10 3D point cloud created in Meshlab.

2.2.1.6 Surface Formation

From the 3D point cloud, a closed surface was formed using meshing in Meshlab [10]. There are two kinds of meshes – triangular and quadrilateral which can be created from the point surface constructing closed surface.

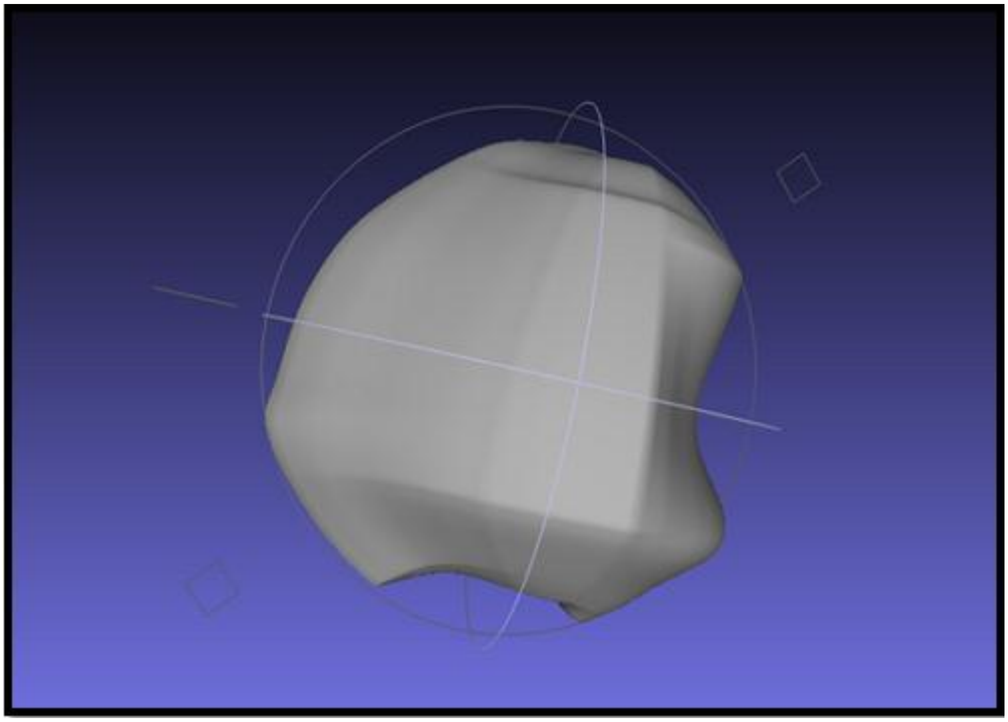

Figure 11 Closed surface formation from the 3D point cloud. This is done in Meshlab.

2.2.1.7 Surface re-meshing

The surface reconstructed was then smoothed using the Poisson surface reconstruction algorithm in Meshlab. The parameters changed are octree depth and solver divider. As the value decreases, the amount of smoothing increases. Effect of these parameters is shown in the images below. Care has to be taken while using these parameters so that the smoothing does not become too aggressive which gets rid of some of the features of the aneurysm. The parameter values were set to 5 for this study purpose as it was the best match. Here, the smoothing was sufficient enough so that it did not show too many sharp edges and also it did not smooth out the aneurysm features too. As the values increase for the octree depth and the solver divide, the smoothing increases proportionately.

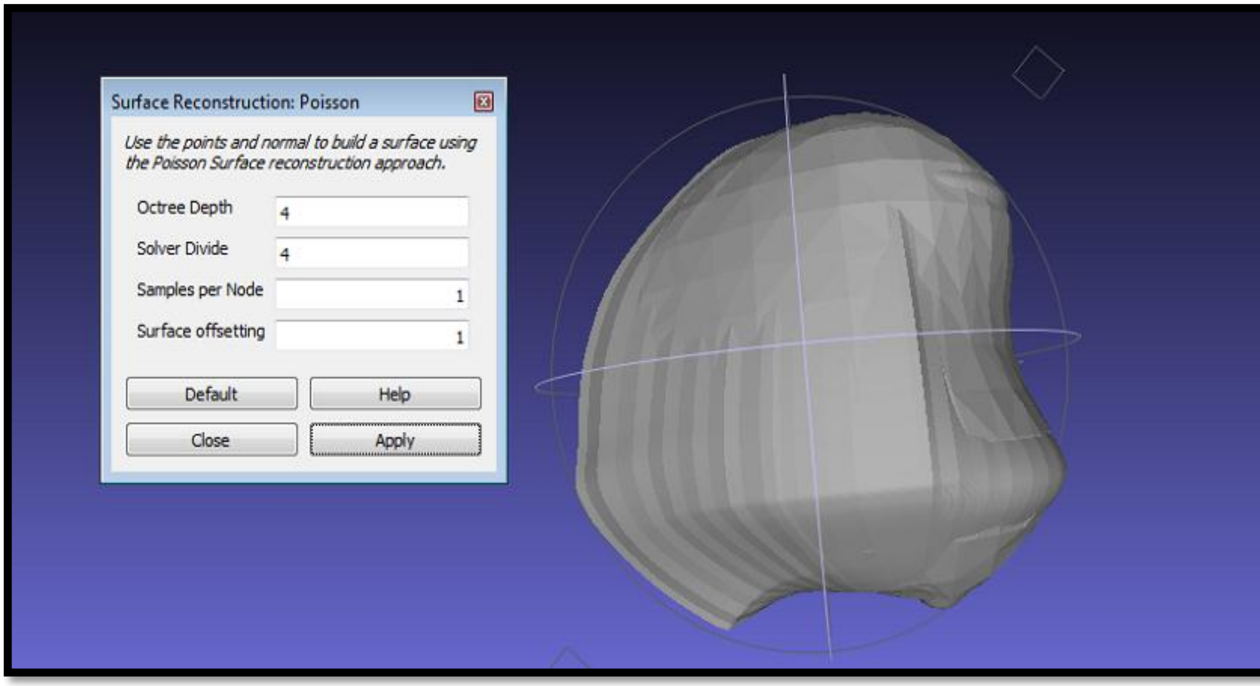

Figure 12 Application of Surface Reconstruction Poisson on the closed surface. The parameters here are Octree Depth = 4 and Solver Divide = 4.

