Computer Aided Surgery (CAS) for Abdominal Aortic Aneurysm (AAA)

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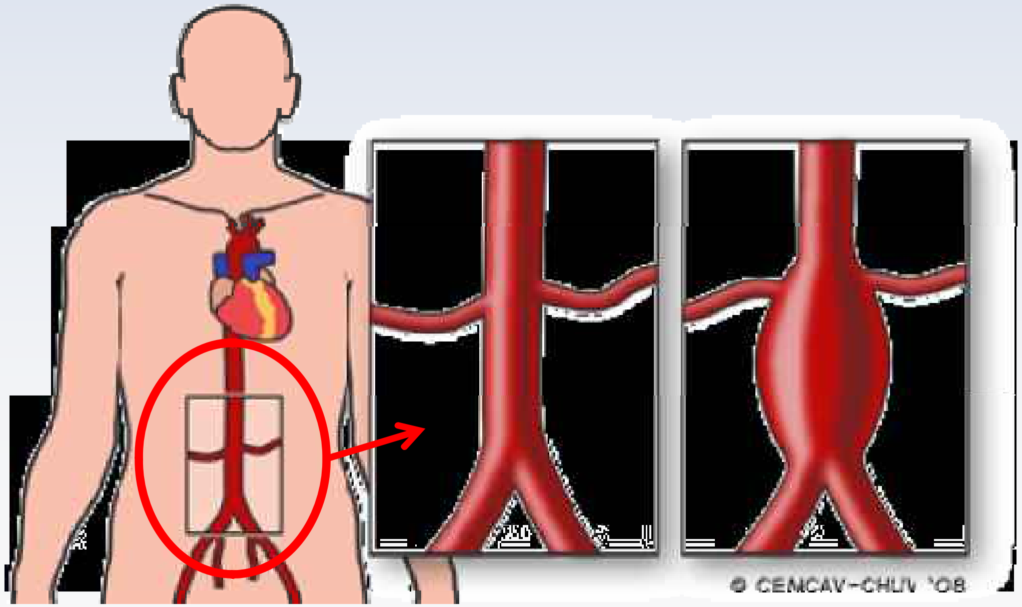
Outline

- Clinical Challenges for Abdominal Aortic Aneurysm (AAA)
- ANGIOVISION Project
- Patient Geometry
- Tuning between simulation results and per-operative data
- Benefits of Endovascular Simulation
- Next steps

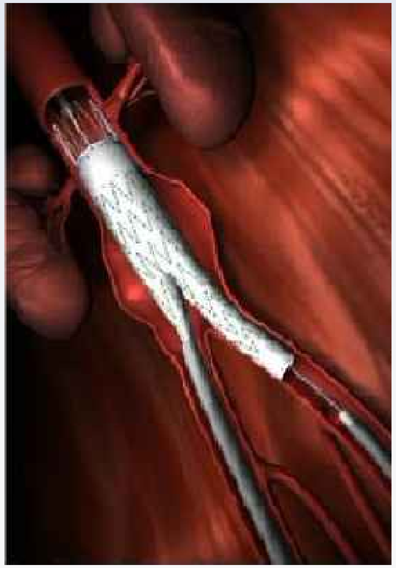
Clinical Challenges for Abdominal Aortic Aneurysm

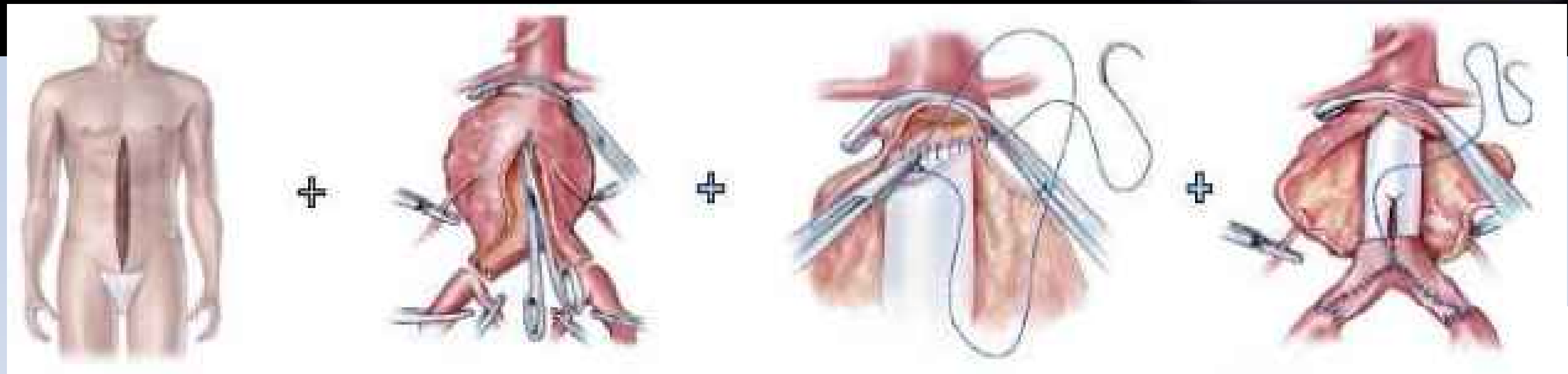
Abdominal Aortic Aneurysm

- **Abdominal Aortic Aneurysm (AAA): a localized dilatation (ballooning) of aortic artery exceeding the normal diameter by more than 50 percent**
- **Prevalence: ~5% for Caucasian men aged 65+**
  - 15,000 ruptures per year in US
  - Rupture of the AAA occurs in 1-3% of men aged 65+, the mortality is 70-95%

