

Hemodynamic Simulations of Implanted Multilayer Flow Modulator

Anna Lisa Restante
Boubker Ait Brik

24-10-2013

COMSOL 2013, Rotterdam

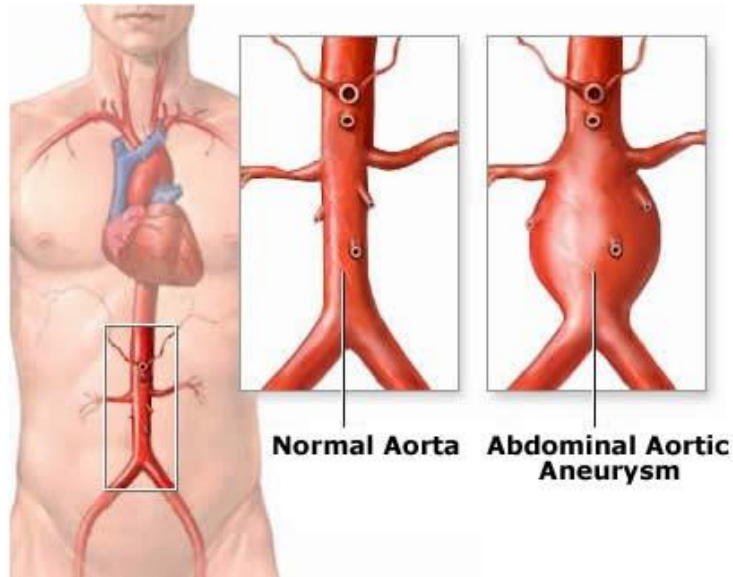


Virtual simulation unit
Isnes, Belgium

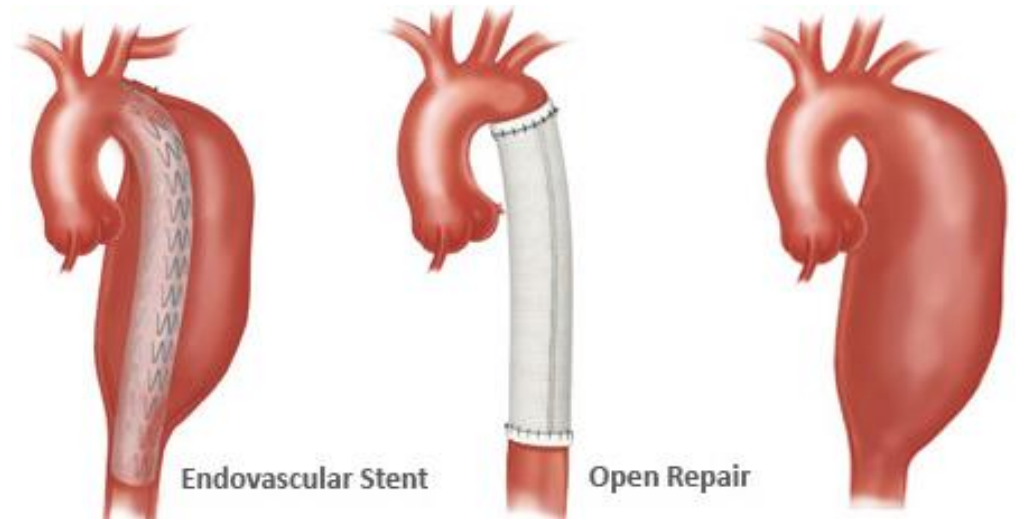


- AORTIC ANEURYSM
- VIRTUAL SIMULATION METHOD WITH REALISTIC AORTA
- MULTILAYER FLOW MODULATOR (MFM) DESIGN
- VIRTUAL SIMULATION WITH REALISTIC MFM