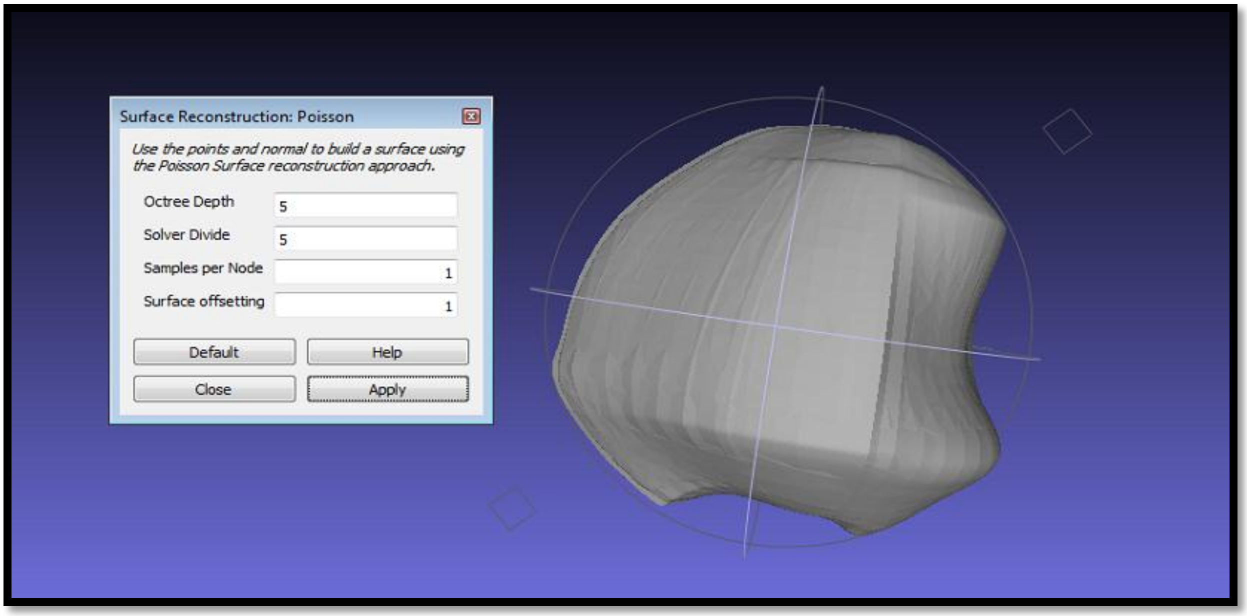

Figure 13 Application of Surface Reconstruction Poisson on the closed surface. The parameters here are Octree Depth = 5 and Solver Divide = 5.

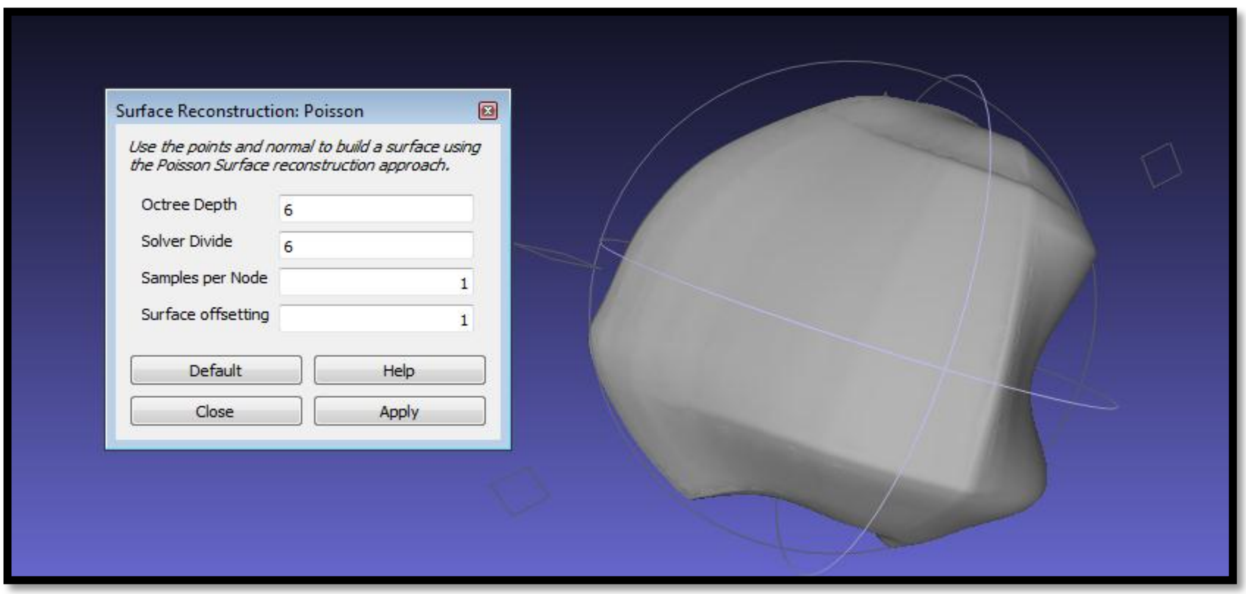

Figure 14 Application of Surface Reconstruction Poisson on the closed surface. The parameters here are Octree Depth = 6 and Solver Divide = 6.

2.2.1.8 Cut the neck plane to get the actual aneurysm geometry

After the 3D surface geometry creation and smoothing, a neck plane was formed using the details provided in the original traces by radiologists. If a neck was given in both the M-L and the A-P views then use them to form a neck plane, else use the neck given on either M-L or A-P view. For the formation of a neck plane, a point and a normal to the plane is needed.

If P1, P2 and P3 are the three neck points obtained from the trace information, then normal to the plane is calculated as below.

$$Normal = (P1 - P2) * (P1 - P3) \quad (2.6)$$

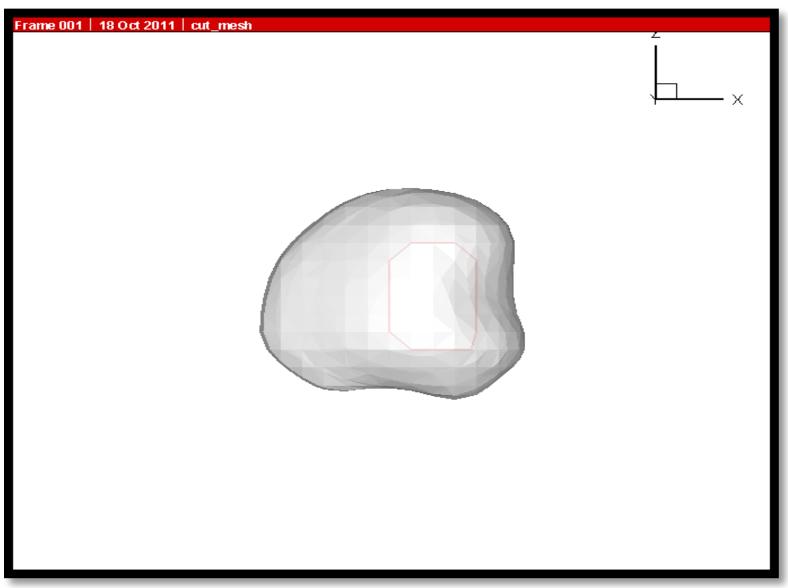

Figure 15 3D aneurysm in M-L view. The red color shows the hidden neck in this view.

