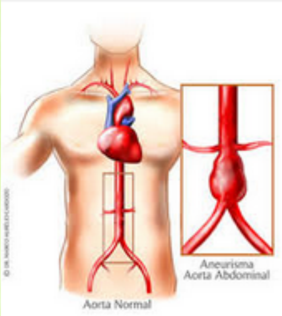
STRESSES IN ABDOMINAL AORTIC ANEURYSM: DETERMINATION OF THE INFLUENCE OF DIAMETER AND ASYMMETRY THROUGH THE FINITE ELEMENT METHOD



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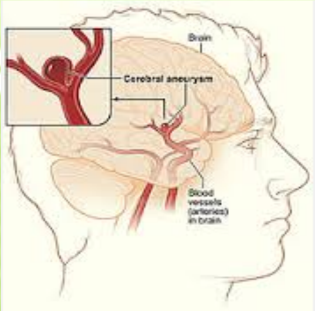
Introduction

An aneurysm is a defect in the wall of an artery that is manifested as a ballooning of a specific area caused by a weakening in the wall of the blood vessel.

The brain, specifically in the Circle of Willis.

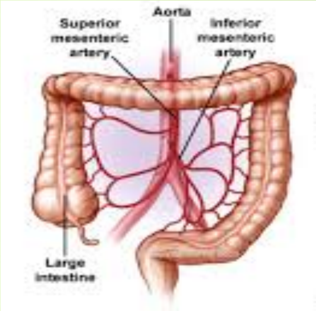


The Popliteal artery in the legs.

The aorta in the abdominal area.

The splenic artery in the arms.

The mesenteric artery in the intestinal tract.



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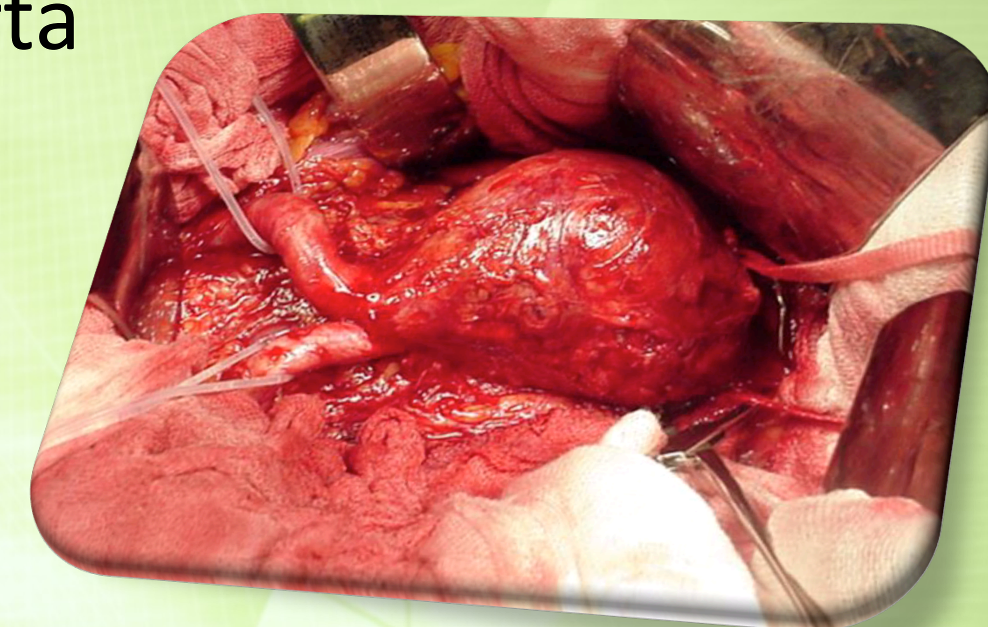
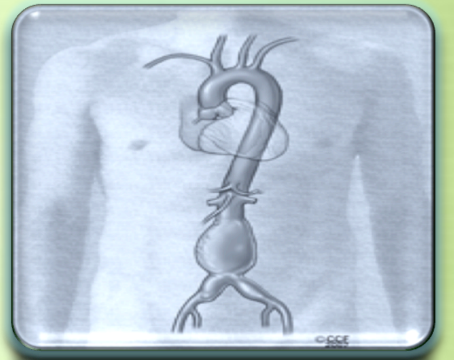
Introduction

Abdominal Aortic Aneurysm (AAA) is the dilation of more than 50% of the normal diameter of the aorta



Scientific Problem

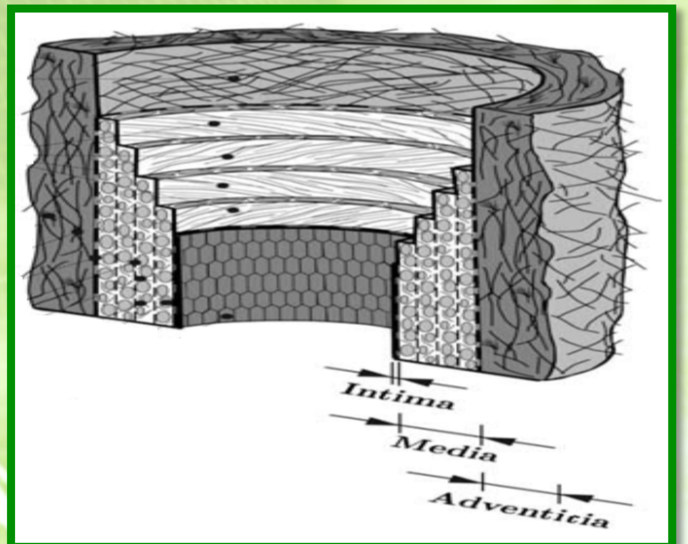
The need to get a AAA model through the Finite method capable of predicting the mechanical behavior and the possible failures.

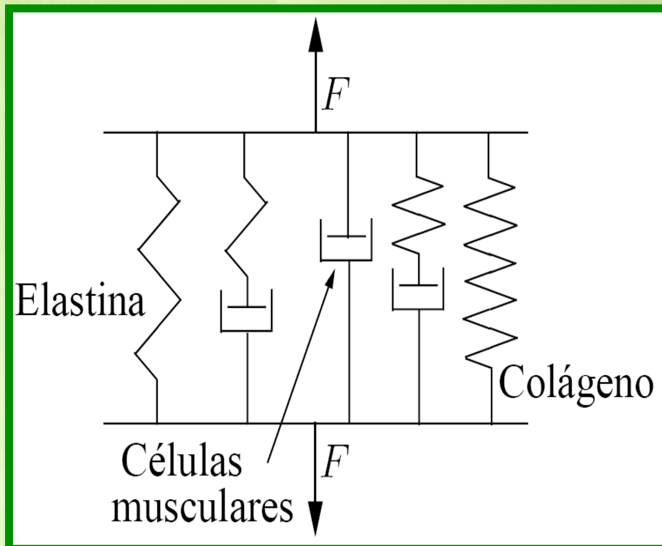


Objective of the Research

To develop a Finite Element model for predicting the behavior of AAA, considering the characteristics and properties of the associated elements.