AORTIC ANEURYSM

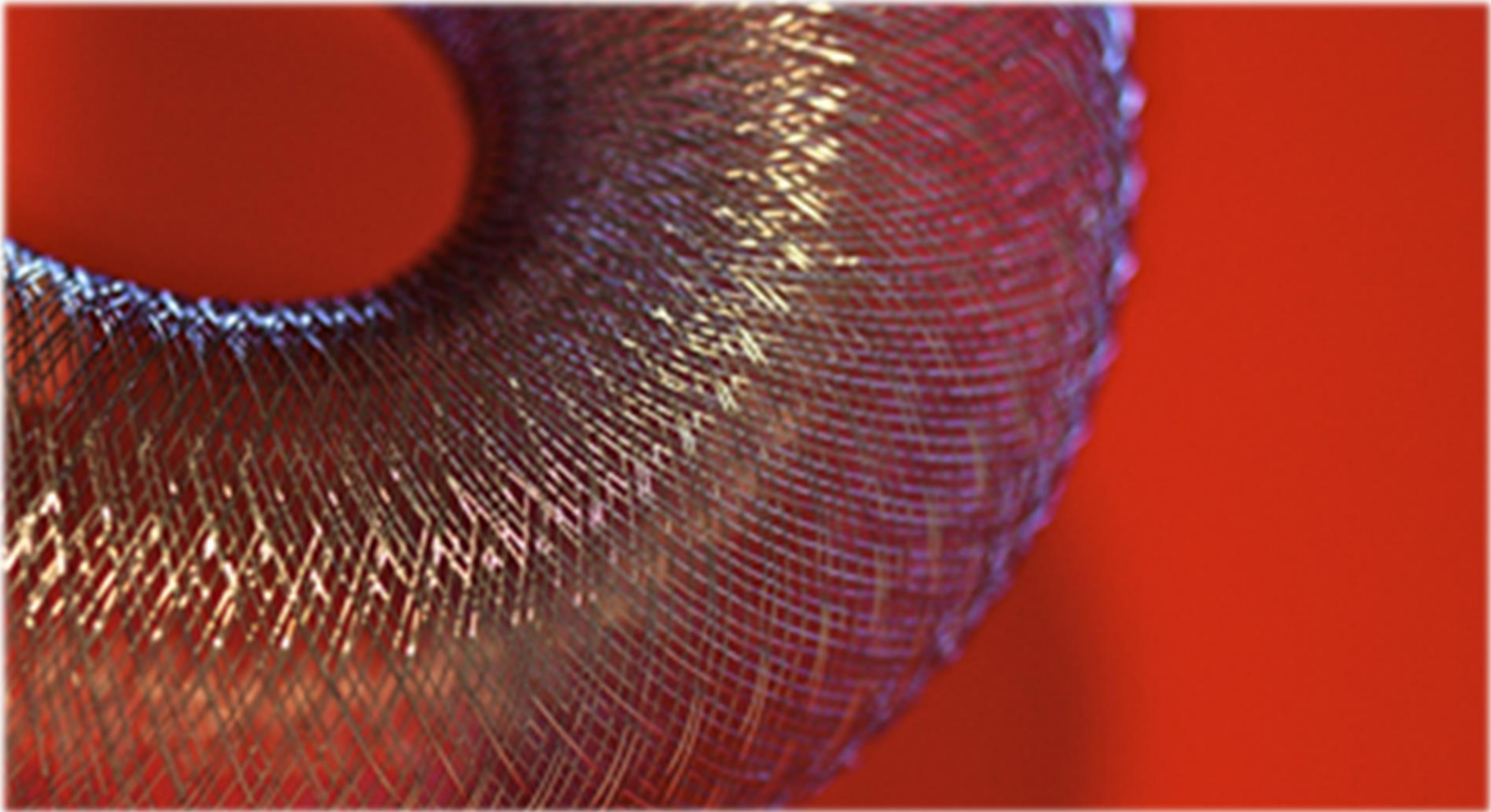


CT-scan 3D reconstruction

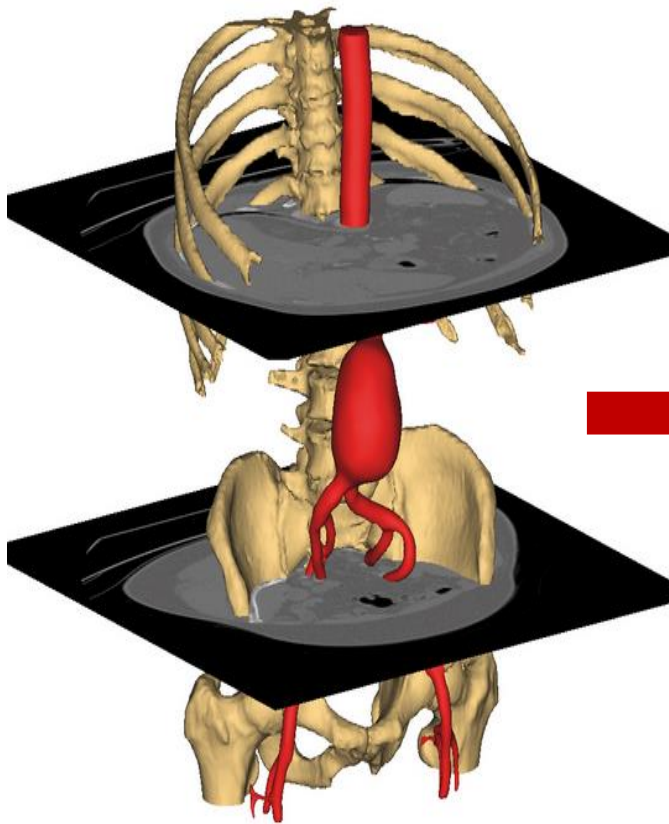


Commonly performed treatment

➤ NEXT GENERATION OF ANEURYSM REPAIR SYSTEM

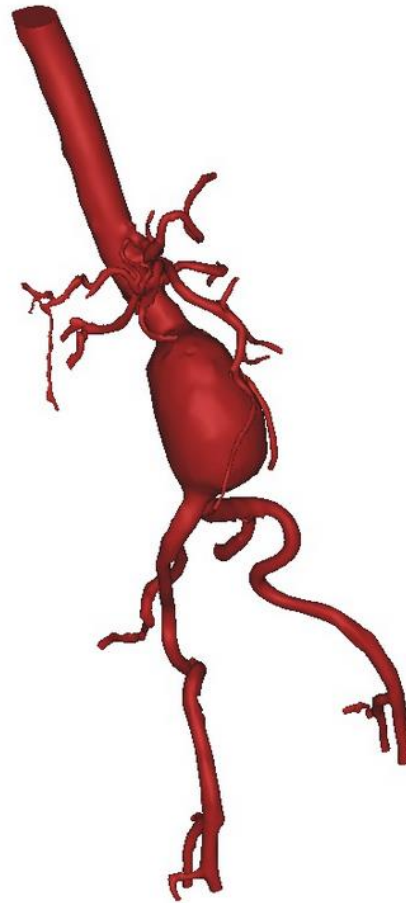


CT-Scan



Clinical Data (Dicom)

Mimics (3D)



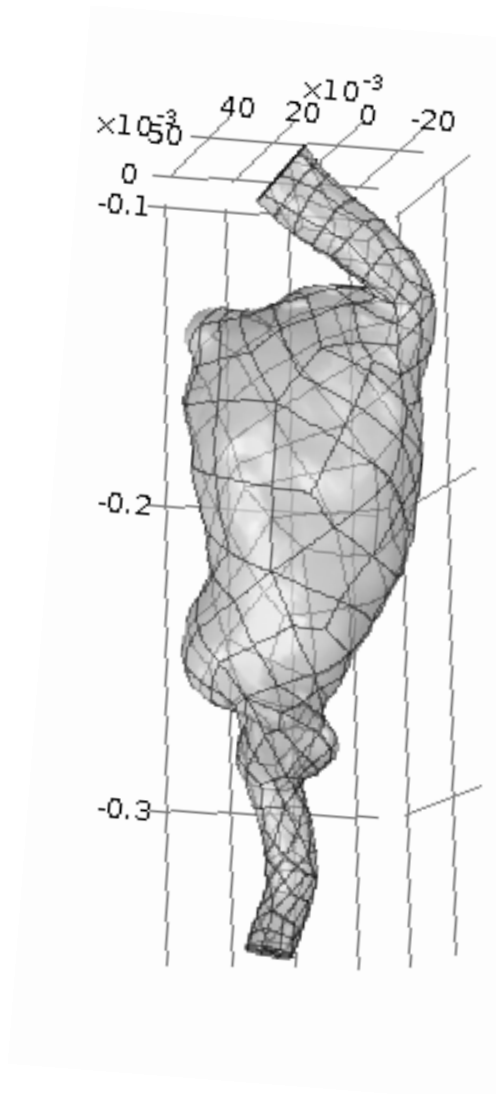
Reconstruction 3D
Geometric Mesh

Comsol (FEA)