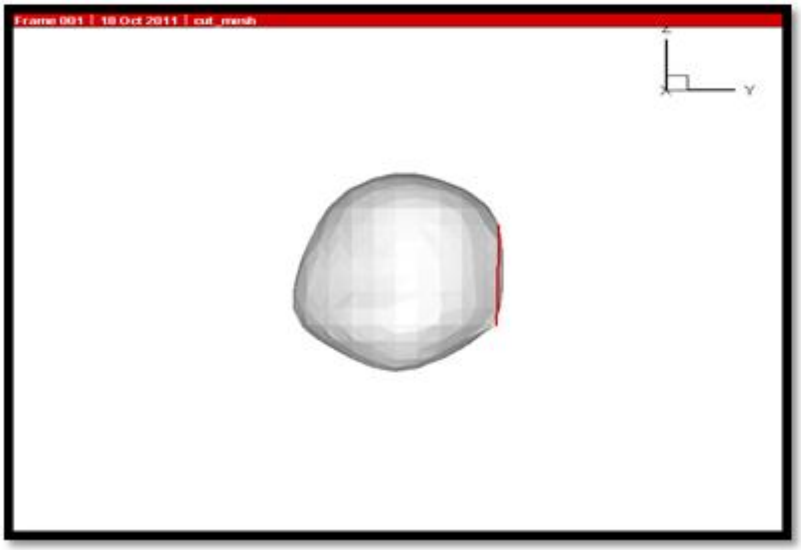

Figure 16 3D aneurysm in A-P view. The red colored line shows the neck plane. It is visible in A-P view.

2.2.2 Estimate the size and shape metrics of aneurysm

After the 3D aneurysm geometry was obtained, the goal was to calculate the size and shape indices to analyze the aneurysm geometry [11]. Aneurysm height, neck diameter, aspect ratio (AR), Volume, Surface Area, Ellipticity index (EI), Non-spherecity index (NSI) were among the few indices calculated [11].The code developed in Matlab by Baoshun Ma[12] was used for calculating these indices.

2.3 Validation Study

To ensure the correctness of the method, a validation study was also performed. The goal here was to test the logic of the 3D reconstruction method developed and ensure there were nothing missing in the developed method for the case where two outlines were perfectly orthogonal and height was the same too. We started off with 3D geometries of aneurysms already available. This data was obtained from the BioMOST lab and it consisted of 10 patient set. Morphological metrics were calculated for this original data set using the Matlab code.

Two orthogonal 2-D projections were taken from this 3D geometry. Then the 3D surface was reconstructed from these two projections using the developed methodology. Similarly for this reconstructed geometry the morphological metrics were calculated using the Matlab code. The indices between the original geometry and the 3D reconstructed geometry were then compared to ensure the validity of the logic of the methodology.

2.4 Compare the morphological metrics from the reconstructed 3D surface with the estimates of radiologists' measurement

During ISUIA's study in the 90's, they formed a large database of biplane cerebral aneurysms from these patients who were followed longitudinally. This unique data may be mined for testing hypotheses on the role of morphology metrics in rupture risk. This is a legacy data – gold data. It contains data of the patients followed over a very long period of time, with inconsistent time gaps. It has a very large number of patients set as well. The only disadvantage with this data is the lesser quality as these are angiogram data and have been collected during the 90's at various centers over the world with various inconsistencies. ISUIA predicts the rupture risk on the basis of the size of the aneurysm. ISUIA approximates the aneurysm as an ellipsoid constructed from the M-L, A-P and C-C dimensions. Morphological metrics were calculated on the basis of this ellipsoid geometry.

A study population of 150 patients was collected randomly from the ISUIA database and the 3D surface reconstruction methodology developed was applied onto this set. The morphological metrics calculated from the aneurysm surfaces developed by 3D surface reconstruction methodology were compared with the morphological metrics calculated. Here, the aneurysm outlines were traced out by radiologists as the engineering eyes were not sufficient for studying the angiogram and locating the aneurysm therein. These traces were used as a reference for digital tracings and then the entire methodology for creating the 3D surface was applied.

CHAPTER 3

RESULTS

3.1 Results of the Validation Study testing the Logic of the Methodology

For testing the validity of the logic of the methodology developed, a validation study was performed. This study consisted of a study population of 10 patient dataset. The real 3D geometry of the cerebral aneurysms was available in this case. The orthogonal projection images were taken from this original 3D geometry and the methodology was applied to reconstruct a 3D geometry. The volume, surface areas and NSIs were compared between the original data and the 3D reconstructed data. The correlation coefficients of volume and surface area were 0.999 and 0.996 respectively. The correlation coefficient for NSI for all the cases was 0.677 and volume > 20 cu.mm was 0.877. These results showed a very good matching between the two results indicating the accuracy of the method in reconstructing a 3D geometry from two perpendicular 2D views. In the cases with smaller volumes a very small difference in any dimension (~0.2 mm or so) can make a huge difference in the NSI. Hence they are not reliable cases for NSI comparison.

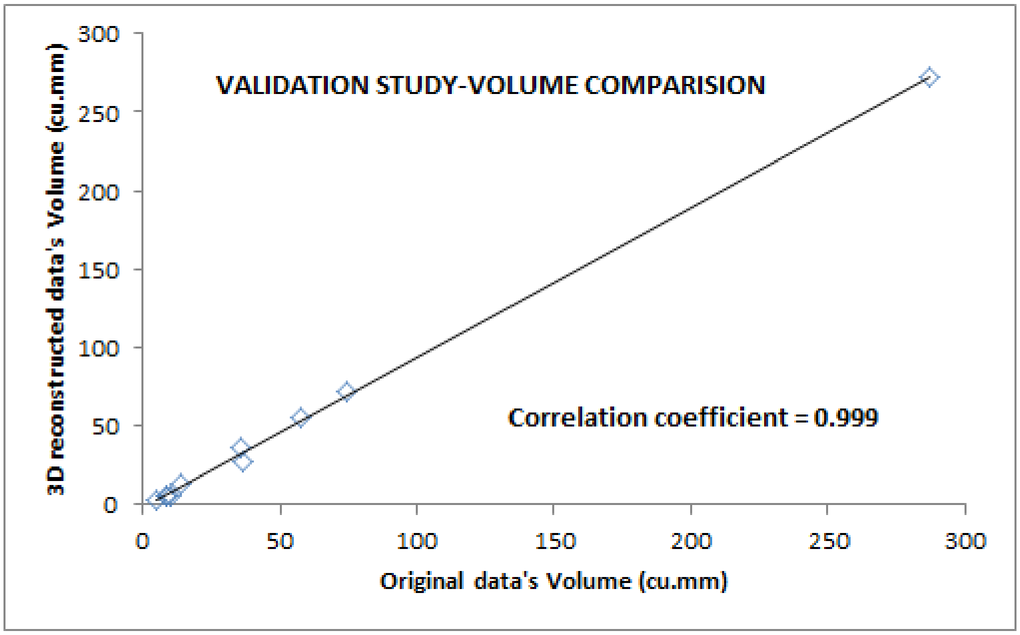

Figure 17 Volume Comparison of the original 3D data against the reconstructed 3D aneurysm. Correlation coeficient = 0.999.