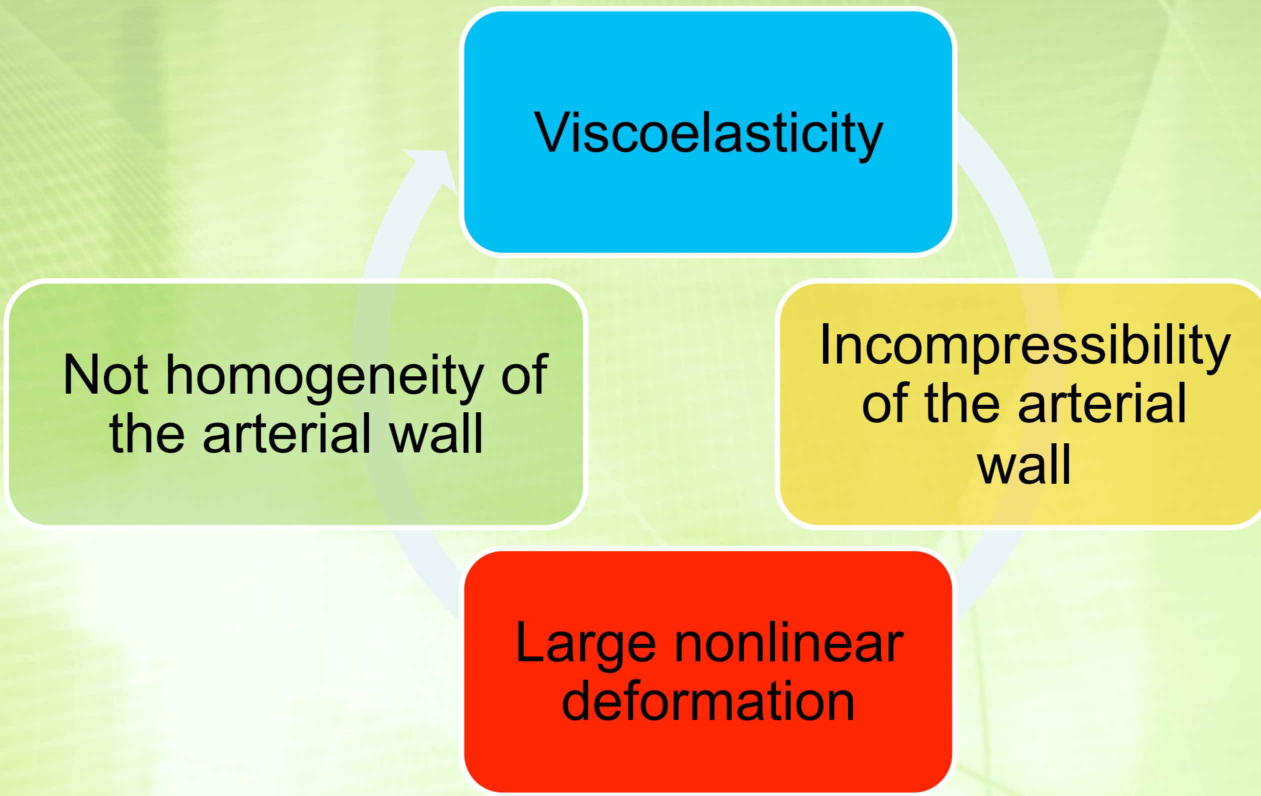
Biological Characterization of Arterial Wall





Main compounds of an artery are: collagen and elastin which give certain elasticity and support to the arteries.

Basic Characteristics of the Aortic Wall



Modeling of Abdominal Aortic Aneurysm

$$R(\mathrm{Z}) = R_a + \left(R_{an} - R_a - c_3 \frac{Z^2}{R_a}\right) \exp\left(-c_1 \left|\frac{Z}{R_a}\right|^{c_2}\right)$$

c_1 is taken as a constant 0,2

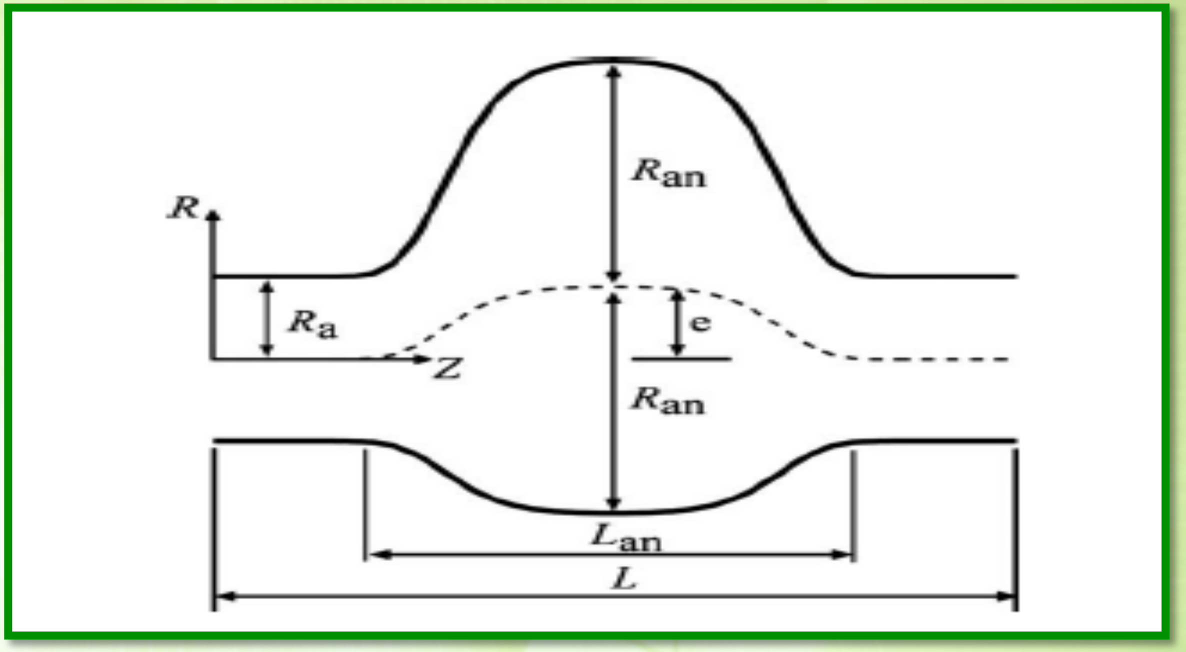
$$c_2 = \frac{4.605}{(0.5\, L_{an}/R_a)^{c_1}} , \qquad c_3 = \frac{R_{an} - R_a}{R_a (0.8\, L_{an}/R_a)^2} .$$

Modeling of AAA

No.	1	2	3	4	5	6	7	8	9	10	11
Ran (mm)	20,2	21,21	22,22	23,23	24,24	25,25	26,26	27,27	28,28	29,29	30,3