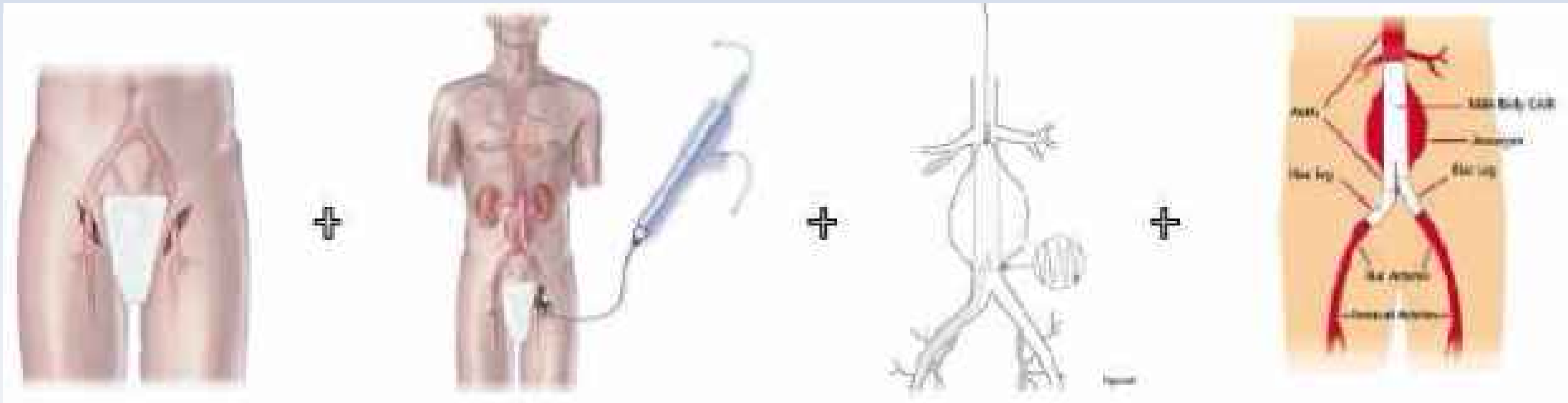


AAA Repair





Open Surgery



Endovascular Treatment

Endovascular treatment is part of what is called "Minimally Invasive Treatment", in principle less risky and more cost effective than traditional surgery; it also allows a much faster patient recovery which can return to active life quicker This solution is however more delicate. Although very promising, numerous doctors are still hesitant to widely adopt it because of various challenges described later.