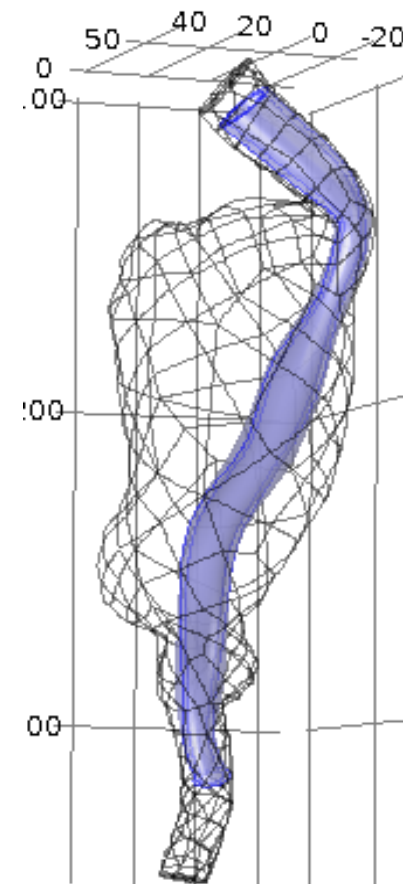


Fluid & Mechanics Analysis

Geometry reconstruction (1)



Without MFM



With MFM
(equivalent element)

Solved physics (1)

new_nancy.mph - COMSOL Multiphysics

Model Builder

Laminar Flow 2 (spf2)

Interface Identifier

Identifier: spf2

Domain Selection

Selection: All domains

1

Equation

Equation form: Study controlled

Show equation assuming: Study 3, Stationary

$$\rho(\mathbf{u}_2 \cdot \nabla)\mathbf{u}_2 = \nabla \cdot \left[-p\mathbf{I} + \mu(\nabla\mathbf{u}_2 + (\nabla\mathbf{u}_2)^T) - \frac{2}{3}\mu(\nabla \cdot \mathbf{u}_2)\mathbf{I} \right] + \mathbf{F}$$

$$\nabla \cdot (\rho\mathbf{u}_2) = 0$$

Physical Model

Compressibility: Compressible flow (Ma < 0.3)

Turbulence model type: None

Turbulence model: k-ε

Advanced Settings

Dependent Variables

Graphics

730 MB | 850 MB

nancytemp.mph - COMSOL Multiphysics

Model Builder

Free and Porous Media Flow (fp)

Interface Identifier

Identifier: fp

Domain Selection

Selection: Manual

1

2

Equation

Equation form: Study controlled

Show equation assuming: Study 1, Stationary

$$\rho(\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot \left[-p\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T) \right] + \mathbf{F}$$

$$\rho\nabla \cdot \mathbf{u} = 0$$

$$\frac{\rho}{\epsilon_p} \left(\mathbf{u} \cdot \nabla \right) \frac{\mathbf{u}}{\epsilon_p} = \nabla \cdot \left[-p\mathbf{I} + \frac{\mu}{\epsilon_p} (\nabla\mathbf{u} + (\nabla\mathbf{u})^T) - \frac{2\mu}{3\epsilon_p} (\nabla \cdot \mathbf{u})\mathbf{I} \right] - \left(\frac{\mu}{K_{br}} + \beta_F |\mathbf{u}| + Q_{br} \right) \mathbf{u} + \mathbf{F}$$

$$\rho\nabla \cdot \mathbf{u} = Q_{br}$$

Physical Model

Compressibility: Incompressible flow

Neglect inertial term in free flow (Stokes flow)

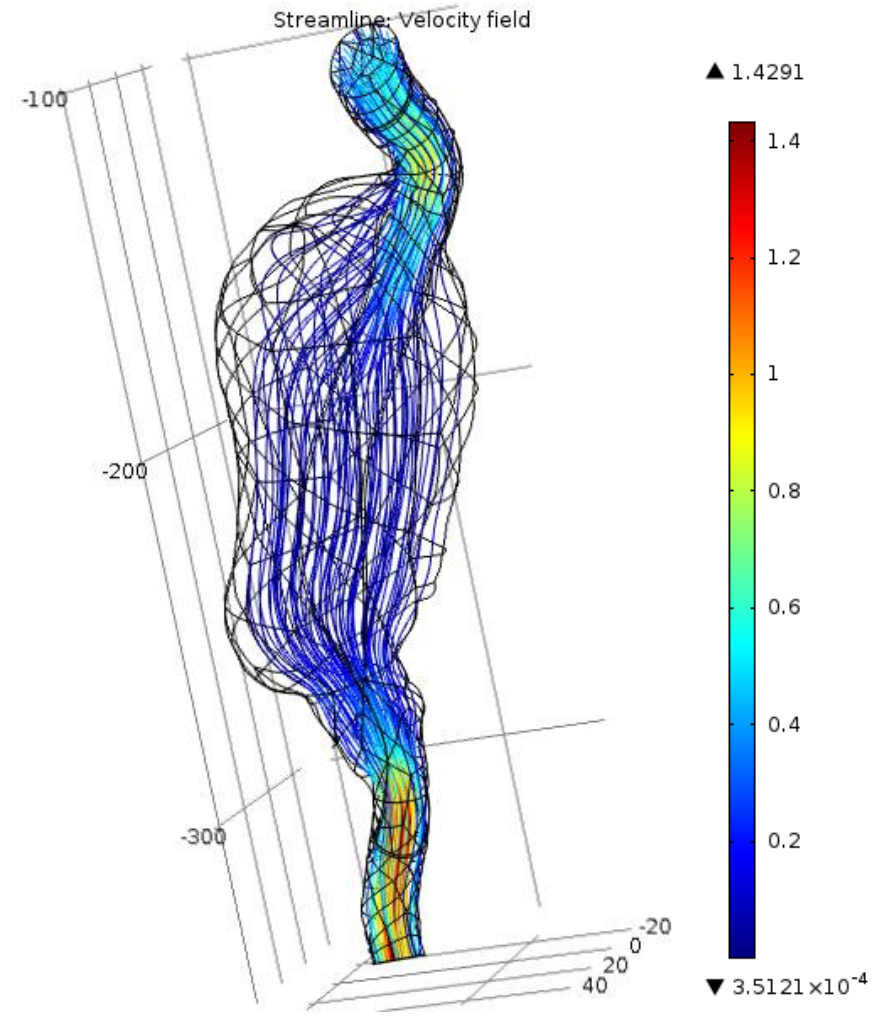
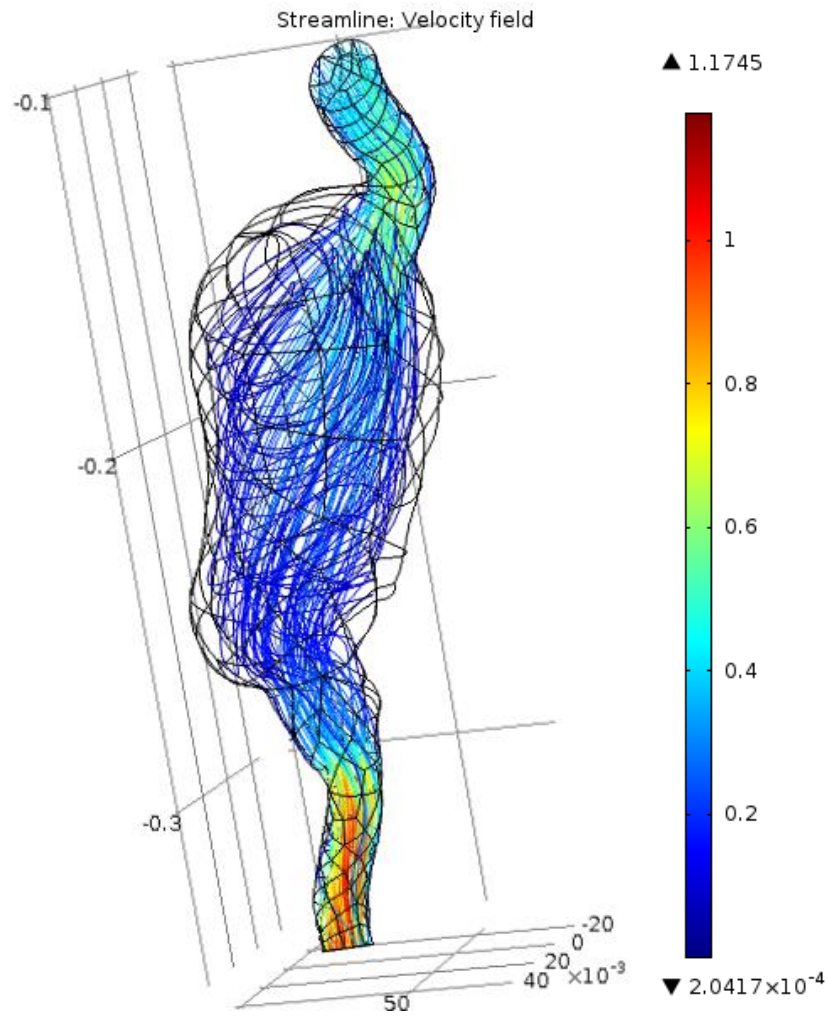
Neglect inertial term in porous media flow (Stokes-Brinkman)