Constant parameters

- Ra = 10,1 mm
- Lan = 80 mm
- L = 120 mm
- δ = 1,8 mm



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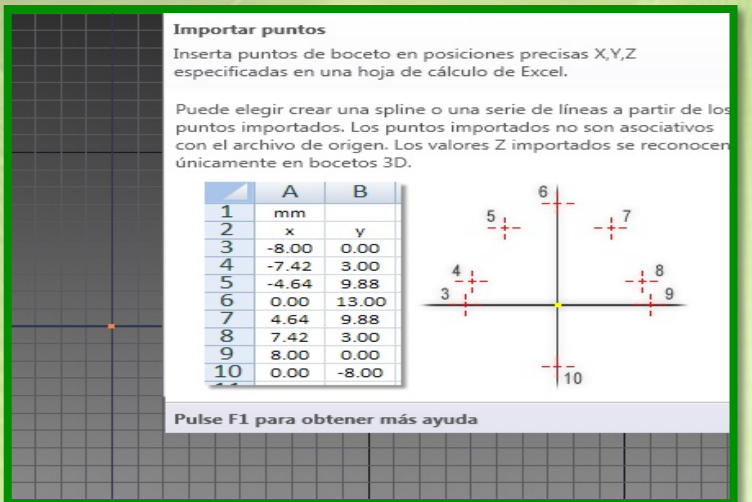
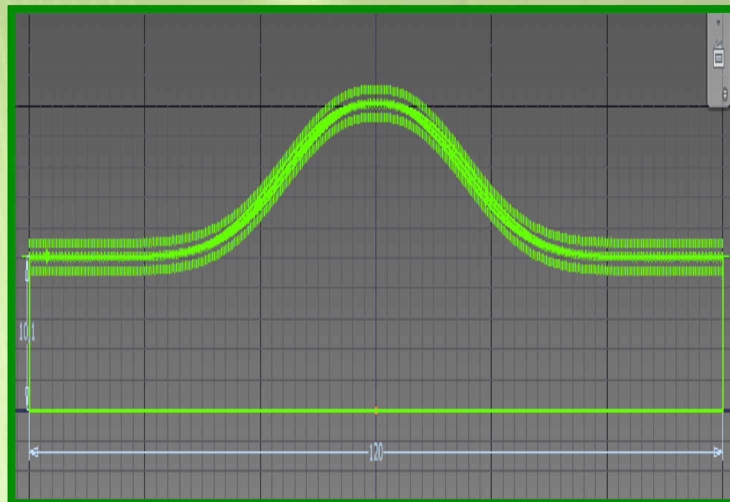
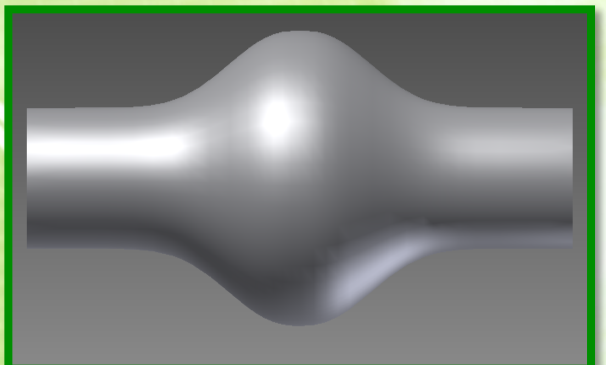
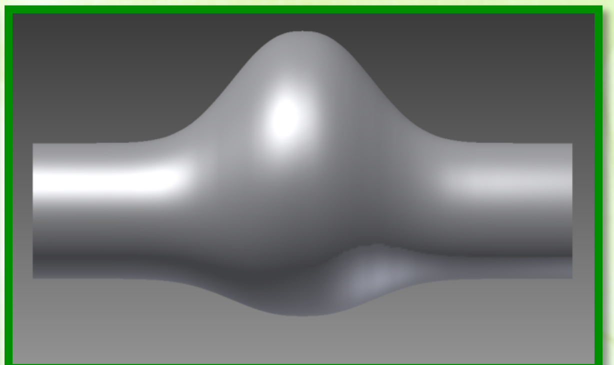
Geometric model



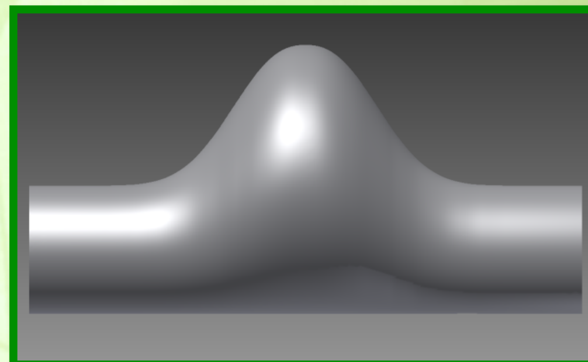




$e = 0$



$e = \frac{(R_{an} - R_a)}{2}$



$e = R_{an} - R_a$

The model is developed by using *Autodesk Inventor Professional 2013*

Materials

Paper	Material symmetry	Thickness	Homogeneous	Stress metric	ILT	Comments
Raghavan et al. (2000)	Isotropic	Uniform 1.9 mm	Yes	Von Mises	–	Nonlinear, patient specific
Wang et al. (2002)	Isotropic	Patient-specific	Yes	Von Mises	Nonlinear, isotropic	ILT thickness 1.75–1.95 mm
Fillinger et al. (2002)	Isotropic	Uniform 1.9 mm	Yes	Maximum principal	–	Stress better than diameter
Wolters et al. (2005)	Isotropic	Uniform 2.0 mm	Yes	Maximum principal	–	Early FSI
Lu et al. (2007)	Isotropic	Uniform 1.9 mm	Yes	Von Mises	–	Inverse method (reference state)
Speelman et al. (2007)	Isotropic	Uniform 1.5 mm	Yes	Maximum principal	Nonlinear, isotropic	Calcification included
Scotti et al. (2008)	Isotropic	Variable 0.5–1.5 mm	Yes	Von Mises	–	FSI, idealized geometry
Rodríguez et al. (2008)	Anisotropic [Holzapfel]	Uniform 1.5 mm	Yes	Maximum principal	–	Idealized geometry
Rissland et al. (2009)	Anisotropic [Holzapfel]	Uniform 2.0 mm	Yes	Von Mises	Linear, isotropic	FSI
Dorfmann et al. (2010)	Isotropic [Demiray]	Uniform 2.0 mm	Yes	Maximum principal	–	Blood pressure gradients
Maier et al. (2010)	Isotropic	Uniform 1.0 mm	Yes	Von Mises	Nonlinear, isotropic	Vorp's Rupture Potential Index
Gasser et al. (2010)	Isotropic	Variable 1.1–1.5 mm	Yes	–	Variable stiffness	Modified Rupture Index

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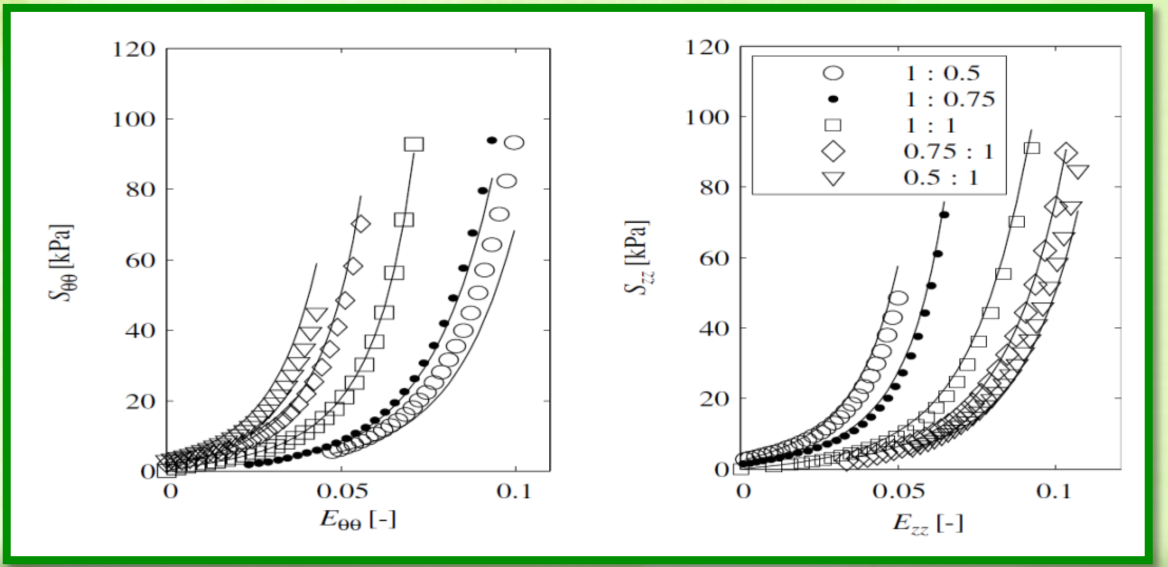
Materials

Use of Stress Energy Functions (SEF) to describe the behavior of aneurysmal wall material: hyperelastic material.