ANGIOVISION Project

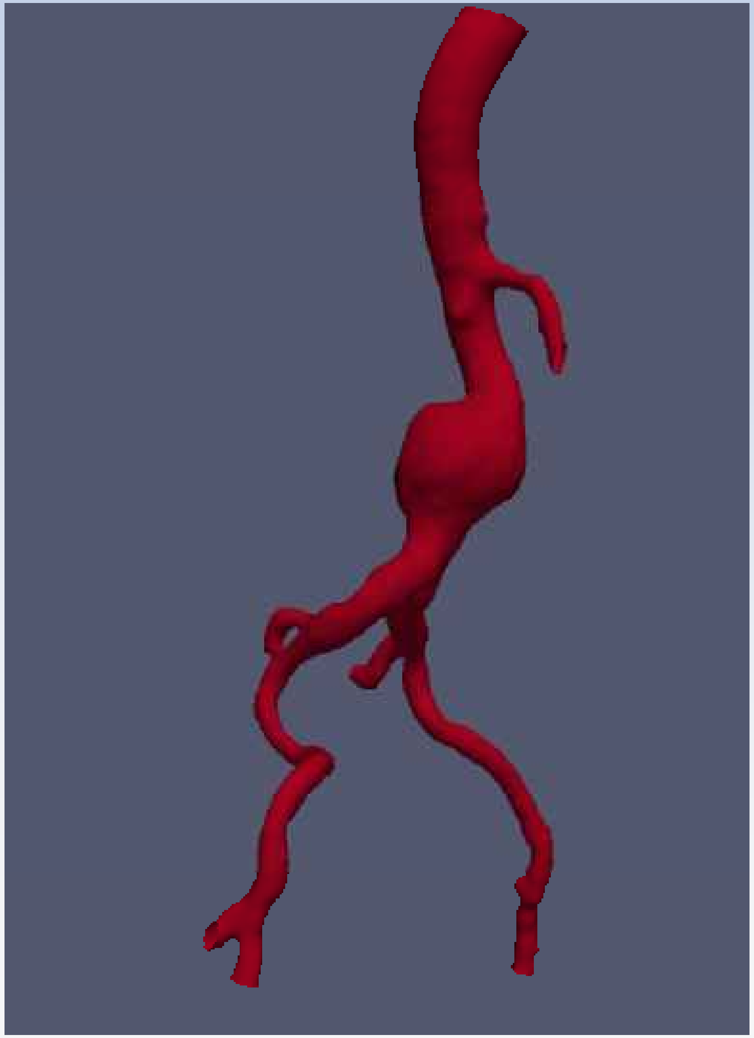
ANGIOVISION Project

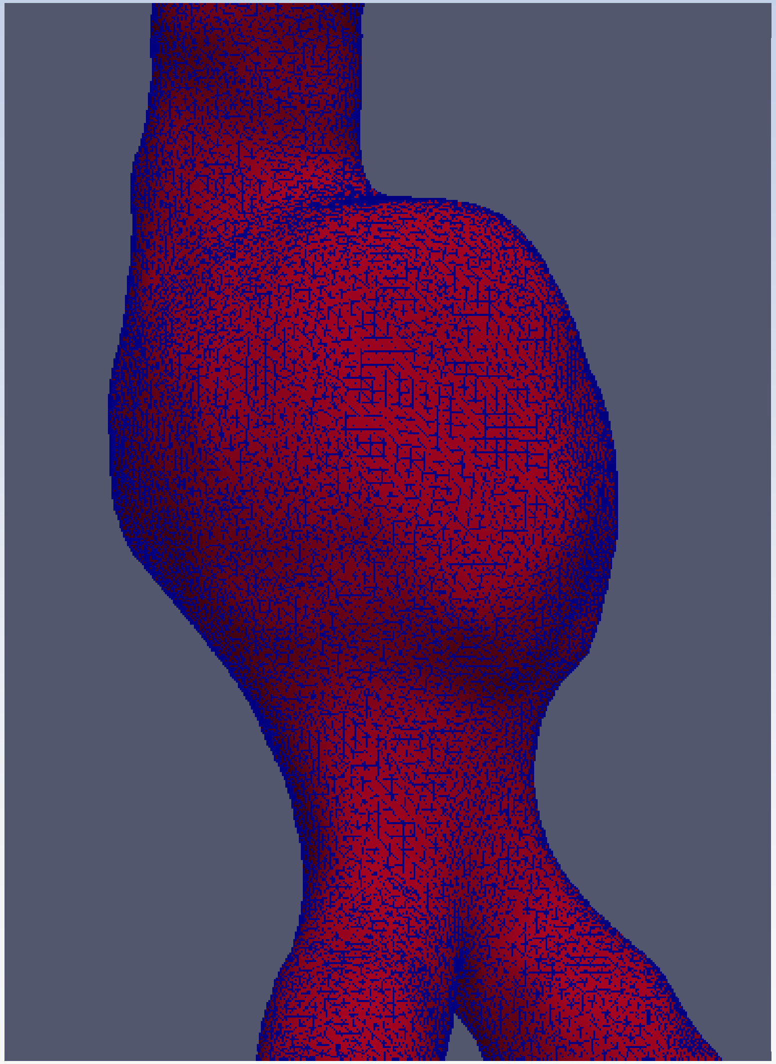
- **ANGIOVISION**
  - French sponsored project to
    - develop and validate a sophisticated patient-specific model
    - aortic stent deployment and artery deformation
  - From 01/2010 to 12/2012

- **ANGIOVISION Partners**
  - **LTSI (Prime):** Lab, Health Technologies and Signal Processing
  - **LAMCOS**: Lab, Biomechanical expertise
  - **CIC-IT & HMN, Hospitals:** (Pr Jean-Pierre Becquemin is the reference surgeon in France for AAA)
  - **THERENVA**: SME, Computer Assisted Surgery Tools
  - **ANSYS France**: Patient Specific FE Simulation