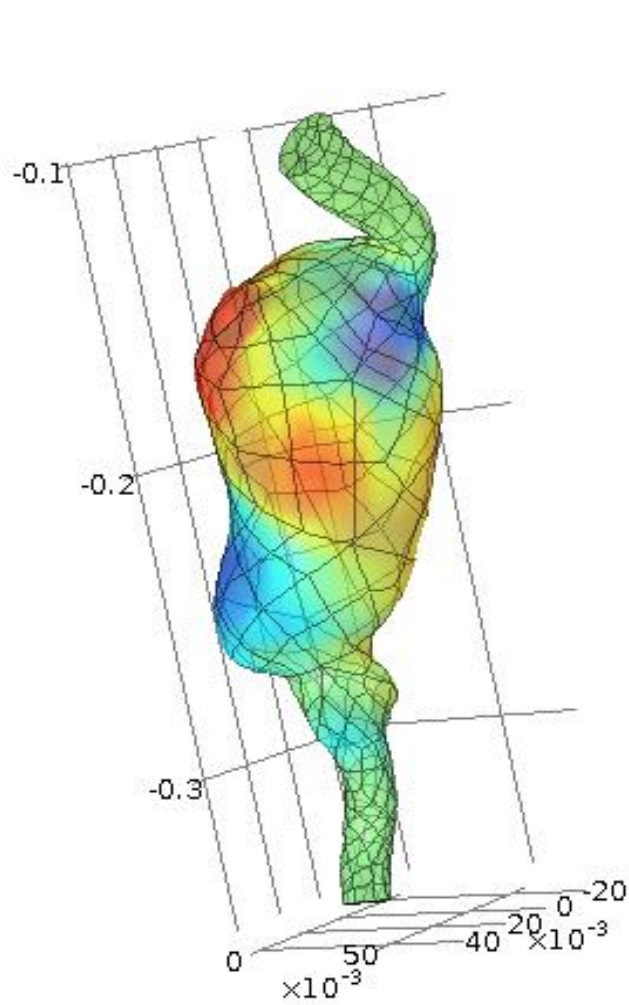
Dependent Variables

Graphics

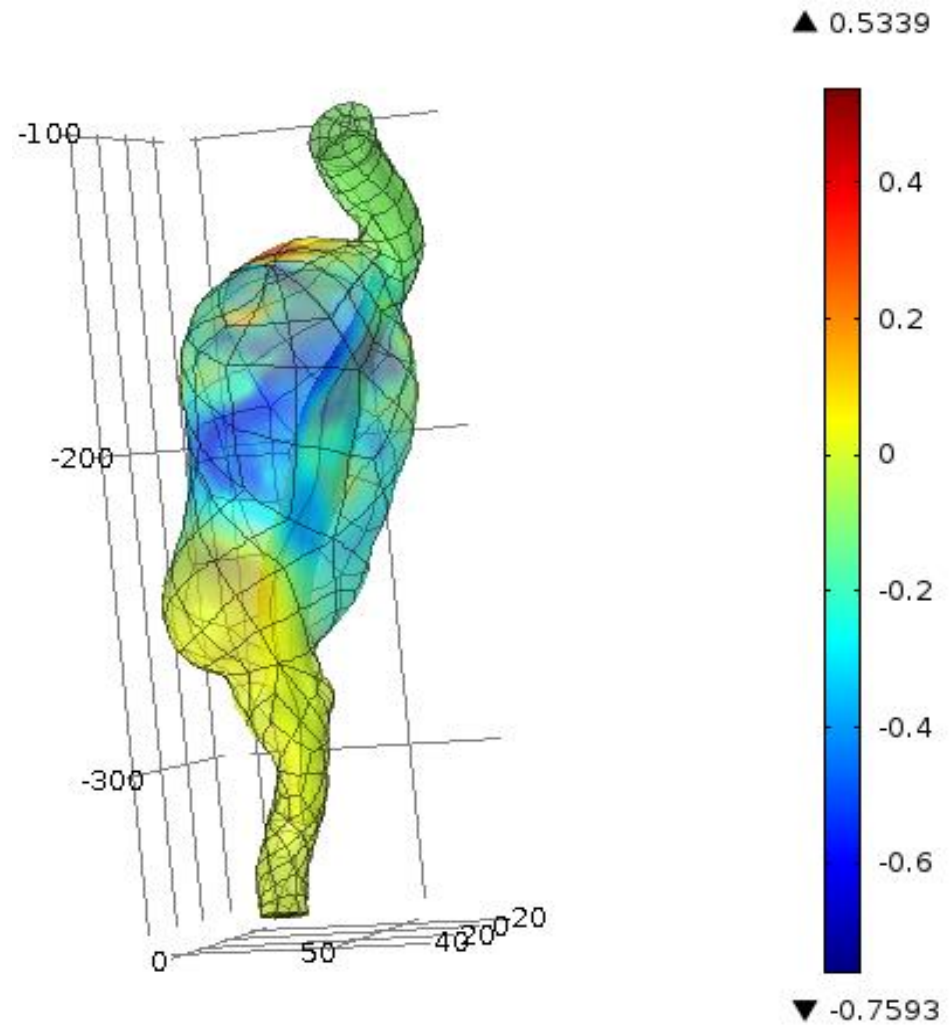
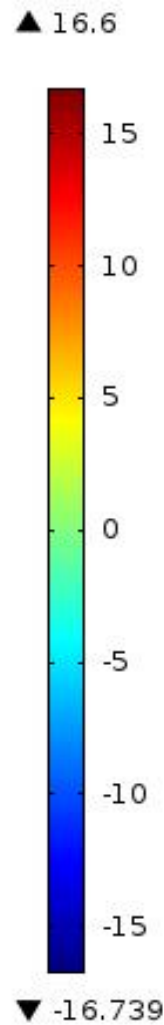
985 MB | 1135 MB