$$W = U(J) + \frac{C_1}{C_2}\left[e^{C_2/2(\bar{I}_1-3)} - 1\right]$$

Density = 121g/cm3

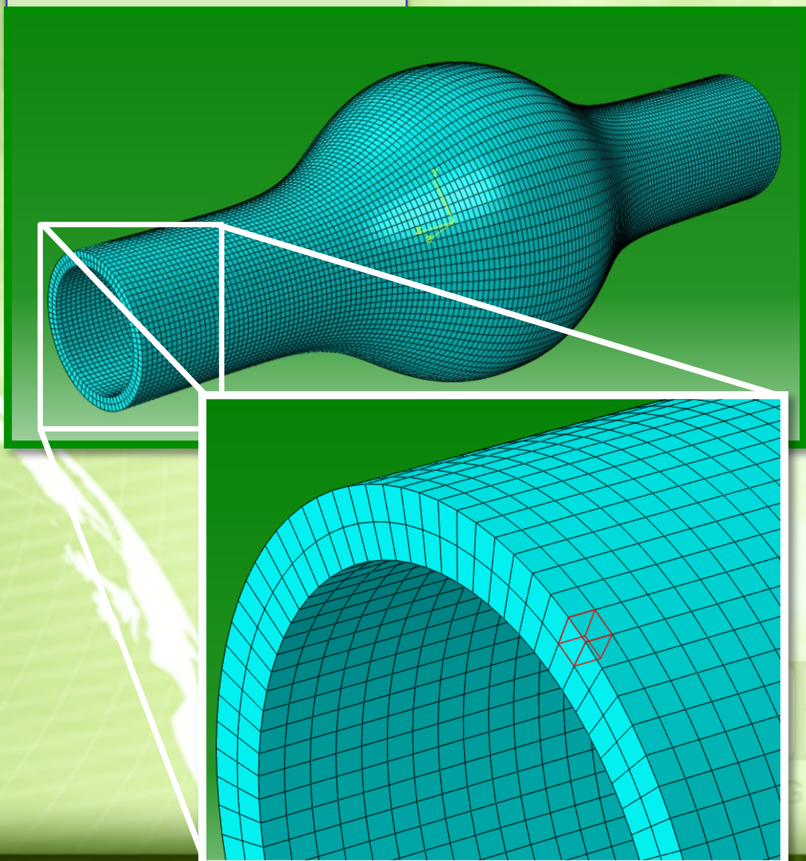
Demiray Model



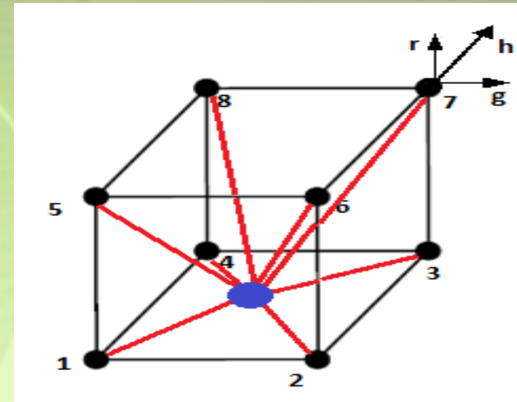
Mesh

C3D8H

- Solid 3D
- hexahedral
- 8 nodes



$$\{u\} = \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \\ u_7 \\ u_8 \end{Bmatrix} = \begin{Bmatrix} g_1 \\ h_1 \\ r_1 \\ \vdots \\ g_8 \\ h_8 \\ r_8 \end{Bmatrix}$$



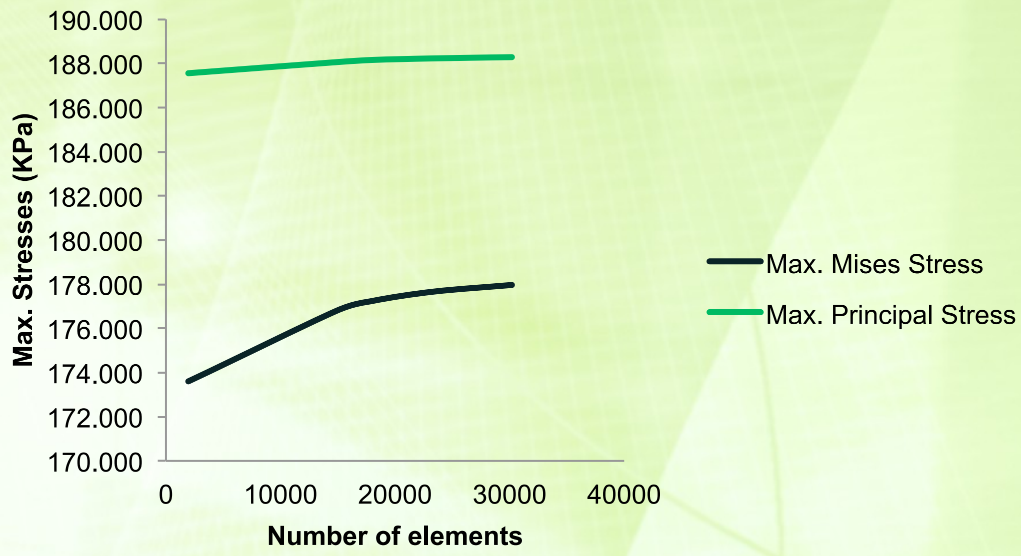
$$\mathbf{u} = N^I(g,h,r)\mathbf{u}^I$$

$$\{\varepsilon\} = [B] * \{u^I\}$$

$$g(x;y;z) = a_1 + a_2x + \cdots a_8$$
$$h(x;y;z) = a_9 + a_{10}x + \cdots a_{16}$$
$$r(x;y;z) = a_{17} + a_{18}x + \cdots a_{24}$$

Mesh

Global size (mm)	Number of elements obtained	Max. Mises Stress	Max. Principal Stress	%Δe Max. Mises Stress	%Δe Max. Principal Stress
2	1984	173,583	187,557	---	---
1	14880	176,796	188,059	1,817	0,267
0,9	18084	177,250	188,160	0,256	0,054
0,8	23408	177,669	188,229	0,236	0,037
0,72	30200	177,968	188,285	0,168	0,030