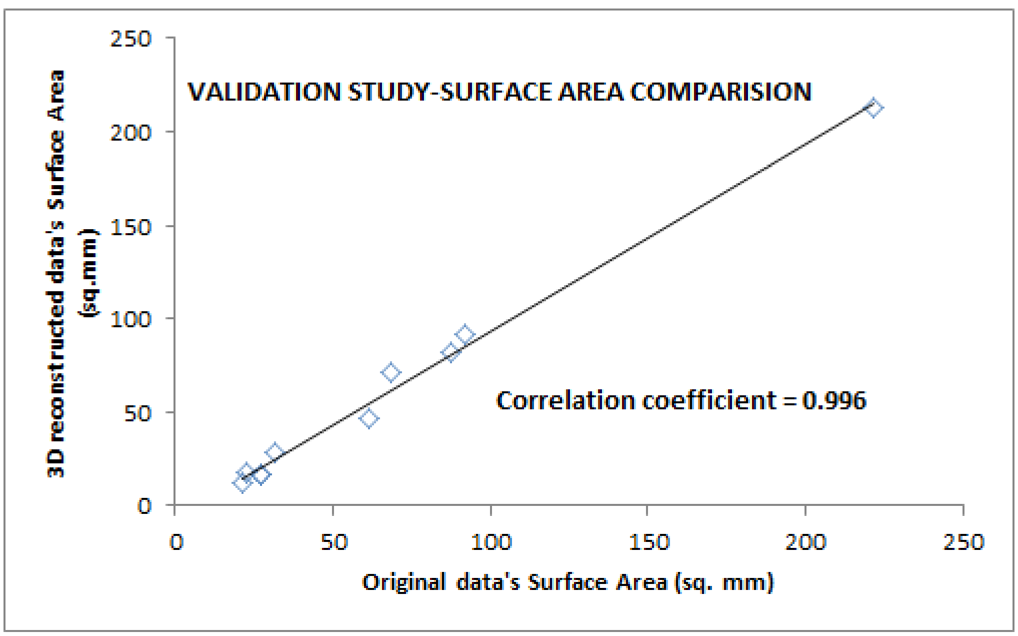

Figure 18 Surface Area Comparison of the original 3D data against the reconstructed 3D aneurysm. Correlation coefficient = 0.996.

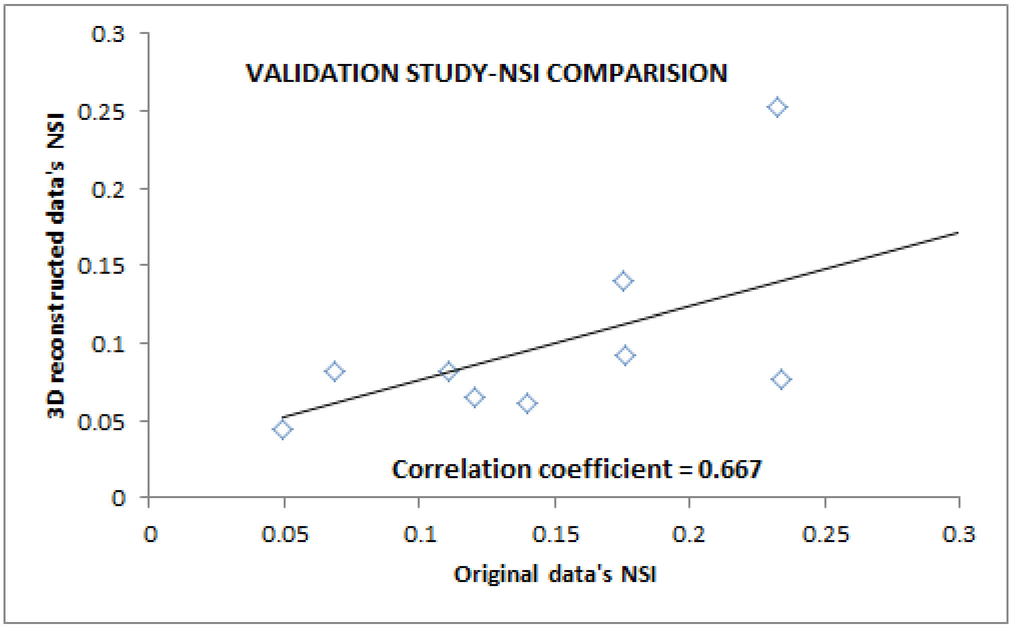

Figure 19 NSI Comparison of the original data against the 3D reconstructed aneusym. Correlation Coefficient= 0.667.

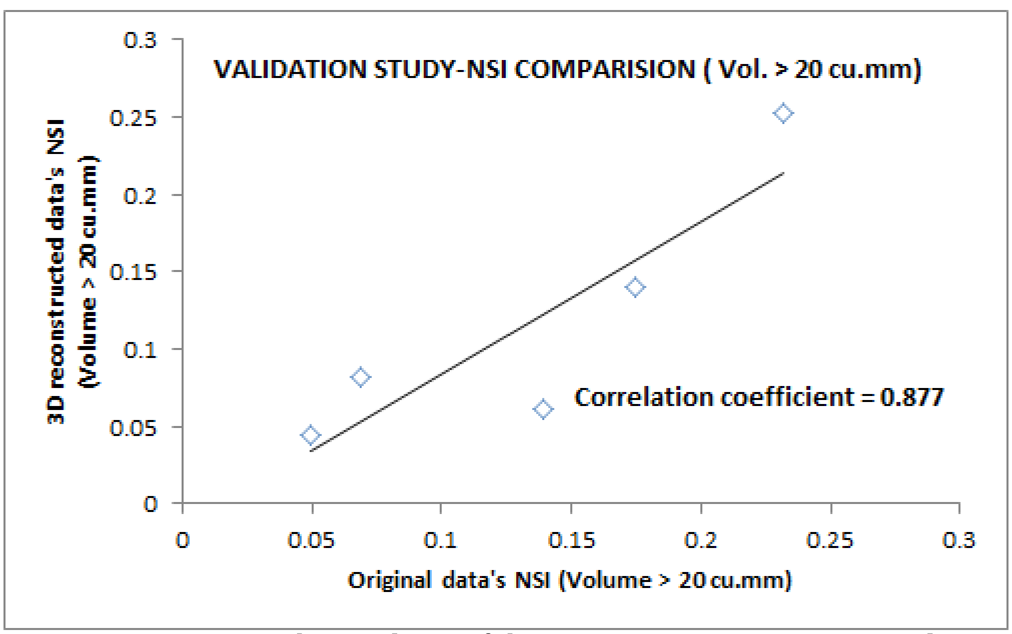

Figure 20 NSI Comparion where volume of the anurysms > 20 cu. mm. Correlation coefficient = 0.877

3.2 Results of the Pilot Study

A total of 150 pilot patient populations were used during this method. Height and neck diameter of the aneurysms were provided by the radiologist on the paper traces. From this study population of 150 patients, 8 cases were cases where there was no aneurysm in it or was an infundibulum. There were 15 cases in which the neck was not clear in the biplane angiograms and had to be adjudicated with the help of the radiologists. Out of these 15 cases, 12 could not be analyzed with a clear neck in any one of the views. Thus, 130 cases were analyzed in all.