Velocity field streamline (1)



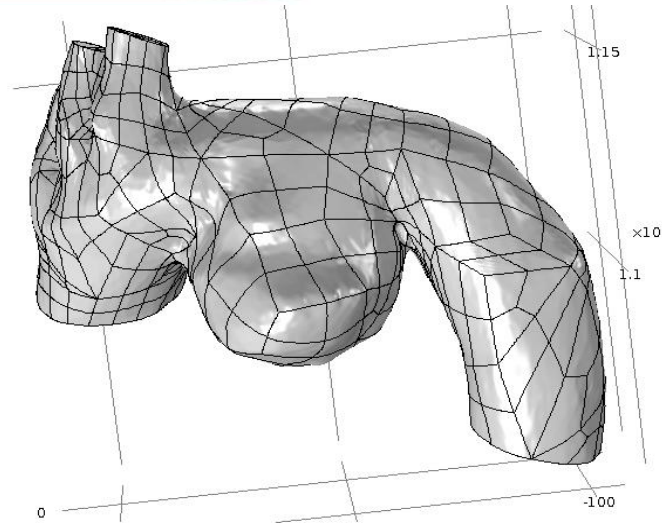


Without MFM

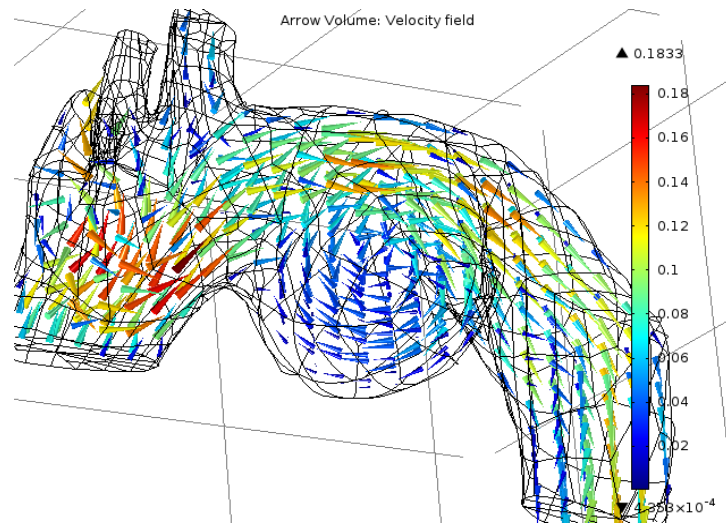


With MFM

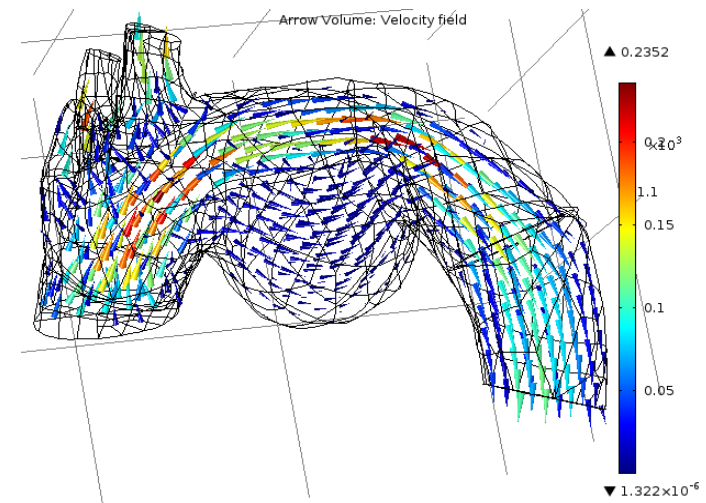
Velocity field (2)