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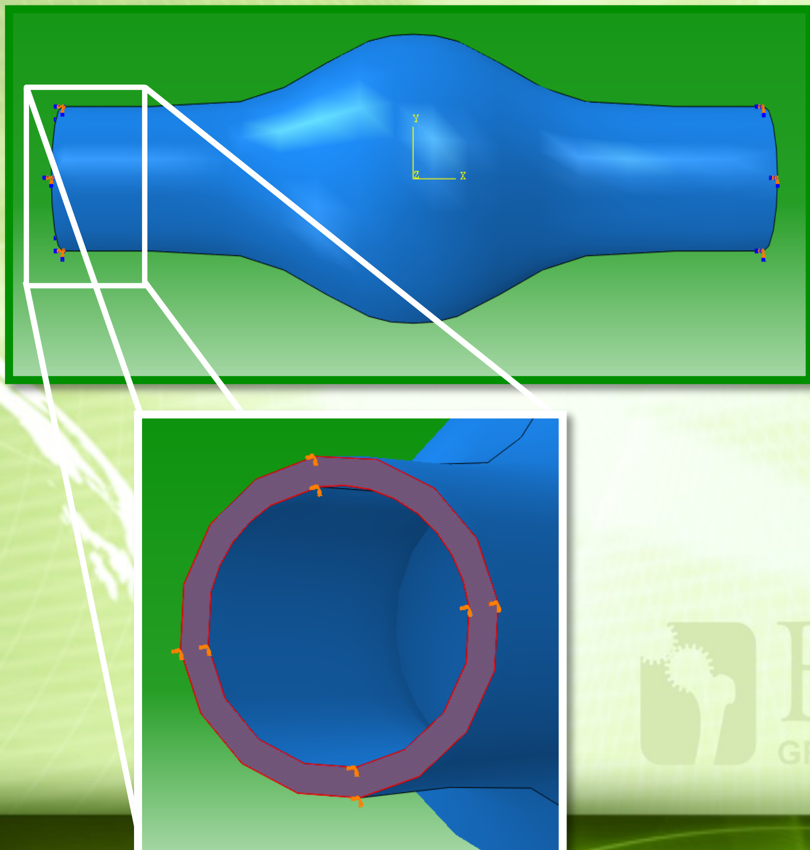
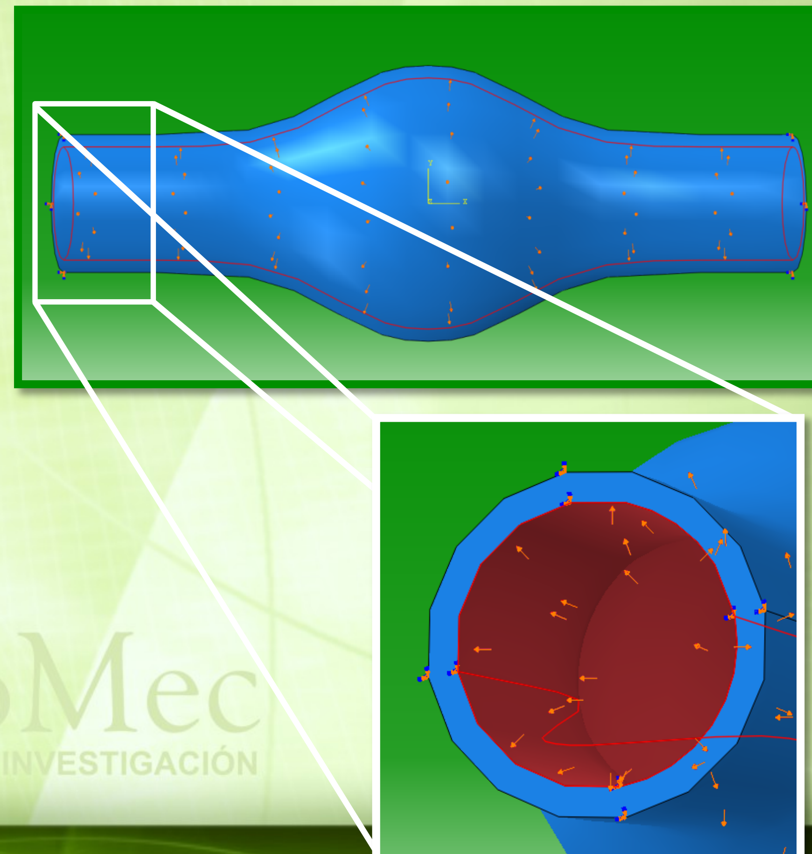
Boundary conditions and load

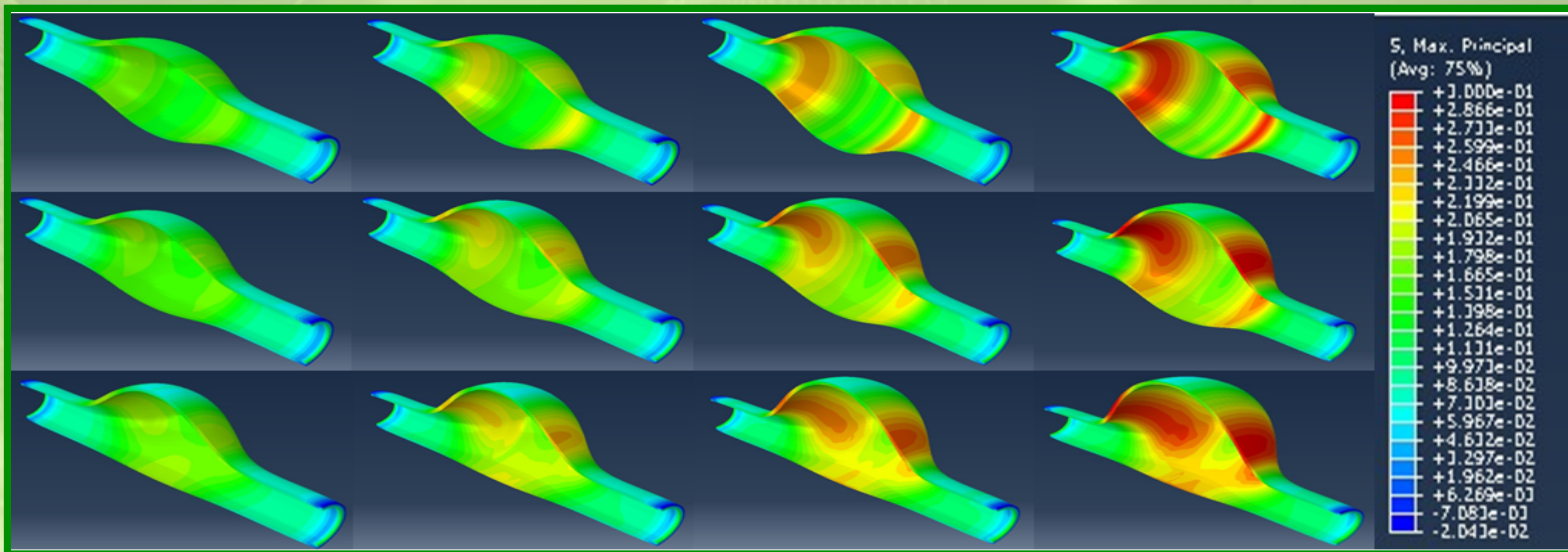
The longitudinal constraining at the proximal and distal parts of the aneurysm due to the renal and iliac arteries was simulated by constraining the displacements to zero at both ends

An inner pressure of 19 kPa 143 mm Hg was applied to simulate the endsystolic conditions since this pressure represents the stage of the cardiac cycle in which the AAA experiences the largest wall stress.





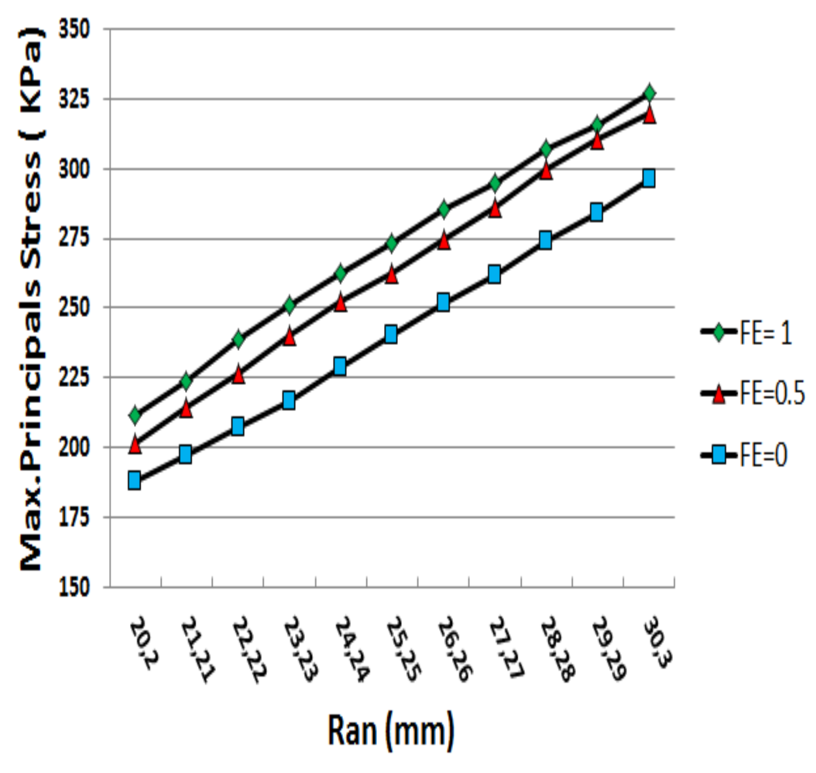
Analysis and Discussion of Results



The maximum values of stress have symmetrical patterns on changes near the ends of AAA in the inside sections of the vasculature.

