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# Computer Simulation On Prediction of Possible Locations of Rupture In An Abdominal Aortic Aneurysm (AAA)

From a biomechanical point of view the possible locations of rupture in an abdominal aortic aneurysm (AAA) could be those points that are subjected to high wall stresses. Where and when rupture will occur in an AAA cannot be predicted. If these locations of rupture can be identified, proper surgical intervention is possible. The present study makes use of images from Computer Tomography (CT) scans of a patient which when converted to solid models using the 3-D solid modeling software can then be analyzed with the Finite Element Analysis (FEA).

It is difficult to predict when an aortic aneurysm will rupture. Early detection and diagnosis are important so that surgical grafting can be done before an aneurysm ruptures. Research has been focused on the relationship of aneurysm rupture to diameter and asymmetry (Vorp, Raghavan & Webster, 1998), surface geometry (Sacks, Vorp, Raghavan, Federle & Webster, 1999, Smith, Sacks, Vorp & Thornton, 2000), finite strain material model (Raghavan & Vorp 2000), and mechanical wall stresses (Raghavan, Vorp, Federle, Makaroun & Webster, 2000). From a bio-mechanical standpoint, risk is more related to mechanical wall stresses (Vorp *et al*, 1998). Determination of wall stresses in an abdominal aortic aneurysm (AAA) would be of great help in evaluating the need for surgical intervention to avoid rupture

(Raghavan & Vorp, 2000). This paper presents a computer simulation to locate possible rupture points of an abdominal aortic aneurysm.

The method currently used in looking at the condition of the aorta is through small openings using a video camera. Imaging methods being used are aortography, intravascular ultrasound (US), computed tomography (CT), and magnetic resonance (MR) angiography for investigations of the lumina (Lee, Williams & Abrams, 1997). There is therefore a need to find a way that will provide an early detection and diagnosis of an AAA, before proceeding with the usual surgical intervention. The present study has been made to develop a cheap and practical way to monitor patients with AAA, using available software and medical equipment.

## Methods and Materials

The determination of the locations of maximum wall stresses in an AAA in this study was done using two phases: solid modeling and finite element analysis. Computer modeling—translating a real world object or phenomena into computer graphics or mathematical equation—was used to make an AAA tissue model. The geometry of the actual tissue of a patient can be approximated using slices from CT scans as it is not practical to see the actual aorta during monitoring. Raghavan and Vorp (2000) evaluated the applicability of using a finite strain constitutive model as a biomechanical tool to evaluate rupture potential of AAA and found a very good agreement ($R^2 > 0.9$) between experimental data and the proposed functional form of the constitutive model. Also, using finite element simulations, they were able to show that the computed AAA wall stresses changed only 4% or less when parameters were varied within the 95% confidence intervals for the population studied. AutoCAD and ProEngineer software were used to create the AAA model. There was also no need to determine important tissue properties for stress and displacement analyses because there is already available data on them. Ansys software was used in the finite element analysis to determine stresses and displacement. As this study–conducted in my (Marañon) home in Bago City, Negros Occidental from 2001 to 2004–is a developmental alternative mechanism, the basis of predicting the locations of high wall stresses was done visually and examined on the basis of the engineering concept of combined stresses in a cylindrical shell.

### Phase I: Solid Modeling

### Scanning of CT Scan Images

The CT scan film of a patient was given to me (Marañon) by a medical doctor for use in this study. It contained 24 slices or sections of the abdominal aorta at 5 mm spacing each. Each section in the film was scanned by a personal computer (PC) scanner into a computer image file (sample, Figure 1).

### Tracing Sections and Lines

Using AutoCAD software, each image file of the section was inserted into a drawing file and traced using the spline command. Other tracing software can be used but this available licensed software at the University of the Philippines in Diliman was used. A total of 36 points was used to create each spline. The 10 cm vertical scale was also traced as a line to serve as a common guide for all sections (sample traced spline and line, Figure 2).

### Blending Sections

From this traced spline and line for every section, ProEngineer software was used to form a solid model of the abdominal aorta. Other solid modeling software can be used but this available licensed software at the University of the Philippines in Diliman was used. The blend command was used. The solid was drawn to a scale of 1mm : 1.9mm.