Virtual Model

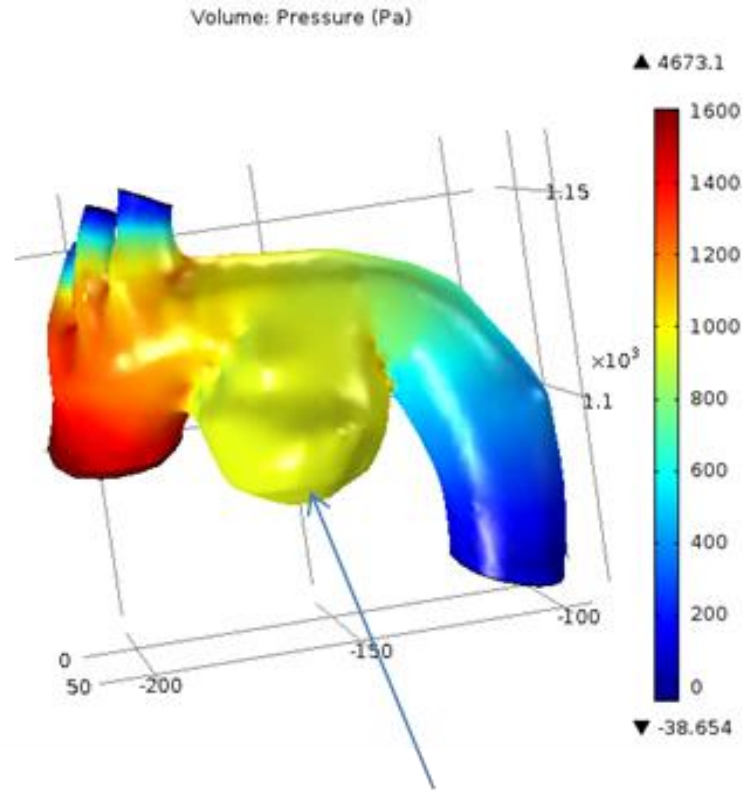


Without MFM



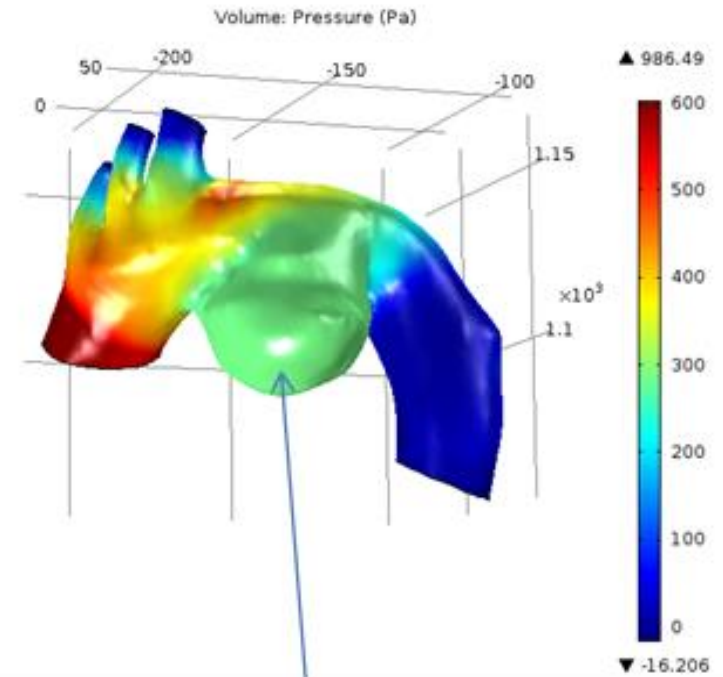
With MFM

Pressure (2)



950Pa

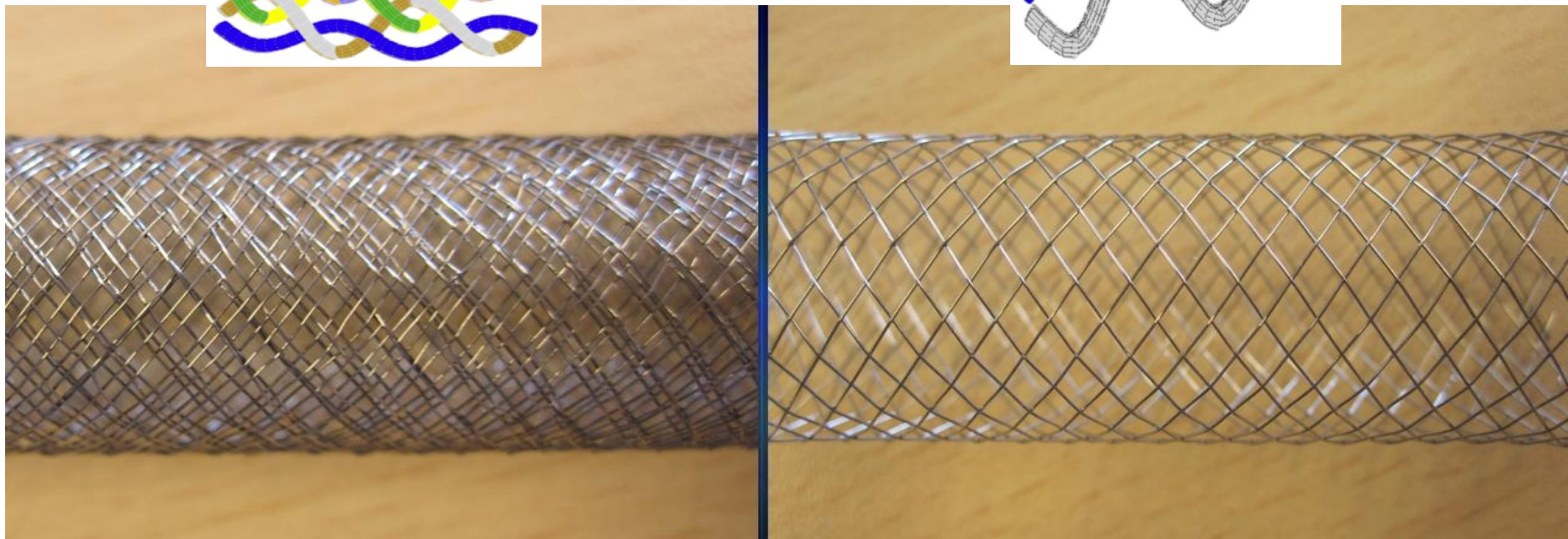
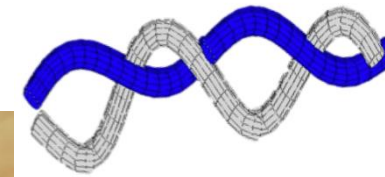
Without MFM



286Pa

With MFM

MULTILAYER FLOW MODULATOR VS MONOLAYER FLOW DIVERSION (MFM™)