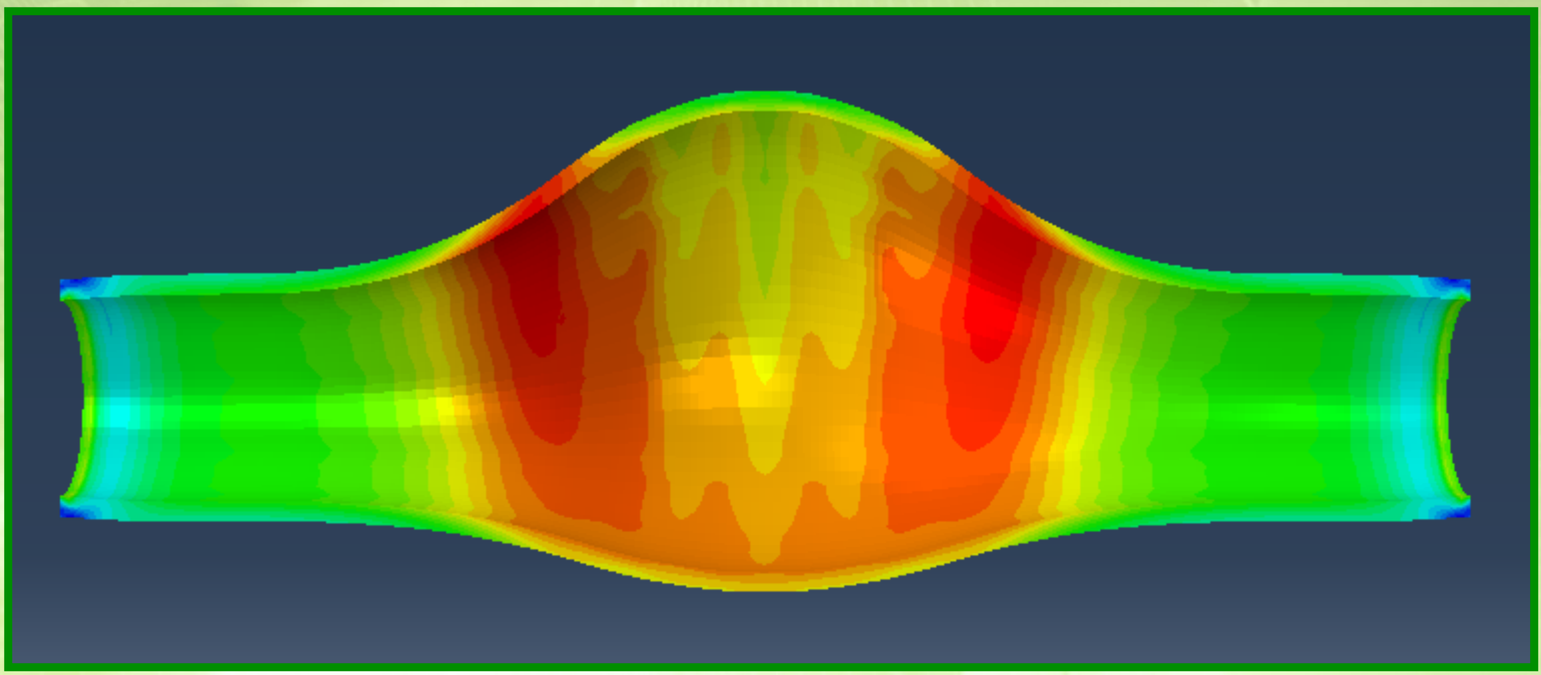
Asymmetrical patterns in the peak values are close to the ends of the encasement inside the artery, but with a strong bias (inclinación) towards the sector where the asymmetry is.

Analysis and Discussion of Results

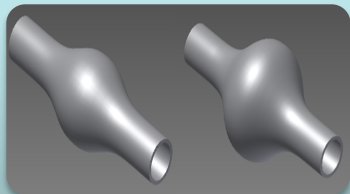


Ran	Max. Principal Stress FE=0	Max. Principal Stress FE=0,5	Max. Principal Stress FE=1
20,2	188,285	201,933	211,336
21,21	197,318	214,515	223,921
22,22	207,260	226,612	238,769
23,23	216,655	240,631	251,345
24,24	228,500	252,334	262,642
25,25	240,206	262,868	273,059
26,26	251,955	274,920	285,338
27,27	261,947	285,946	295,006
28,28	273,670	300,010	306,763
29,29	283,961	310,224	315,725
30,3	295,865	320,140	327,139

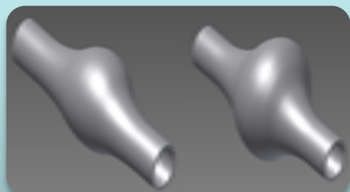
Analysis and Discussion of Results



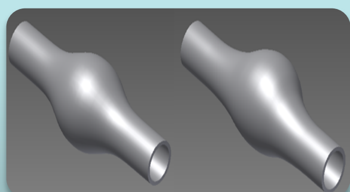
Analysis and Discussion of Results



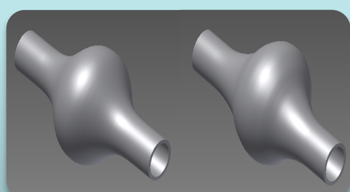
32.1 %. Diameter



32.5 %. Diameter



14,7 %. Asymmetry

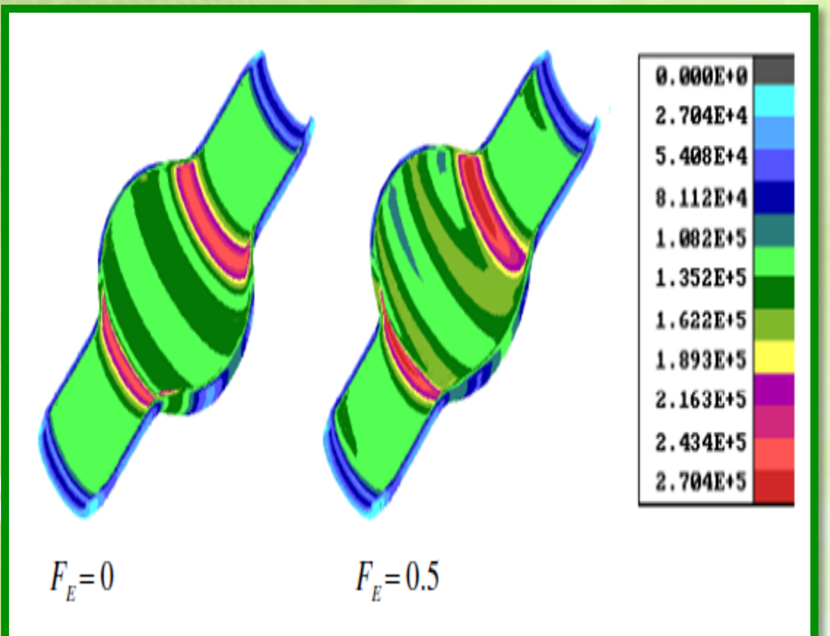


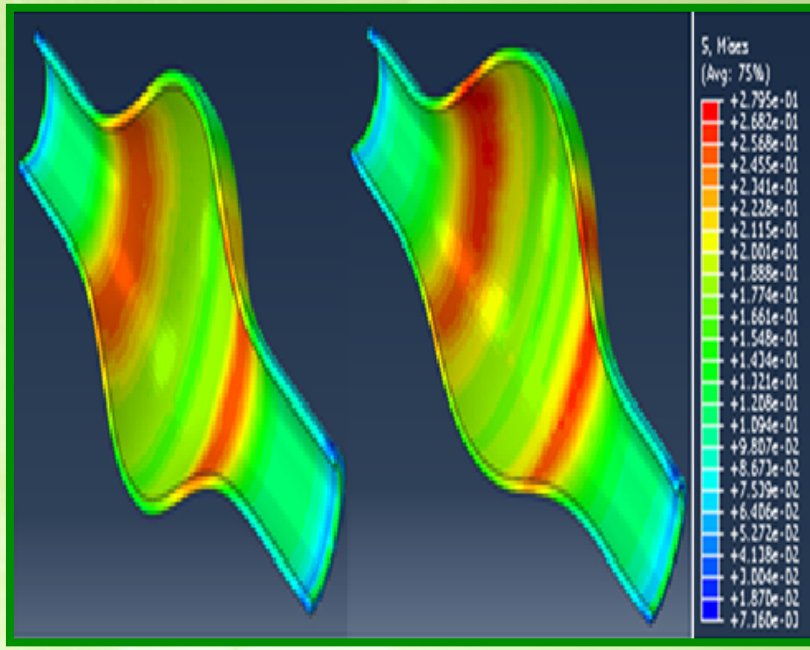
15,1 %. Asymmetry

Validation of Results

-Von Mises Stresses **- geometric similarities** **-Isotropic Hyperelastic Behavior**