### Shell Creation

Using the ProEngineer software (Parametric Technology Corporation, Waltham, MA, USA), the solid model was opened and the shell command was used to create the shell. The shell should have a uniform thickness of 1.5mm or 3.61mm in the drawing but for a more conservative result, 1.1mm as wall thickness was used.

### Saving AAA Model Into IGES Format

In order that the ProEngineer file of the AAA model be imported to the Ansys software (Ansys Inc., Houston, PA, USA), it must be converted into a format which Ansys can accept. One format is the International Graphics Exchange System (IGES) format. The next step was to save the file in the IGES format.

## Phase II: Finite Element Simulation

### Importing Solid Model

The file in the IGES format was then imported into the Ansys software with the aid of the Mechanical Toolbar. Other finite element software can be used but our choice was the available licensed software at the University of the Philippines in Diliman.

### Assigning Material Properties

The model has to be assigned its material properties. Structural properties such as the elastic modulus of 5 MPa and Poisson's Ratio of 0.49

were specified based on the results of previous studies that showed that the AAA tissue is nonlinear, hyperelastic and anisotropic (Raghavan & Vorp 2000). For a simplified analysis and verification of this developmental alternative mechanism, the AAA tissue was considered to be linear, hyperelastic, isotropic, thin-walled shell in this study using a finite strain shell element with 4-nodes (shell 181) assigned to the model.

### Assigning Loads and Constraints

Next, loads and constraints must be assigned to the meshed model. An internal pressure load of 0.016 MPa (20 mm Hg) to simulate end-systolic conditions was assigned to the model as a basis because this value differs from patient to patient. This internal pressure was applied to the shell considered as thin-walled, as it is at this stage of the cardiac cycle that the AAA is most likely under maximum wall stress (Raghavan & Vorp 2000). The systolic pressure was used in the static stress analysis evaluation of the maximum stress acting on the AAA wall for the assessment of its risk of rupture (Raghavan *et.al.*, 2000). The top and bottom areas were axially constrained and the outer surface of the AAA model was considered as load-free (Vorp *et.al.* 1998).

### Loads Assignment

The fourth step was to assign loads to the meshed model. In addition, both ends of the AAA tissue were constrained in the axial direction.

### Analysis Type

For this initial study, a structural static analysis was employed. The shear stresses caused by flowing blood were shown to be small in magnitude compared to the stresses caused by the distention of the wall so this was not considered (Vorp *et.al.*, 1998).

### Determining Wall Stresses

The wall stresses were solved using static analysis with internal pressure and fixed axial constraints on the shell. Quadrilateral shell elements are usually used for shells as presented in previous studies. In this study, Ansys software 4-node finite strain shell elements (shell 181) was used to mesh the model because 1) it is suitable for analyzing thin to moderately-thick shell structures; 2) it is well-suited for linear, large rotation, and/or large strain nonlinear applications; and 3) it enhances the accuracy in bending-dominated problems (Ansys Documentation version 6.0). Von Mises stress distribution was used in the determination of equivalent wall stresses as a convention because it is the best index in the absence of a suitable failure theory for AAA tissue (Raghavan *et.al.,* 2000).

Visual color legends of stresses was used as basis for determining locations of high wall stresses in an AAA and investigation was made using the engineering concept of combined stresses in a cylindrical shell in addition to tangential and hoop stresses.

## Results

### Solid Model of the Aorta

The resulting solid model of a patient's AAA using ProEngineer software blend command where the posterior and anterior positions are presented shows that the solid model is slightly bigger than the actual dimensions of the patient's AAA since a scale of 1mm : 1.9mm was used (Figure 3). The resulting shell model of a patient's AAA using ProEngineer software shell command (Figure 4) reveals that the maximum thickness that was accepted by the software was only 1.1mm due to the irregularities of the cross sections so this value was used. The file was saved also to the IGES format in preparation for import to Ansys software.

### Mesh of the Model

A total of 19 areas were meshed using smart sizing mesh. The meshed model of the AAA is shown in Figure 5.

### Wall Stresses

The von-Mises stress was solved. The resulting stress plot of the AAA in pascals (Pa) appears in Figure 6.

### Wall Displacement

The maximum displacement is located in the lower part of the bulging section (displacement plot, Figure 7).