Patient Segmented Data & Geometrical Modeling

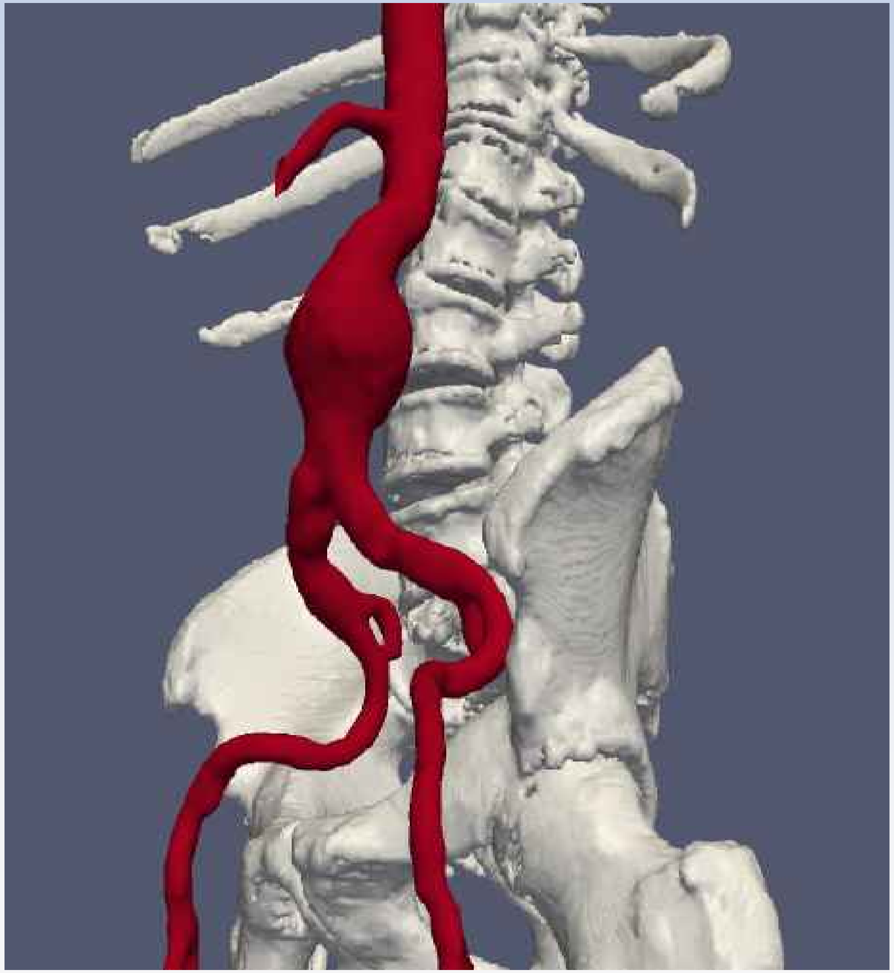
Patient Segmented Data



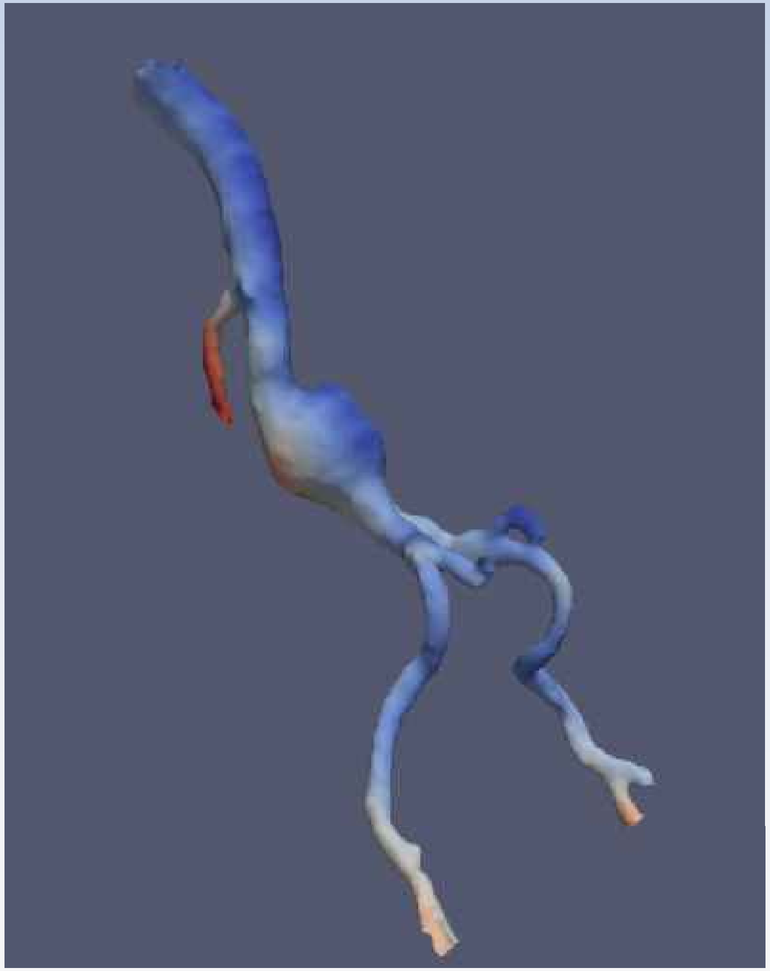


High quality segmented data, STL Format

Patient Segmented Data

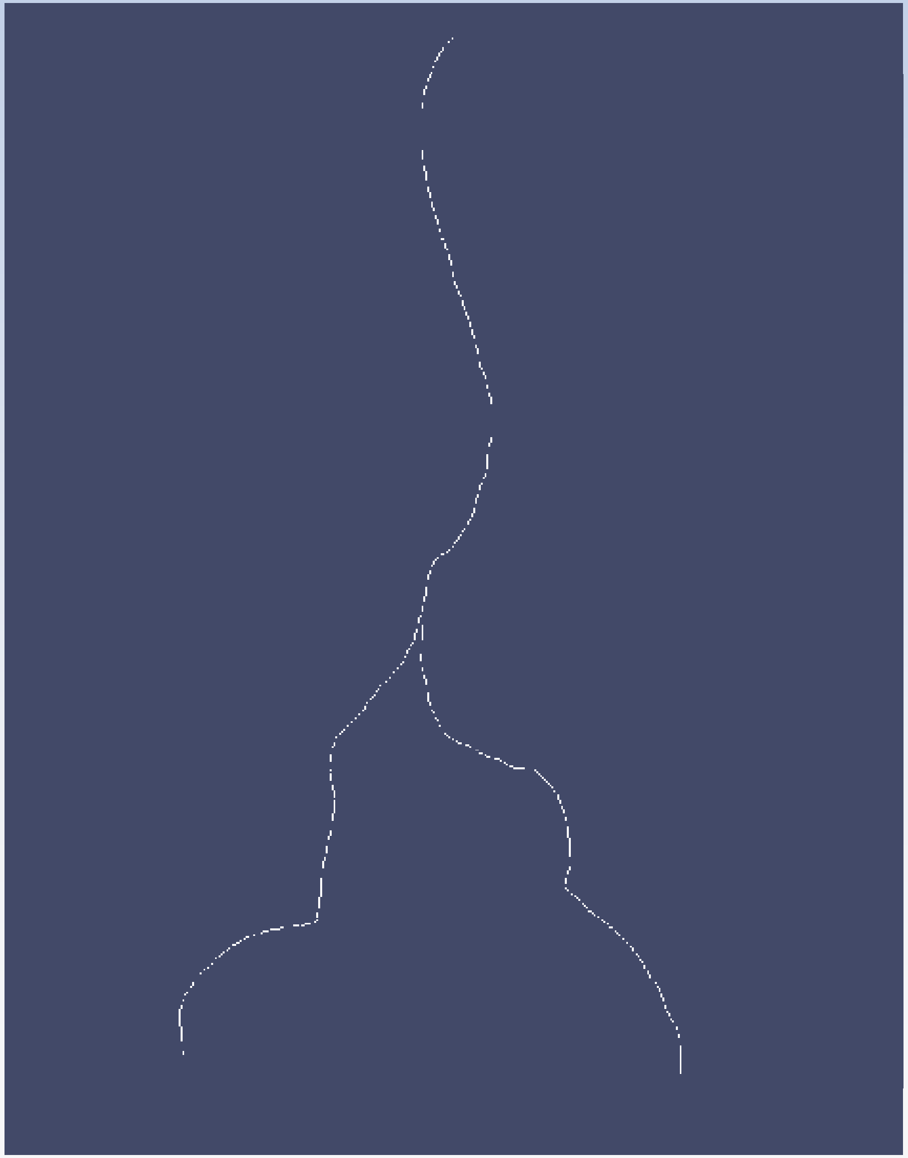


Iliac and aortic arteries close to the spine