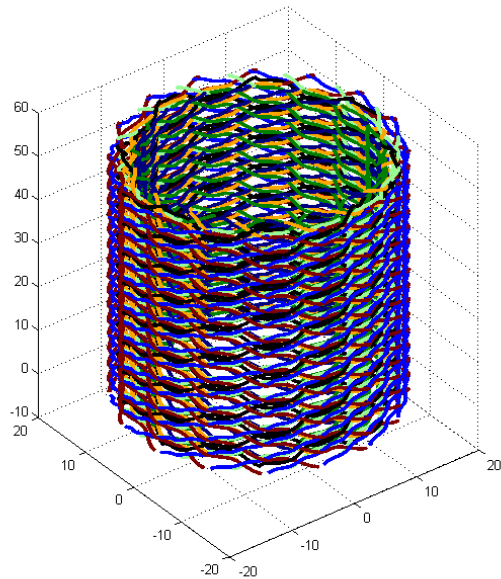
MULTILAYER - 3D

MONOLAYER- 2D

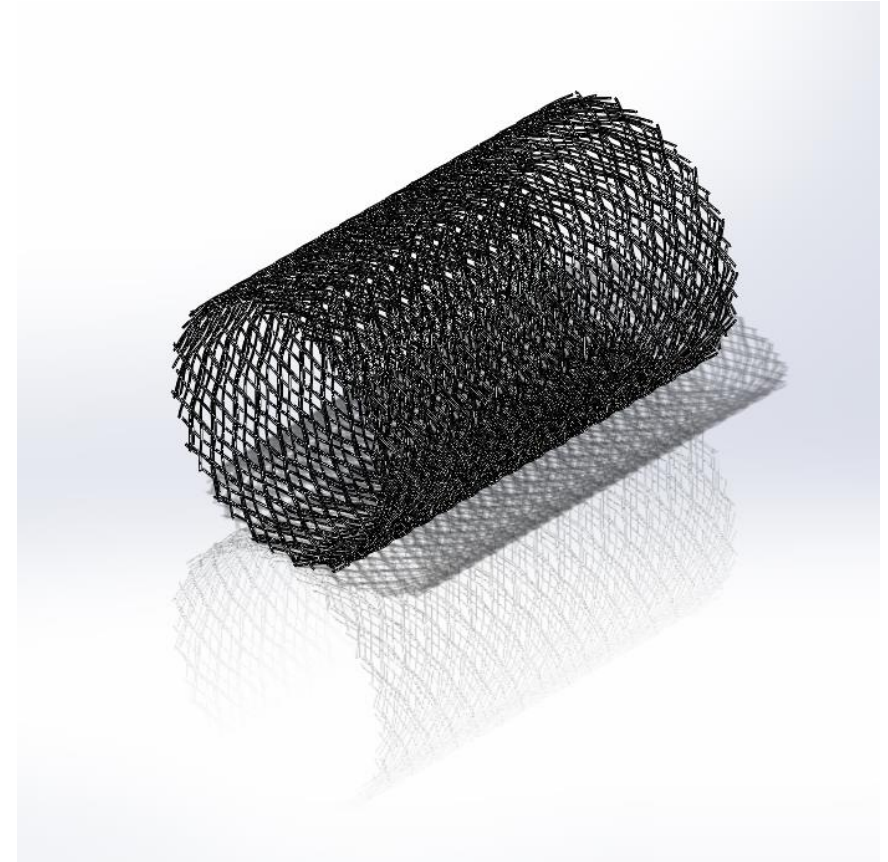
1. MULTILAYER - 3D



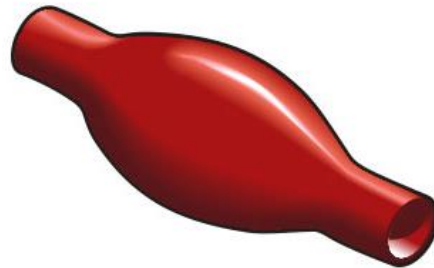
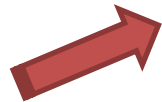
2. ANALYTICAL RECONSTRUCTION



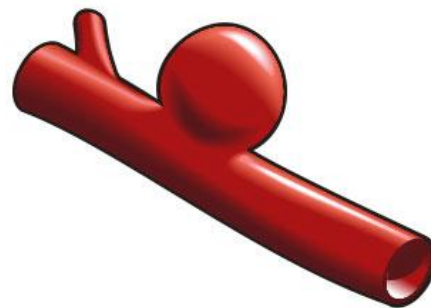
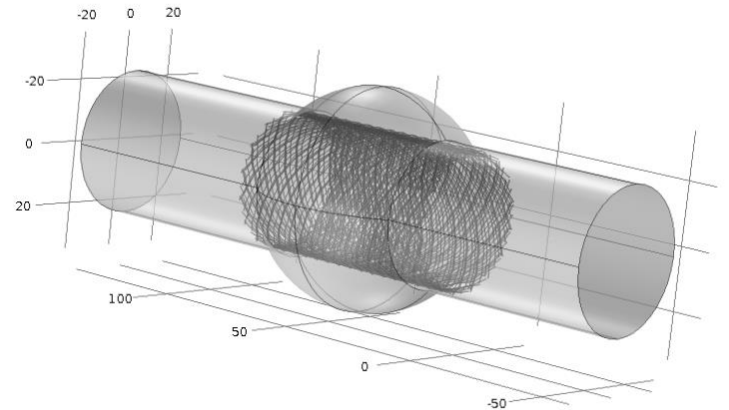
3. VIRTUAL RECONSTRUCTION



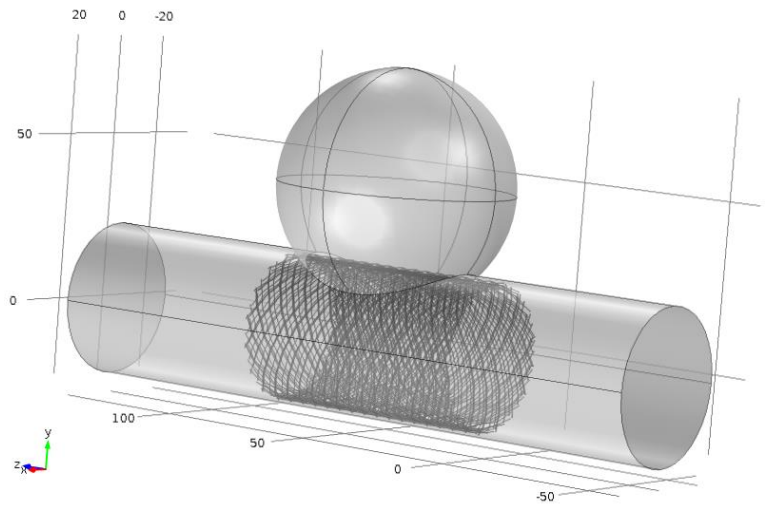
VIRTUAL SIMULATION METHOD (2)



Fusiform aneurysm



Saccular aneurysm



Solved physics (2)

COMSOL Multiphysics - prova-version43-bis-fusi.mph

Model Builder: prova-version43-bis-fusi.mph (root)

- Global Definitions
- Model 1 (mod1)
 - Definitions
 - Geometry 1
 - Materials
 - Laminar Flow (spf)
 - Fluid Properties 1
 - Wall 1
 - Initial Values 1
 - Inlet 1
 - Outlet 1
 - Mesh 1
 - Study 1
 - Step 1: Stationary
 - Solver Configurations
 - Results
 - Data Sets
 - Derived Values
 - Tables
 - Velocity (spf)
 - Slice 1
 - Streamline 1
 - Pressure (spf)
 - Export
 - Reports

Properties: Domain Selection: All domains

Fluid Properties:

- Density: ρ User defined: 1060 kg/m³
- Dynamic viscosity: μ User defined: 0.0035 Pa·s

Graphics: 3D model of a cylinder with a meshed interior.