A correlation is a number between -1 and +1 that measures the degree of association between two variables (call them X and Y). A positive value for the correlation implies a positive association (large values of X tend to be associated with large values of Y and small values of X tend to be associated with small values of Y). A negative value for the correlation implies a negative or inverse association (large values of X tend to be associated with small values of Y and vice versa) [13].

The height and neck diameter measures calculated from the 3D geometry closely matched with the radiologists' measures. This ensured the correctness of the method. The graphs showing the results of the same are shown below. They also have the corresponding correlation coefficient values and their high values indicate how closely they match.

The volumes, surface areas and NSI values were also compared then. The correlation coefficients of volume and surface areas were quite high indicating good match between them. The correlation coefficient of NSI comparison was very low indicating a discrepancy in the NSI calculation in both the methods.

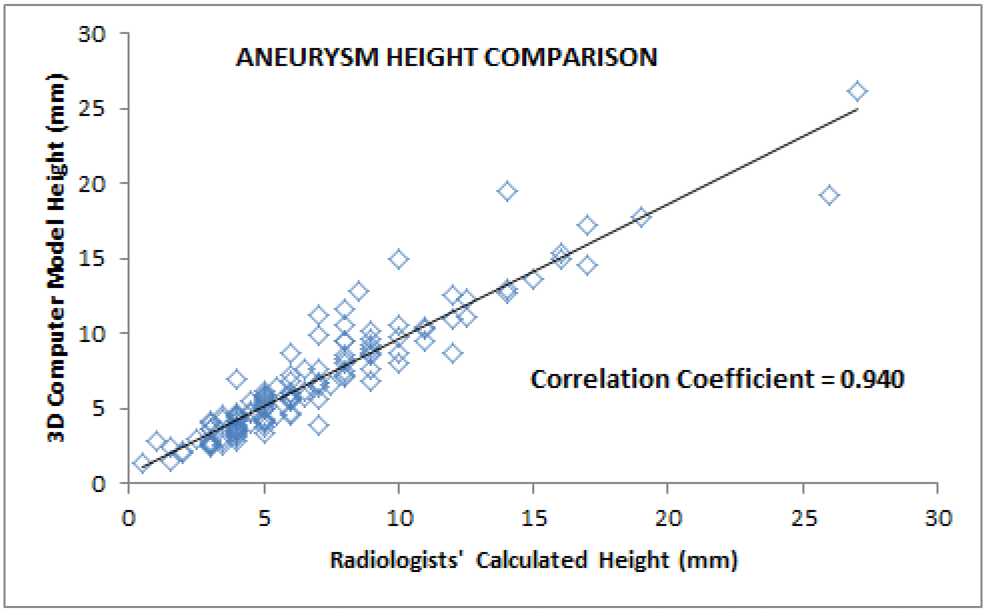

Figure 21 Aneurysm Height Comparison between the radiologists' and Computer Model Calculations. Correlation coefficient = 0.940.

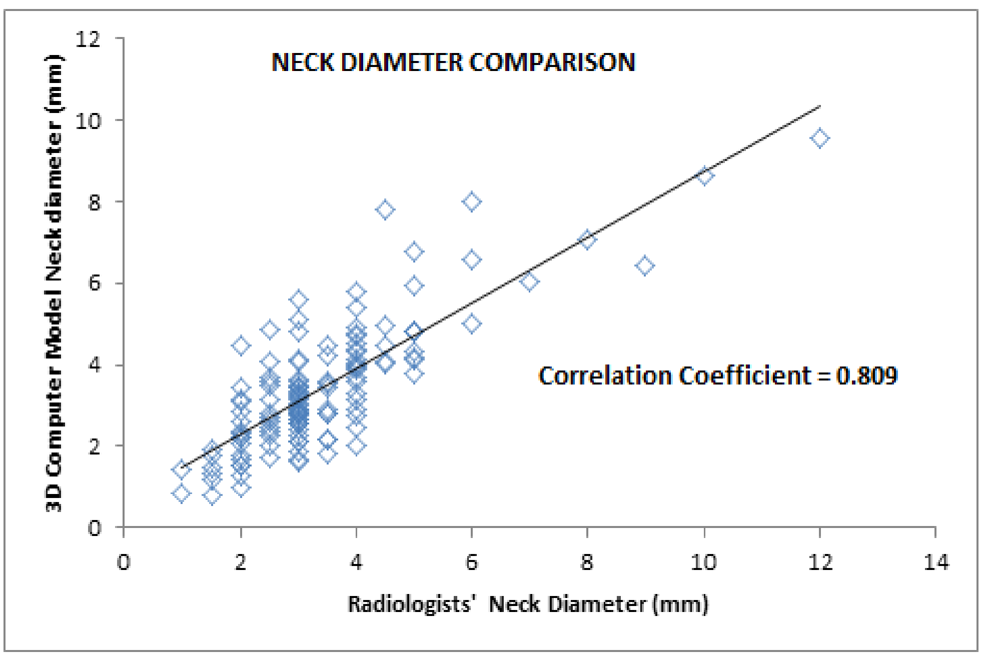

Figure 22 Aneurysm Neck Diameter Comparison between the radiologists' and Computer Model Calculations. Correlation coefficient = 0.809.

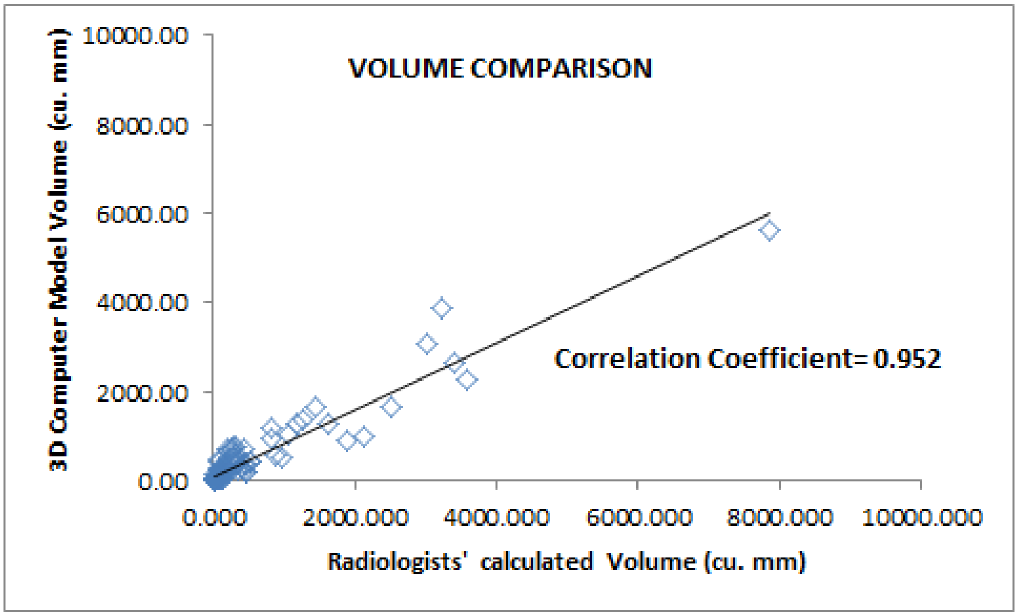

Figure 23 Volume Comparison between Radiologists' and Computer Model Calculations. Correlation coefficient = 0.952.