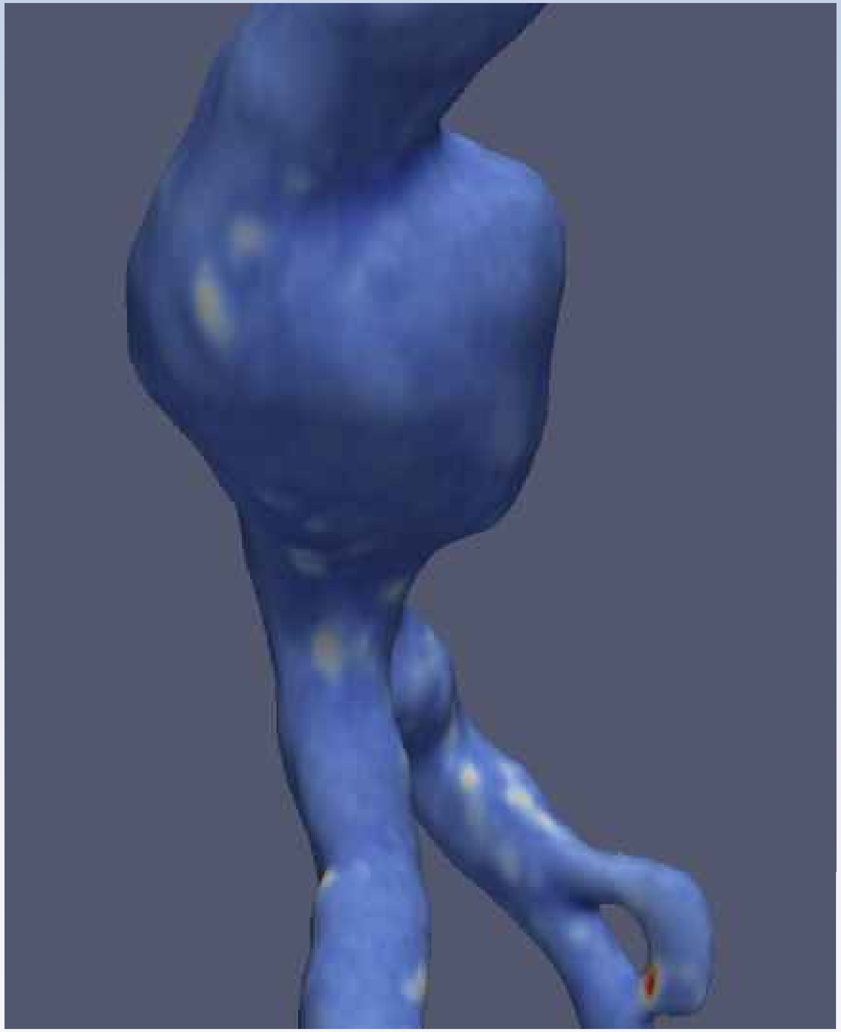


Distance between artery and spine

Patient Segmented Data



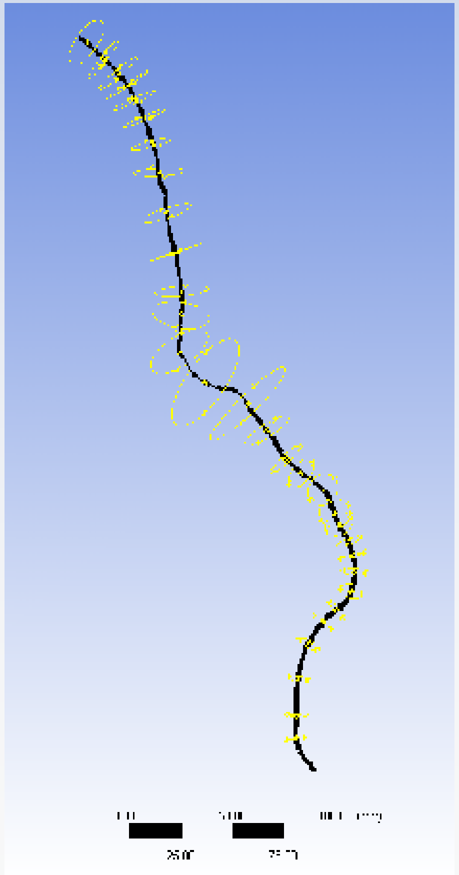
Extraction of the vessel centerline

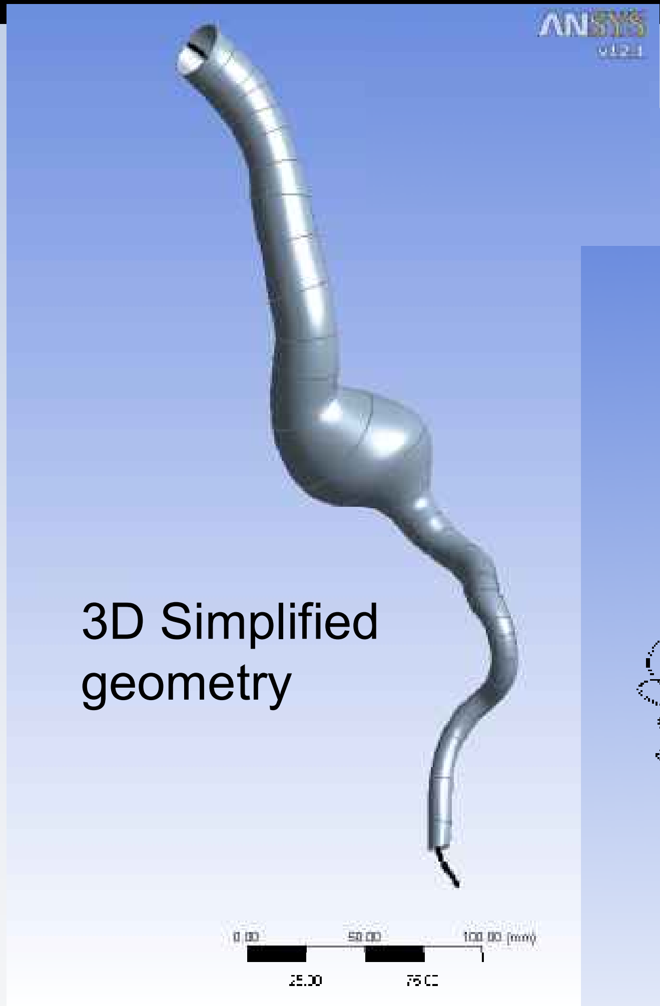


Artery wall property (healthy (blue) , calcified (white))