Messages | Progress | Log | Results

3.59 GB | 3.67 GB

COMSOL Multiphysics - stent_nu.mph

Model Builder: stent_nu.mph (root)

- Global Definitions
- Model 1 (mod1)
 - Definitions
 - Geometry 1
 - Import 1 (imp1)
 - Cylinder 1 (cy1)
 - Sphere 1 (sph1)
 - Union 1 (uni1)
 - Difference 1 (dif1)
 - Form Union (fin)
 - Materials
 - Laminar Flow (spf)
 - Fluid Properties 1
 - Wall 1
 - Initial Values 1
 - Inlet 1
 - Outlet 1
 - Shell (shell)
 - Mesh 1
 - Study 1
 - Study 1
 - Study 2
 - Results

Properties: Interface Identifier: spf

Domain Selection: All domains

Equation: Equation form: Study controlled

Show equation assuming: Study 1, Stationary

$$\rho(\mathbf{u} \cdot \nabla) \mathbf{u} = \nabla \cdot \left[-p\mathbf{I} + \mu(\nabla \mathbf{u} + (\nabla \mathbf{u})^T) - \frac{2}{3}\mu(\nabla \cdot \mathbf{u})\mathbf{I} \right] + \mathbf{F}$$

$$\nabla \cdot (\rho \mathbf{u}) = 0$$

Physical Model: Compressibility: Compressible flow (Ma < 0.3)

Turbulence model type: None

Turbulence model: k-ε

Neglect inertial term (Stokes flow):

Dependent Variables

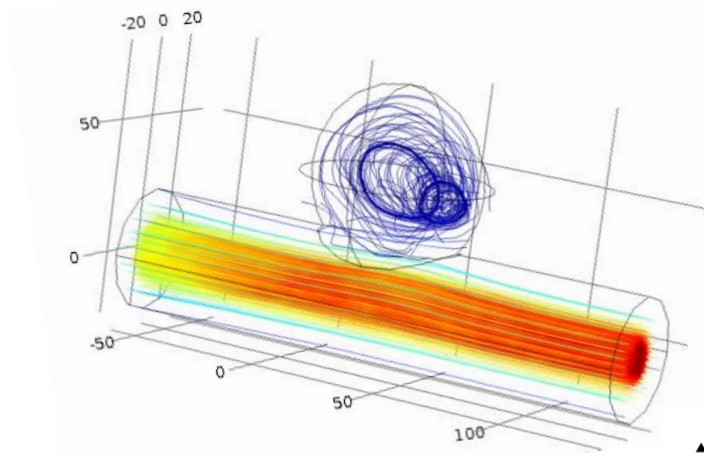
Graphics: 3D model of a stent with a meshed interior.

Messages | Progress | Log | Results

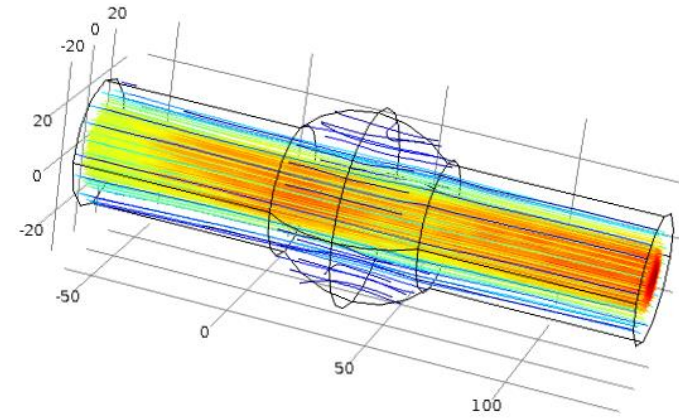
COMSOL 4.3.0.151

6.39 GB | 6.49 GB

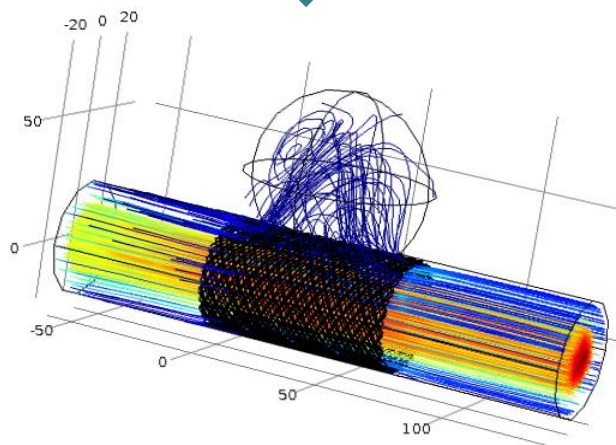
Velocity field streamline



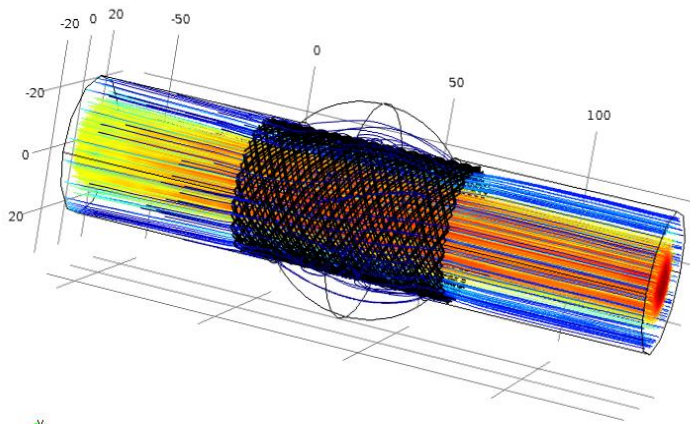
(a) Saccular aneurysm



(b) Fusiform aneurysm

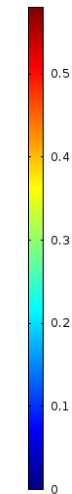


(c) Saccular aneurysm with MFIM implanted



(d) Fusiform aneurysm with MFIM implanted

▲ 0.5791



WE HAVE INTRODUCED TWO DIFFERENT APPROACHES

- VIRTUAL SIMULATION WITH REALISTIC AORTA,
ALTHOUGH EQUIVALENT ELEMENT IS USED FOR THE MFM
- VIRTUAL SIMULATION WITH REALISTIC MFM,
ALTHOUGH IN A SIMPLIFIED AORTA GEOMETRY

NEXT STEP:

- VIRTUAL SIMULATION WITH REALISTIC AORTA & REALISTIC MFM