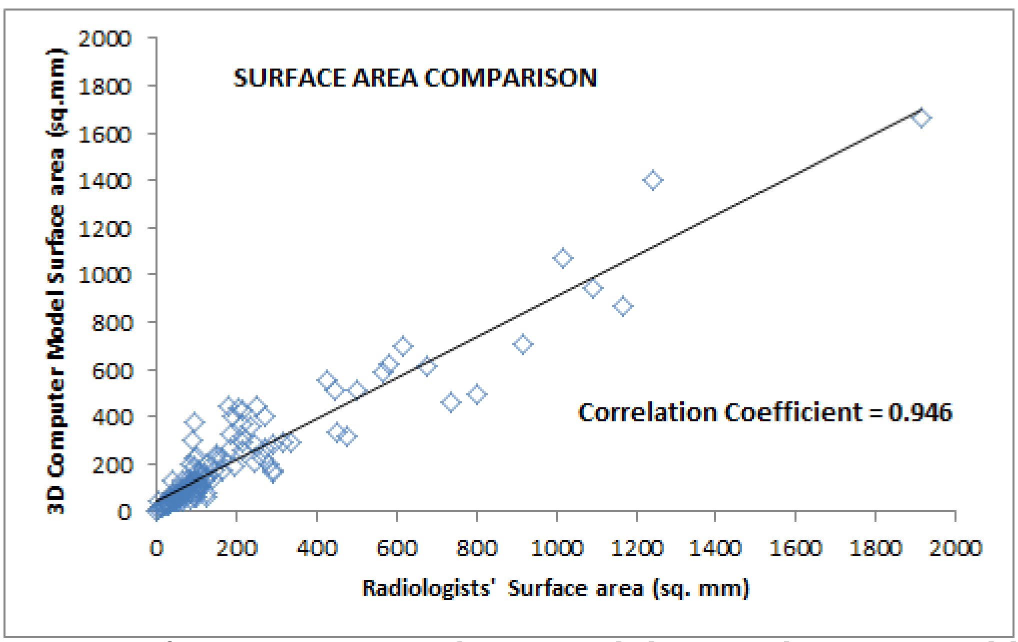

Figure 24 Surface Area Comparison between Radiologists' and Computer Model Calulations. Correlation coeffficient = 0.946.

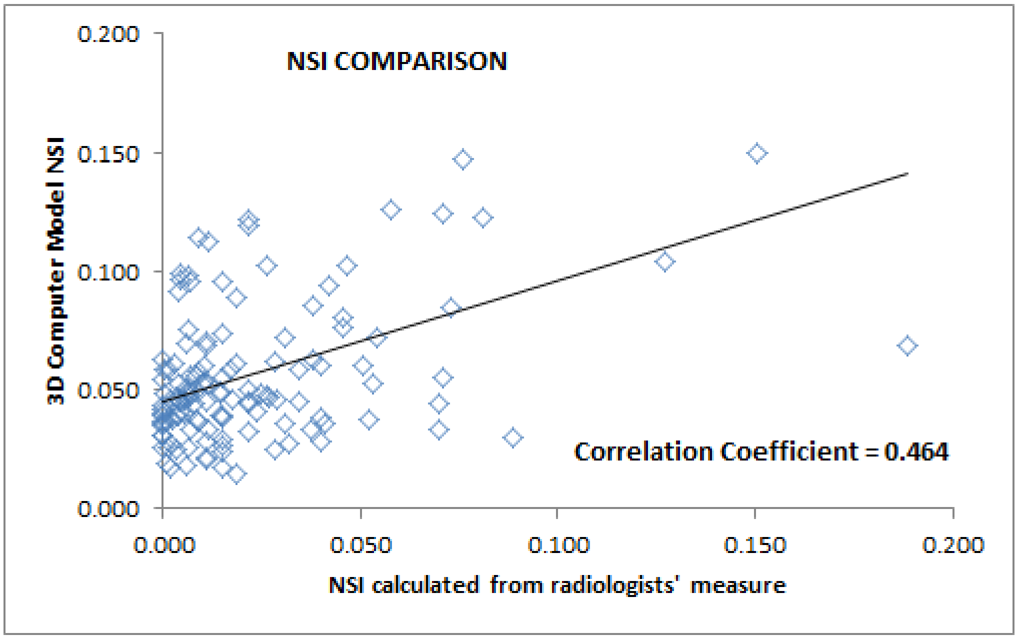

Figure 25 NSI comparison between Radiologists' and Computer Model Calculations. Correlation Coefficient = 0.464.

CHAPTER 4

DISCUSSION

4.1 Introduction

This entire study was very important in analyzing the shape and size characteristics of aneurysms from biplane angiograms. The ISUIA followed the patients over a long duration of time collecting the biplane angiograms. This is a legacy data. From the big data population, 150 patients were chosen for this study. It is important for the radiologists to know the accurate shape and size characteristics as the aneurysm rupture can be predicted from this. The methodology was developed for 3D reconstruction of aneurysms from biplane angiograms with good accuracy.

Over the years methods of 3D reconstruction from biplane angiograms have been developed. There is an ellipsoid method which forms an ellipsoid from the two biplane angiograms. This is a rather approximate estimation of the 3D geometry [14]. There are other methods too which needs more information than just the biplane angiograms. [15] This method is novel in the sense that it just needs very basic information for the formation of 3D geometry. It needs two biplane angiograms with the orientation between them and one matching point between the two images. Only using this little information the 3D geometry can be constructed using the 'Curve Morphing' approach used here. It provides better accuracy than the traditional ellipsoid approach followed.

4.2 Overview of the entire approach

The aim of the research was to utilize the gold legacy data from the ISUIA to study the aneurysm shape and size characteristics. This data was collected longitudinally over a long period of time with patients being followed up in not so timely manner. Also, the quality of the data was poor considering the time period in which the data was collected and it being angiograms. The methodology for 3D reconstruction was developed from the biplane angiograms using the ‘Curve Morphing’ approach.

This methodology was validated using the study population of 10 aneurysms from the BioMOST laboratory. In this study, two orthogonal projections were taken from the original 3D aneurysm geometry and the aneurysm was reconstructed using the methodology developed. The high values of the correlation coefficients of volume, surface areas and NSI indicated the validation of the logic of the methodology developed. Correlation coefficient values of NSI were comparatively lower for the entire population but for the cases with volume>20 cu.mm the correlation coefficient values increased. For smaller volumes, a little difference in any of the A-P, M-L and C-C sizes causes a big difference in the volumes and in turn affects the NSI too.