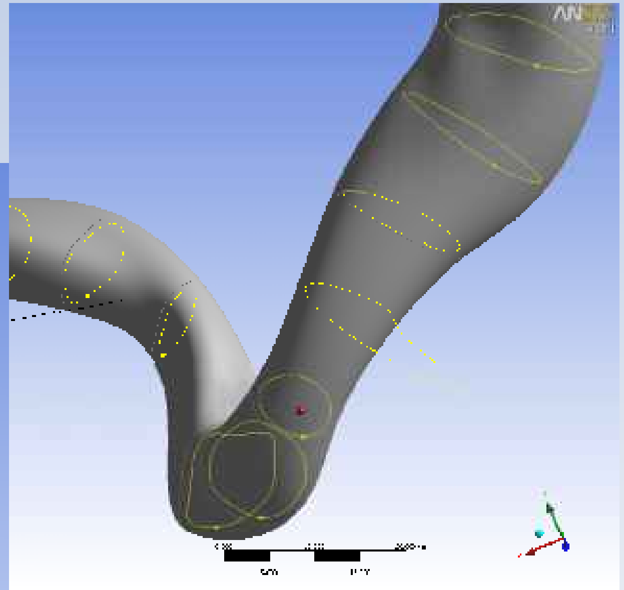
Generation of a Simplified Geometry

Simplified geometry with centerline and circles





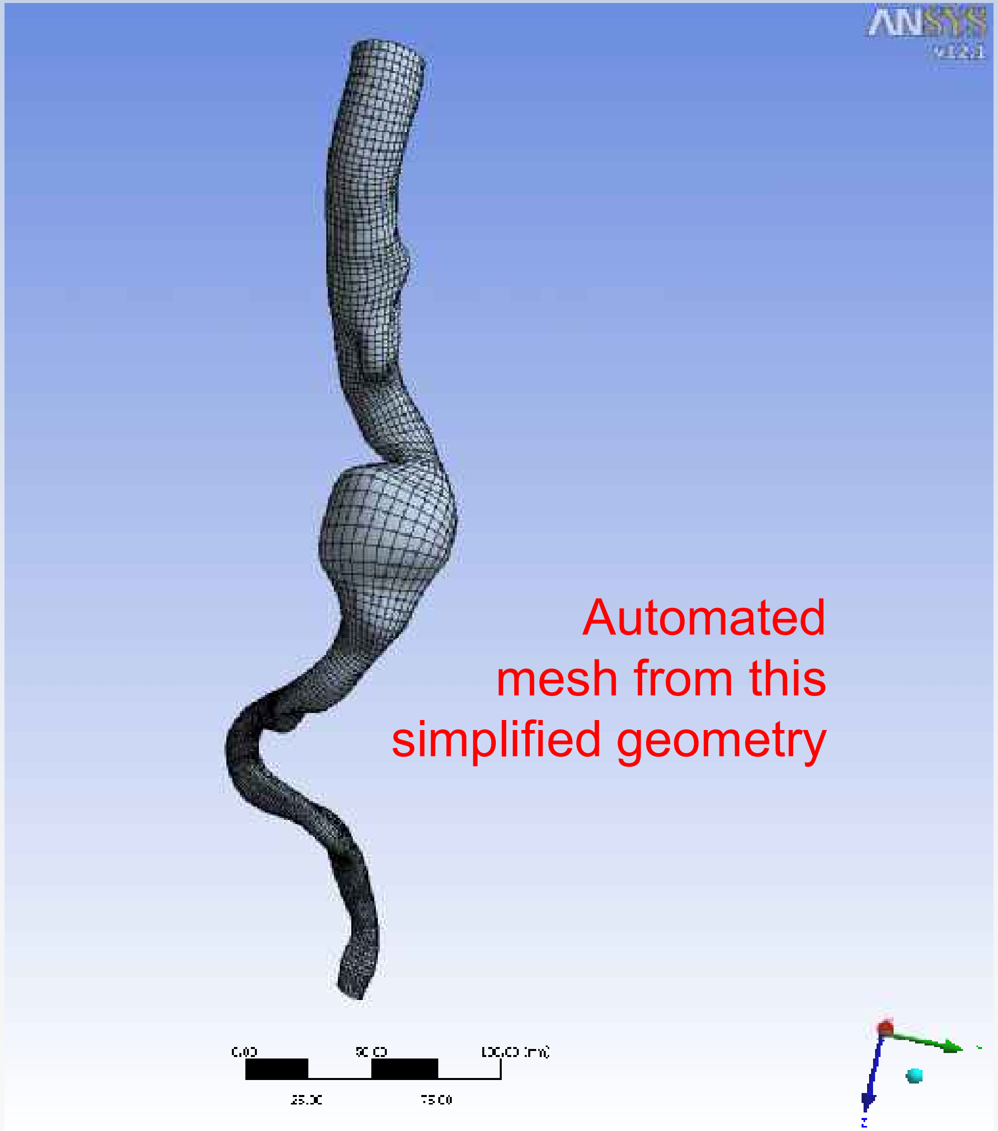
3D Simplified geometry



More than 40 **splines** in normal plans along the centerline

Simplified Geometry using Splines

Comparison between detailed geometry and simplified geometry



Automated mesh from this simplified geometry

Endovascular Simulation

Endovascular Treatment

1. Insert a flexible guidewire inside iliac artery (near hip) until a position above the AAA
2. Insert a flexible catheter around flexible guidewire