Ra = 10.1 y F_R = 2.75



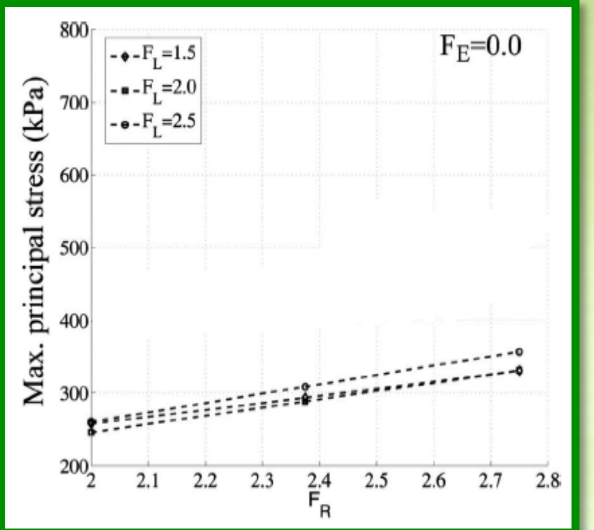


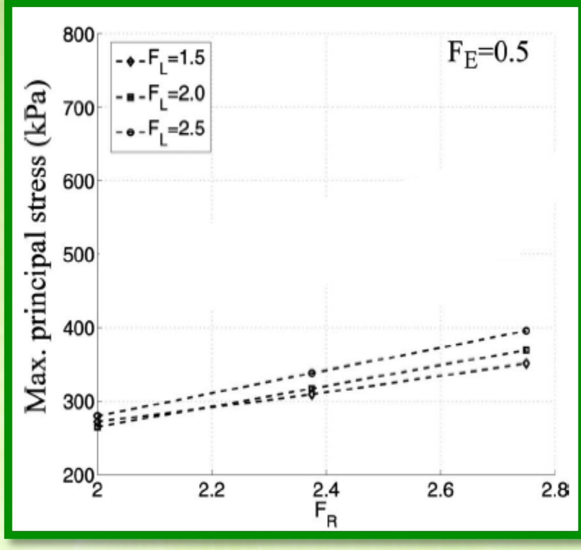
Dejan Veljković et al, 2012

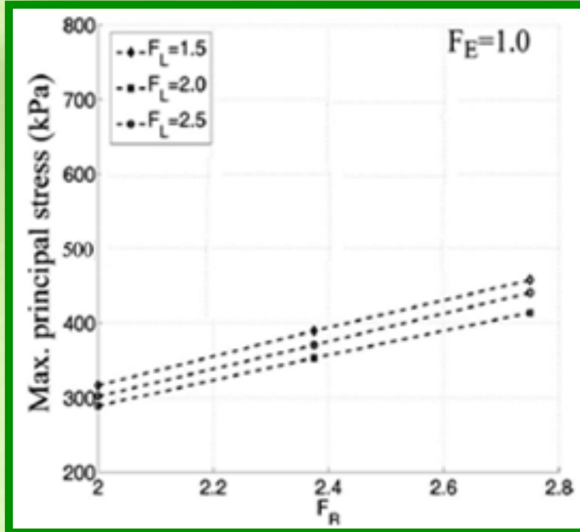
- F_E=0 $\sigma_{máx}$= 243.40 (kPa).
- F_E=0,5 $\sigma_{máx}$= 270.40 (kPa).

- F_E=0 $\sigma_{máx}$= 250.72 (kPa).
- F_E=0,5 $\sigma_{máx}$= 279.18 (kPa).

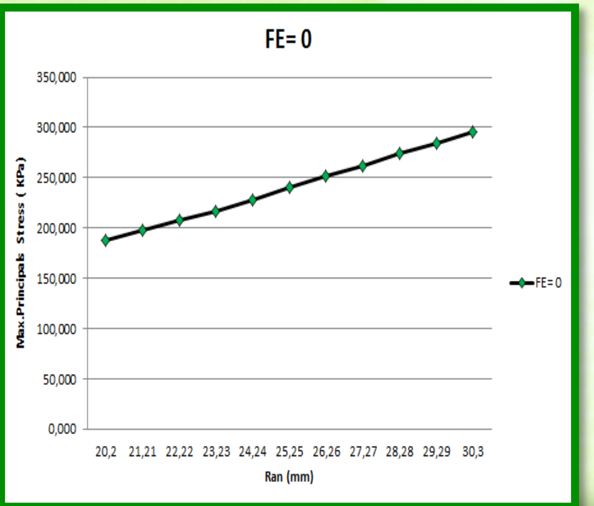
Validation of Results

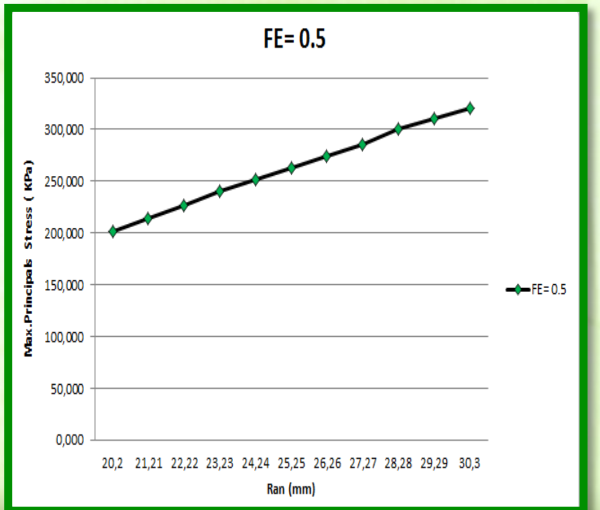


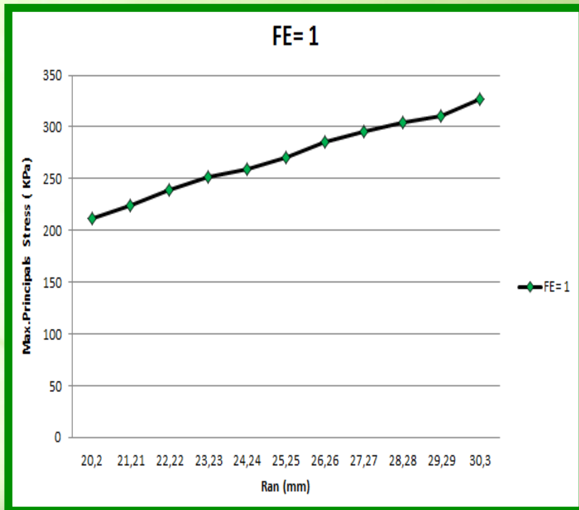




Rodríguez et al 2008







Our Results

Conclusions

- ✓ A characterization of the structure of the arterial walls related to the parameters of the mechanical behavior was defined.

- ✓ The mechanical behavior of the arterial wall material such as soft biological tissue has been clearly explained as well as the features for modeling.

- ✓ A geometric model was defined by using a parabolic-exponential equation that shows the real geometry of the aneurysm with a high degree of accuracy.