The developed methodology was applied on the study population of 150 patients from the ISUIA database. From this study population of 150 patients, 8 cases were cases where there was no aneurysm in it or was an infundibulum. There were 15 cases in which the neck was not clear in the biplane angiograms and had to be adjudicated with the help of the radiologists. Out of these 15 cases, 12 could not be analyzed with a clear neck in any one of the views. Thus, 130 cases were analyzed in all. More insight from the radiologists was needed as some of the cases did not have a clear neck and the aneurysms were difficult to visualize. After the aneurysm traces and the necks were clearly visualized on the paper, it was replicated onto the computer images. Then from the two aneurysm outlines the 3D point set was developed using the ‘Curve Morphing’ approach. The 3D surface formed from the point set was smoothed using the Poisson Surface Reconstruction algorithm in Meshlab. The 3D aneurysm geometry was obtained by cutting the neck plane information available from the biplane angiograms. The code developed by Boashun Ma, was then applied onto these geometries for the morphologic metrics calculations.

The morphologic metrics obtained from the reconstructed 3D aneurysms were compared to the morphologic metrics obtained from the ellipsoid approximation of the aneurysms from the radiologists. The method of reconstructing a cerebral aneurysm from biplane angiograms worked out really well as indicated by the validation study results too. The results of the height and neck diameter closely match with the radiologists' calculations of the same which ensured the correctness of the reconstruction method for the data. Hence, the method was carried out for calculation of volume, surface area and other shape indices. All the metrics showed a good sense of agreement apart from the NSI. There was a big discrepancy in the NSI values measured by the two methods. The reasons for those are explained in the section below.

4.3 Reasons of difference in NSI measurement

The way by which aneurysm was defined just from the two biplane views differed in the radiologists' and computer model.

According to the radiologist, aneurysm was assumed to be an ellipsoid defined by the anterior-posterior, medial-lateral and cephalic-caudal dimensions.

According to the 3D model, aneurysm is recreated using the tracings from two biplane angiogram views.

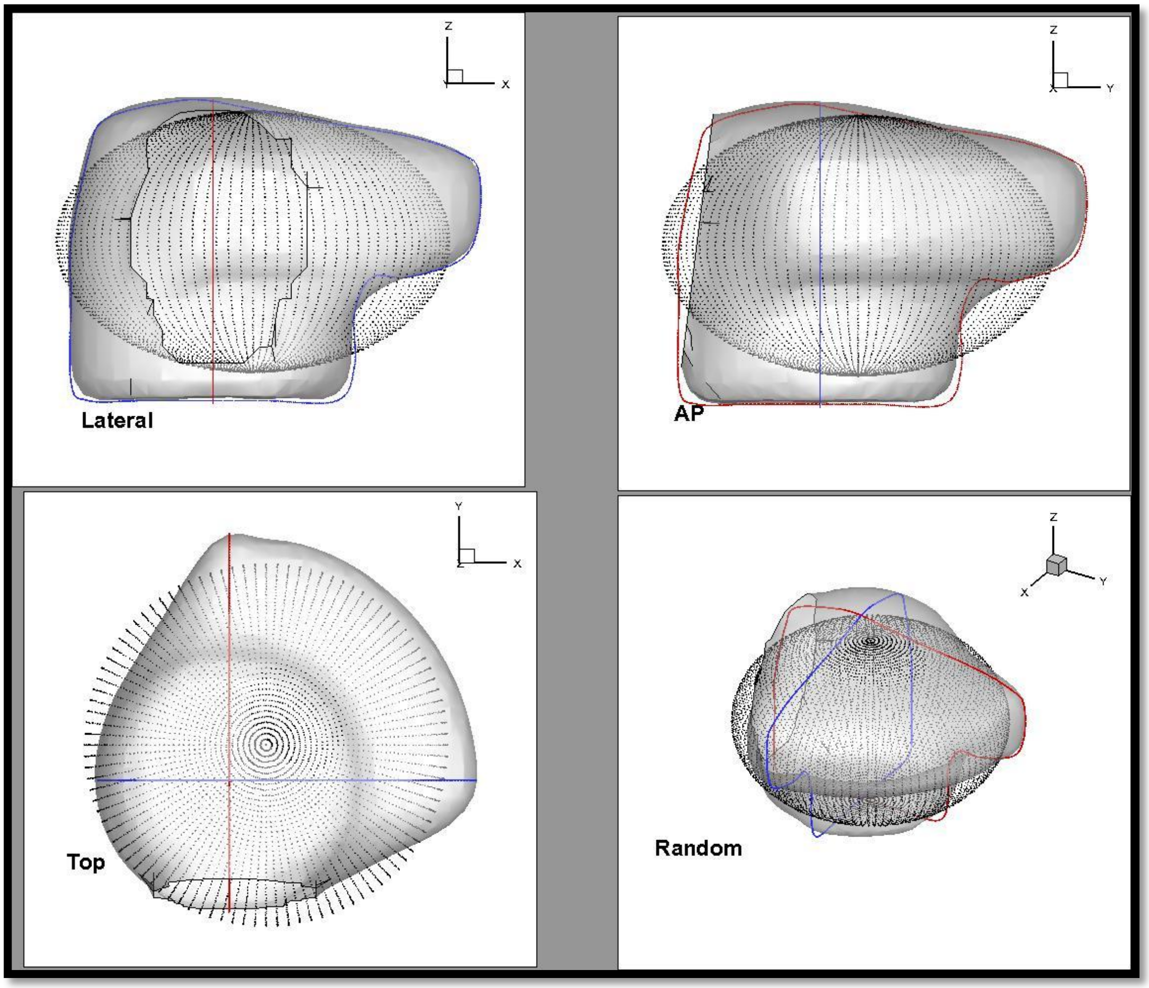

Figure 26 This figure depicts the comparison of the aneurysm geometry as defined by the radiologists' and the one constructed by the computer. The top-left, top-right, bottom-left and bottom-right views are the views from the M-L, A-P, top view and random view. Patient Code = 80-506.

The following are the three main reasons for the difference in NSI.

1) Irregularity:

   Aneurysm shape is asymmetric/irregular in computer model and this is not captured by the symmetry in the ellipsoid in radiologist. In reality, the aneurysm is not a perfect ellipsoid. The irregularities in the aneurysm as shown in the biplane traces are not captured in the ellipsoid method whereas it is captured by the 3D model created.