### Effect of Concavity on Wall Stress

A specific geometry was used to determine the effect of concavity factor on wall stress. Concavity factor was defined as the ratio of depth to width of opening. The computed wall stress in pascals (Figure 8) increases to a maximum located on concave surface as the concavity increases to a certain value and the computed wall stress decreases where its location shifts to the inflection points after a certain value where the computed wall stress is maximum.

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## Discussion

Results indicate that the sections are irregular and asymmetric in the AAA tissue model. This differs from patient to patient. Thickness was made constant to investigate the effects of other factors although it is considered as one of the major factors causing rupture of tissue. To be conservative in the monitoring process, the minimum thickness in the CT scan slices should be used in the model.

This equivalent stress is patient-dependent so it would not be used as a general basis for analysis. The locations of these high stresses can be seen visually on the vertices of saddle surfaces (necks) which convexes internally, especially on those that expand or stretch and/or experience bending and twisting motions; and at inflection points. This is so because if we apply the same pressure to two surfaces, one concave internally and one concave externally (saddle surface), and compare the resulting stresses, higher amount of stress would be experienced by the surface which is concave externally or convex internally. Further, bend and twist effects increase the wall surface stress.

The movement of an AAA tissue when simulated is found to be geometry-specific which causes axial stresses, bending stresses, and torsional stresses to be experienced by the tissue in addition to the hoop and tangential stresses due to internal pressure. In addition to thickness and internal pressure, axial load, bending moment and torque should also be considered in the prediction of locations where rupture in an AAA could occur. The most conservative approach, therefore, is to consider the combined effects of all of these stresses in an AAA.

In actual AAA geometry where there are changes in concavity, inflection points are also critical locations as a combination of hoop and tangential stresses are experienced. It is necessary that geometry and stresses should be evaluated in the monitoring of patients with AAA so that appropriate surgical intervention could be done prior to rupture of tissue.

## Conclusion and Recommendations

Pending more studies to confirm our results, it is possible that time and sites of AAA rupture may be predicted before surgical intervention with the use of CT scans and computer simulation. The value of maximum equivalent stress is a function of the sections, thickness, asymmetry, shape, surface geometry, tortuosity, concavity or curvature, strain or expansion, bending, twist, and so on. The locations of high stresses in an AAA that can be possible locations of rupture aside from thickness are those on the inflection points and vertices of the internal convex surfaces (necks) that expand or stretch due to internal pressure and/or experience twist and/or bend.

Further studies are needed on the use of modern imaging methods and software. The following important points must be taken into consideration: the use of the actual varying thickness of the AAA for a more accurate instantaneous result for a specific patient; the AAA as a nonlinear, anisotropic, finite strain material; the effects of fatigue due to the cyclic behavior of internal pressure from systolic to diastolic and vice versa; the effects of the velocity and weight of the blood flowing through' the abdominal aorta; and, the eddy effect.

## Acknowledgments

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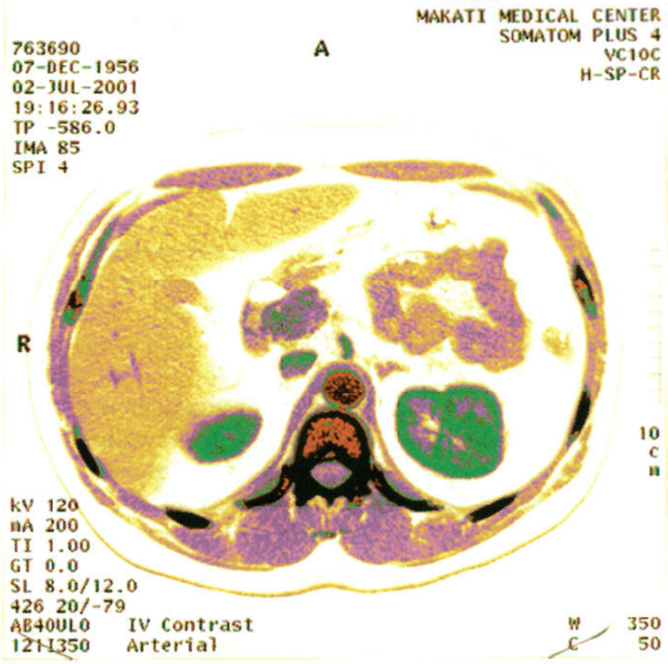

Figure 1. A sample image file scanned from a CT scan film.