3. Take off flexible guidewire
4. Insert stiff guidewire (e.g. Lunderquist™) inside flexible catheter
5. Take off flexible catheter
6. Insert stent delivery catheter around stiff guidewire
7. Deploy stent
8. Eventually another procedure to deploy a leg stent in the second iliac artery

- **Our goal is to predict artery deformation and medical device deformation for the steps 4, 6 and 7**

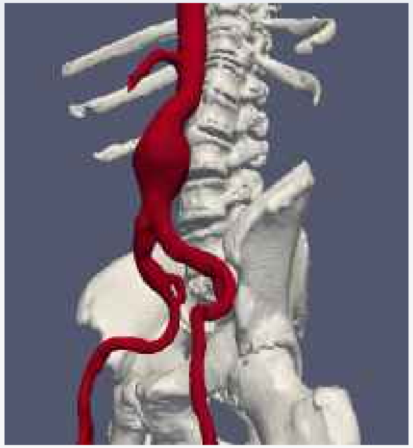
The first steps involving flexible devices do not deform the artery

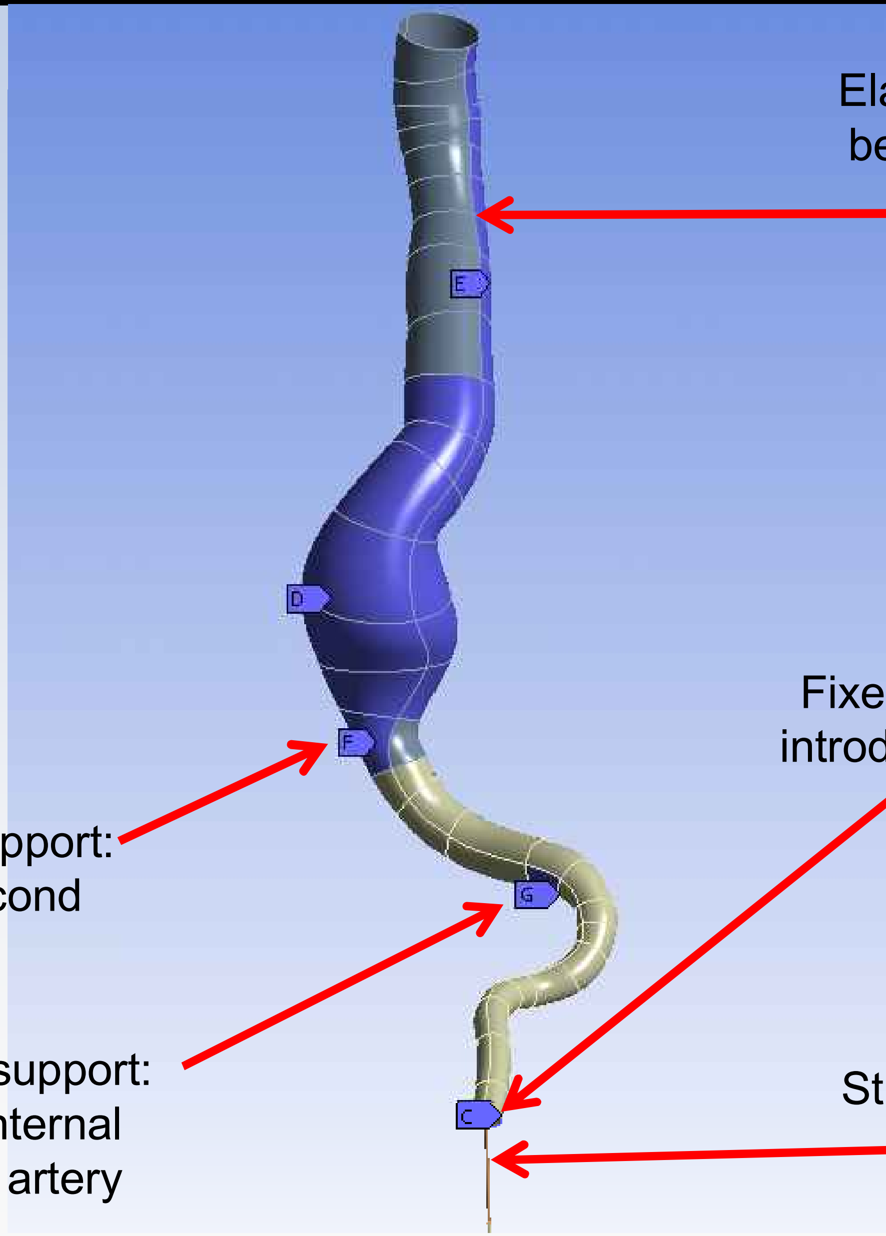
Simulation of Stiff Guidewire Insert: Modeling the Cardiovascular Environment