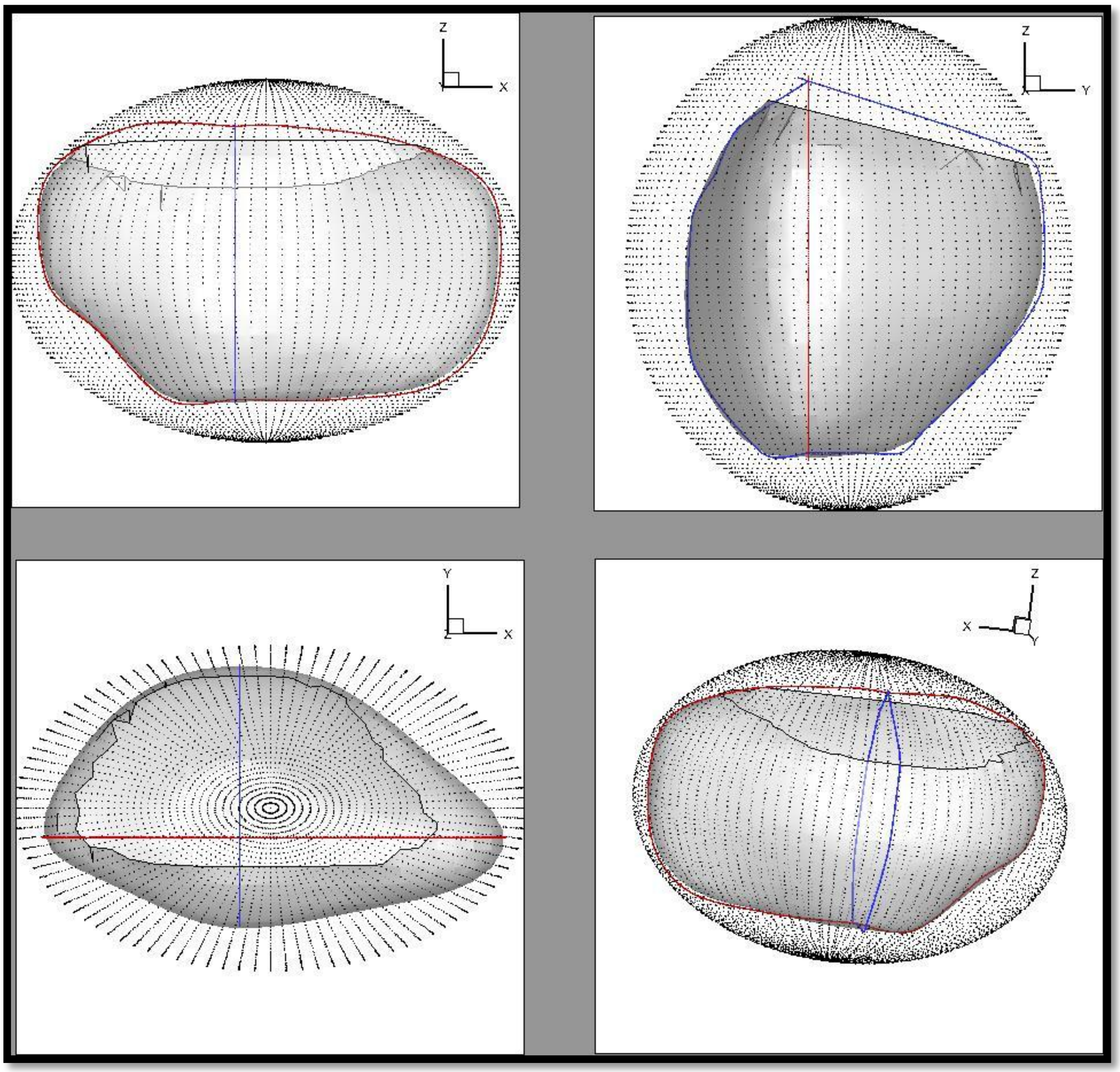

Figure 27 This figure depicts the comparison of the aneurysm geometry as defined by the radiologists' and the one constructed by the computer. The top-left, top-right, bottom-left and bottom-right views are the views from the M-L, A-P, top view and random view. Patient Code = 65-537.

2) Scaling:

The scaling of the image from pixels to millimeter dimensions is done using skull size from the paper traces. But when Lateral and AP dimensions do not reconcile (i.e., if the max 'height' of the aneurysm do not match), they are forced to reconcile in computer model. Here, the AP view is scaled according to the dimension in ML view so that the maximum size matches in the two cases. But this is not the case with the radiologists' ellipsoid method.

3) Positioning:

In computer model alone, it is necessary to position/register the M-L and A-P views in 3D space. This is done by visually matching the center of the neck (where possible). The aneurysm shape can be affected by the manner in which they are positioned.

There are also three minor reasons:

1) Neck:

Aneurysm is truncated by the neck in computer model, but no such neck truncation exists in radiologist calculation

2) Modeling artifacts:

In computer model alone, where the two views look extremely different, it can create some bumps in shape that are not real. Some artifacts such as flattening, wriggling can occur due to interpolation used in the curve morphing technique. Smoothing, however, was performed to reduce the effect of these artifacts.

3) Tiny size:

When the aneurysm is small (<3 mm A-P, M-L, C-C dimension or ~ <25 cu.mm volume), then the tracings can be poor and/or exacerbate round-off errors. Radiologists' measurement rounds off numbers to nearest 1 mm in most.

CHAPTER 5

CONCLUSION

The legacy data from ISUIA was analyzed with good accuracy. The 3D models were developed and the size and shape indices were calculated. The validation study with the 10 patient set depicted the accuracy of the reconstruction method. It shows that method depicts good results with volume and surface area of the aneurysm. The correlation value for volume and surface area are 0.999 and 0.996 respectively. It shows good results with NSI as well, the correlation value being 0.877 (Vol. >20 cu.mm). This ensured the overall accuracy of the reconstruction method using the shape blending technique.

The result of the 150 set population was validated with the height and neck diameter of the aneurysm calculated by the computer model compared against the radiologists' measure. The correlation values for height and neck diameter comparison were 0.940 and 0.809 depicting the aforesaid. The correlation values for surface area and volume were 0.946 and 0.952 which depicts good match as well. The correlation value for NSI was 0.464 which shows a discrepancy between the two measurement methods. This was because of the fundamental difference by which the aneurysm was visualized by the radiologists' and the computer model. According to the radiologist, aneurysm was assumed to be an ellipsoid defined by the anterior-posterior, medial-lateral and cephalic-caudal dimensions.

While according to the 3D model, aneurysm was recreated using the tracings from two biplane angiogram views using the shape blending technique taking the aneurysm original shape from the angiograms into account.

The results depicted the accuracy of the method by which the aneurysm was reconstructed using the shape blending technique. Hence, it shows the value of the method. It can be used by the radiologists' to calculate the shape and size indices with greater accuracy. It can be especially useful to replace the ellipsoid technique of the radiologists' to calculate the shape features. This method can be used to calculate the shape indices with greater accuracy. This method took about 30 minutes to analyze one patient data.

In a nutshell, the methodology was developed for 3D reconstruction of aneurysms from biplane angiograms. The logic of this developed methodology was validated too. The developed methodology applied on the study population showed that it is going to provide better accuracy for the shape characteristics than the ellipsoid approximation of the aneurysms by the radiologists. The true shape of the aneurysm cannot be captured by the ellipsoid approximation of the aneurysms and the developed methodology provides a much better way to characterize the aneurysm and in turn predicting the rupture risk.

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