Figure 2. A sample of the traced spline and line from an image

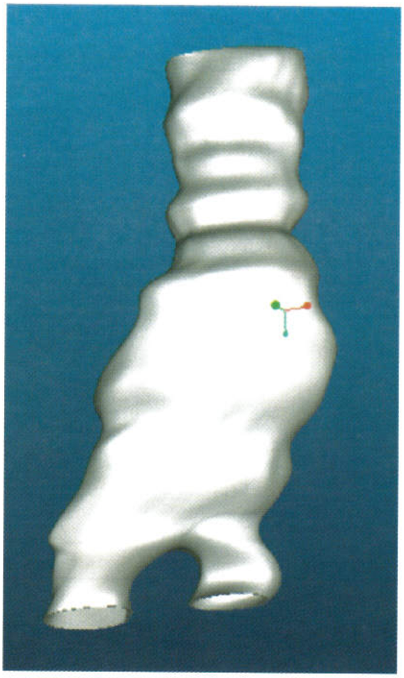

Figure 3. Solid model of a patient's AAA.

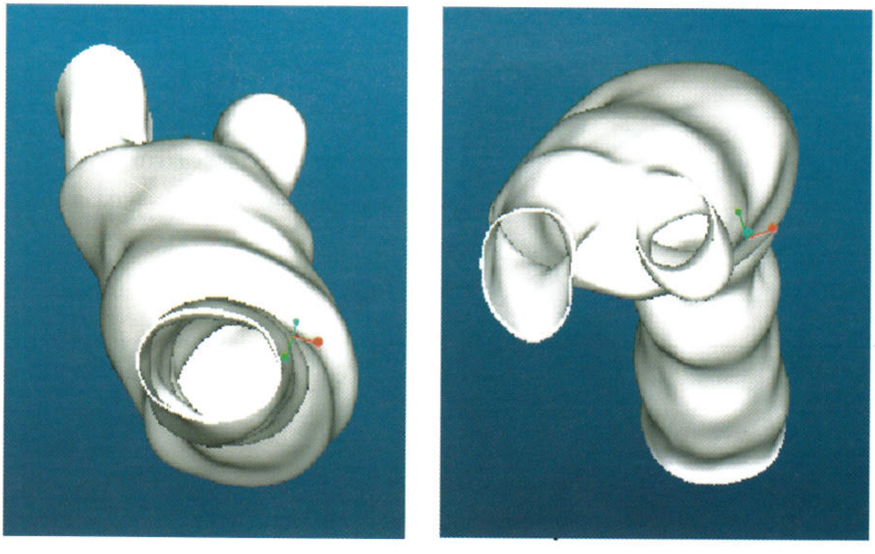

Figure 4. Shell model of a patient's AAA.

Figure 5. Meshed model of an AAA tissue.

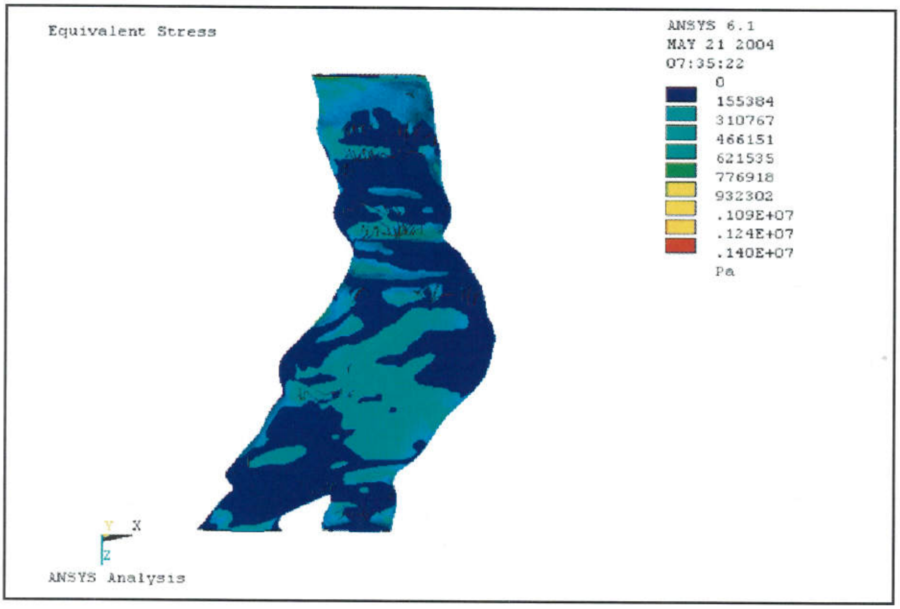

Figure 6. Equivalent stress plot results of a patient's AAA in Pascals.