Conclusions

- ✓ The Abaqus program allowed the use of the Stress Energy Function that recreates the material behavior of the abdominal aortic aneurysm.

- ✓ Factors (diameter and asymmetry) significantly influence the Maximum Principal Stress and Von Mises Stress values, When increasing the diameter or the AAA asymmetry degrees, then the stress values increases too (Von Mises and Maximum Principal Stress).

Recommendations

1) For further simulations, you may take into account the internal pressure of the artery as well as the external one.

2) You may analyze the influence of the aneurysm length in the stresses.

3) You may get the geometry of Abdominal Aorta Aneurysm through medical imaging.

4) Use a material behavior that best describes the development of aorta aneurysm model.

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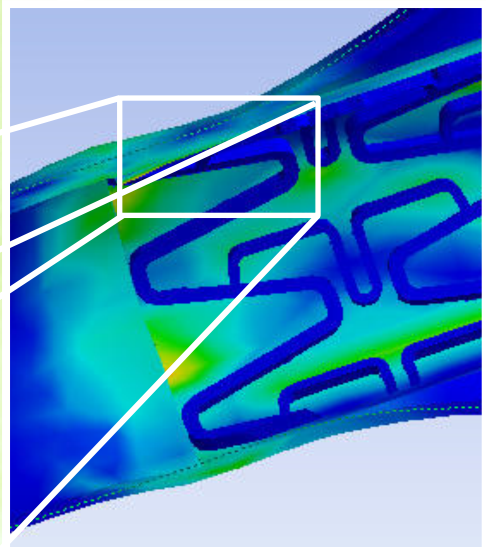
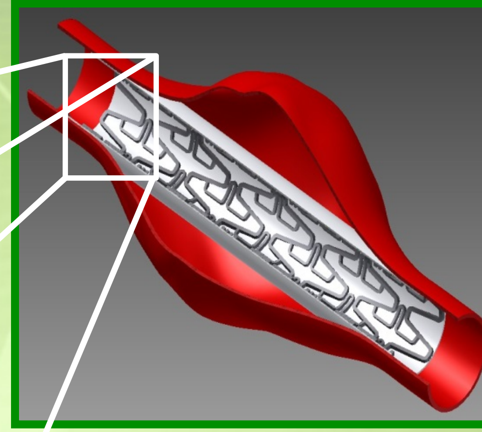
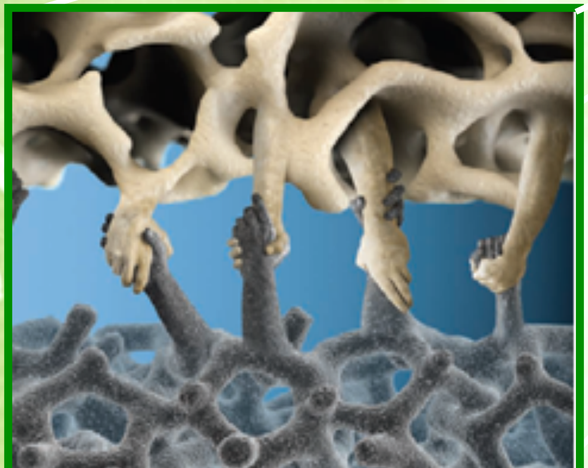
Future Direction

$$\Psi = U(J) + C_1(\bar{I}_1 - 3) + \frac{k_1}{2k_2}\{e^{k_2[(1-\rho)(\bar{I}_1 - 3)^2+\rho(\bar{I}_4 - \bar{I}_4^0)^2]} - 1\}$$
$$+ \frac{k_3}{2k_4}\{e^{k_4[(1-\rho)(\bar{I}_1 - 3)^2+\rho(\bar{I}_6 - \bar{I}_6^0)^2]} - 1\}$$

Anisotropic Model
" Holzapfel"

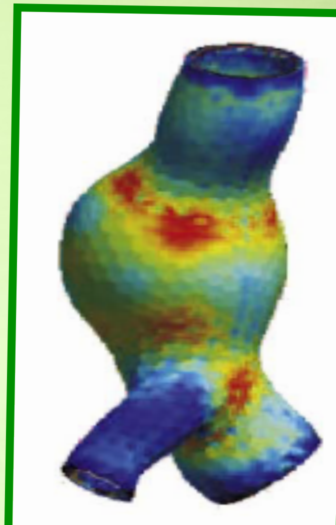






"smart coating"

Stent-Graft Migration



" Geometry through medical imaging"

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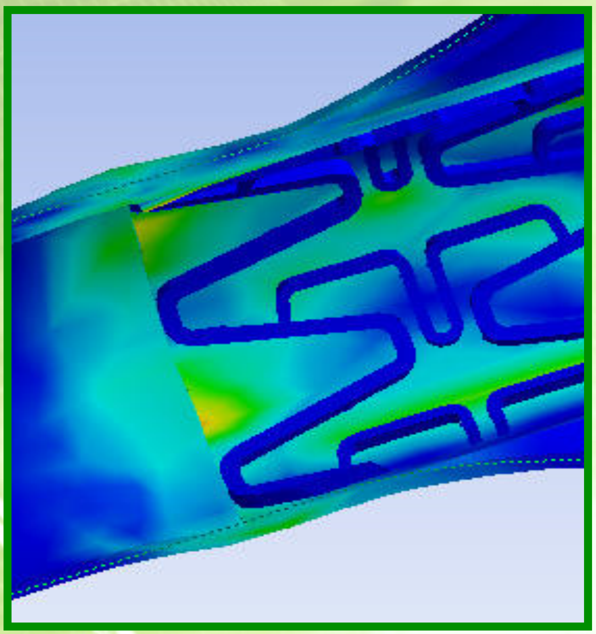
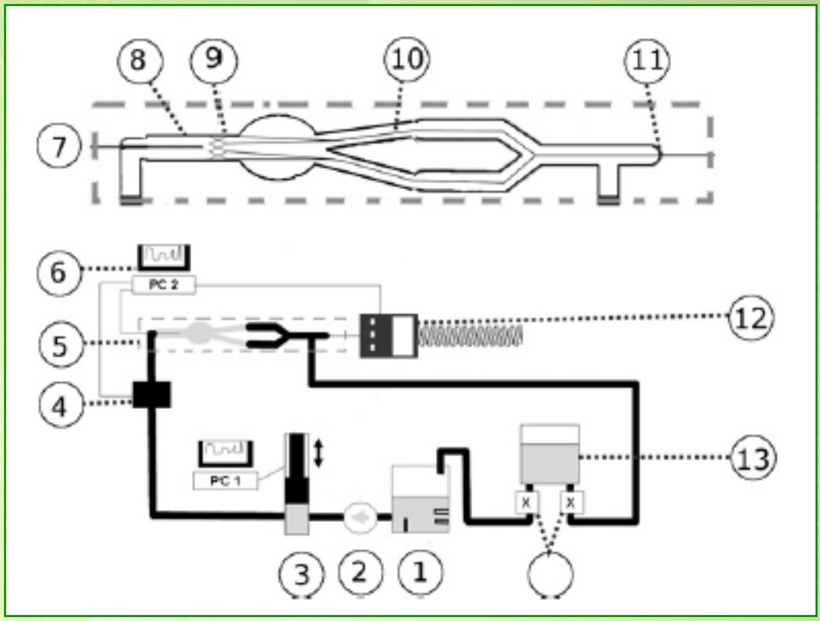
Future Direction

"The Finite Element Method"



" Flow loop used for displacement test"



T.J. Corbett et al, 2011

MATHEMATICAL MODEL

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Cálculo de engranajes plásticos.

La huella de contacto indicador de precisión en engranajes de tornillo sinfín.

Coeficiente de corrección en engranajes como factor de conversión entre sistemas AGMA e ISO.

Thank You !!!