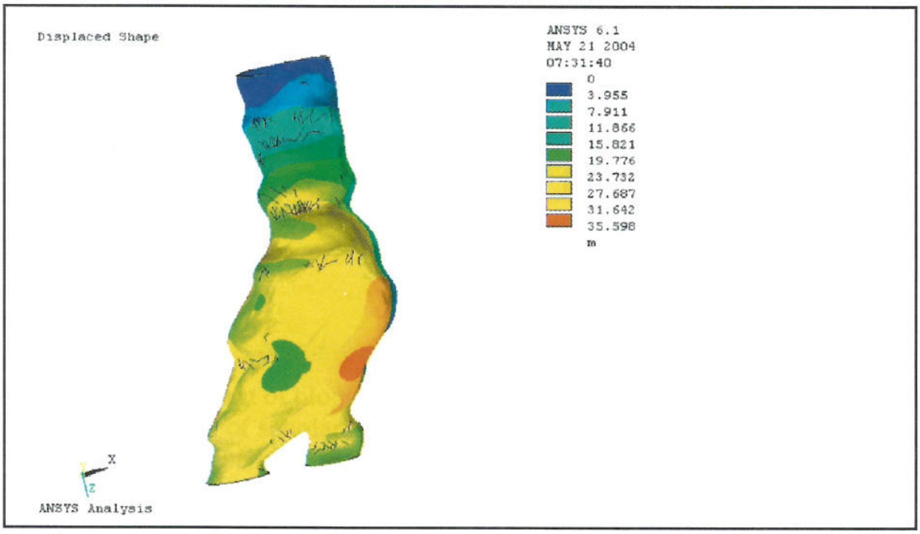

Figure 7. Displacement plot results of a patient's AAA.

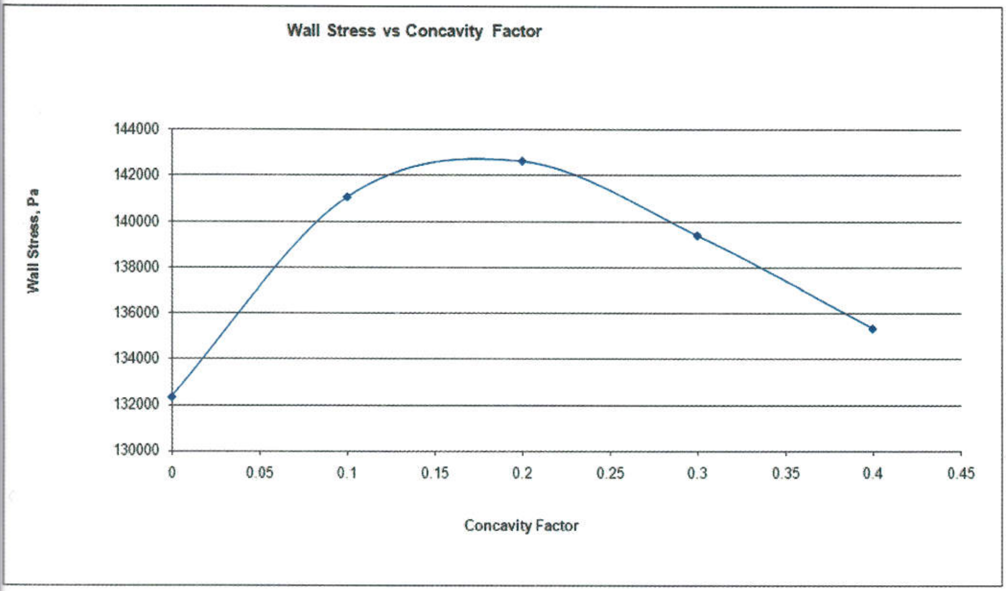

Figure 8. Concavity factor vs wall stress.