Artery wall thickness
- Iliac: 0.8mm
- Aorta: 1.5mm

Young's Modulus: 12 MPa
Poisson: 0.49

Aorto-iliac structure geometrical movements constrained by surrounding abdominal structures





Elastic support between aorta and spine

Fixed support at introduction point

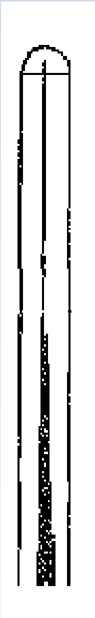
Elastic support: link to second iliac

Elastic support: link to internal femoral artery

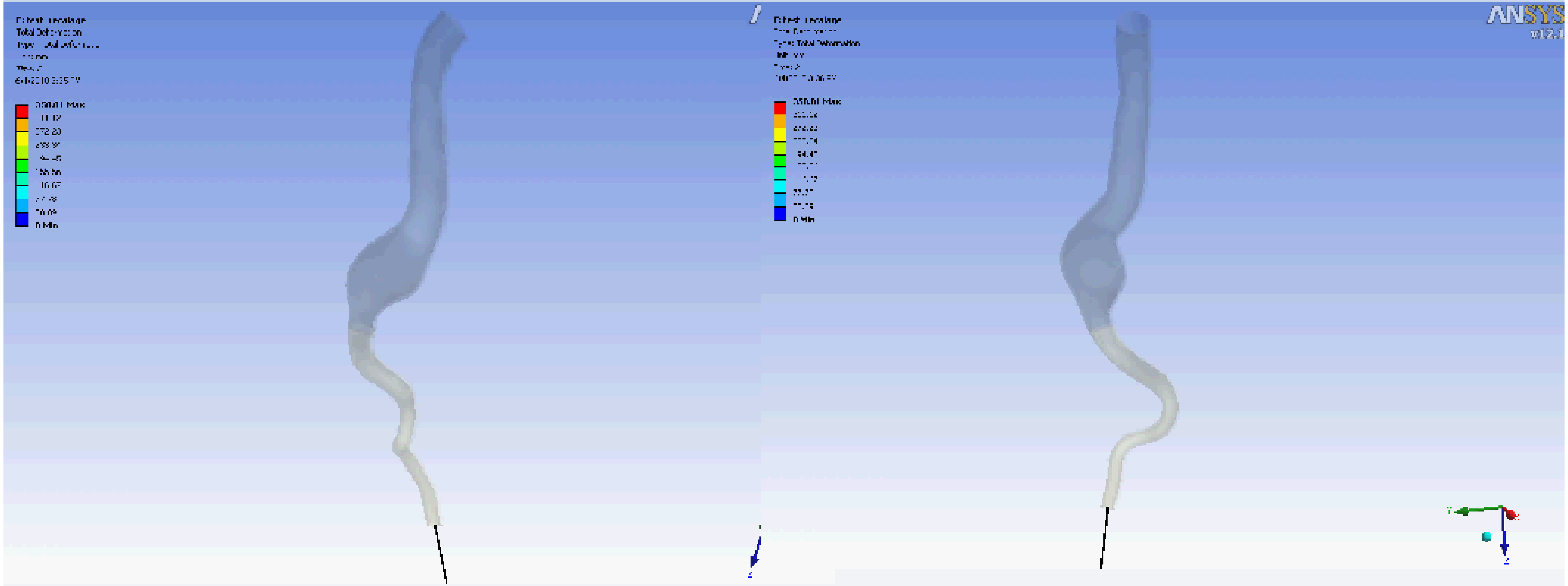
Stiff guidewire - Lunderquist

Stiff Guidewire

- Diameter: 1mm
- Length: 350-400mm
- Head: half sphere
- BC: Prescribed Displacement
- Linear Elastic Steel
- Poisson ratio: 0.3
- Variable Young's modulus:
  - 0-40 mm: 2 000 MPa
  - 40-60 mm: 8 000 MPa
  - 60-80 mm: 20 000 MPa
  - 80-100 mm: 50 000 MPa
  - 100-120 mm: 100 000 MPa
  - >120mm: 180 000 MPa

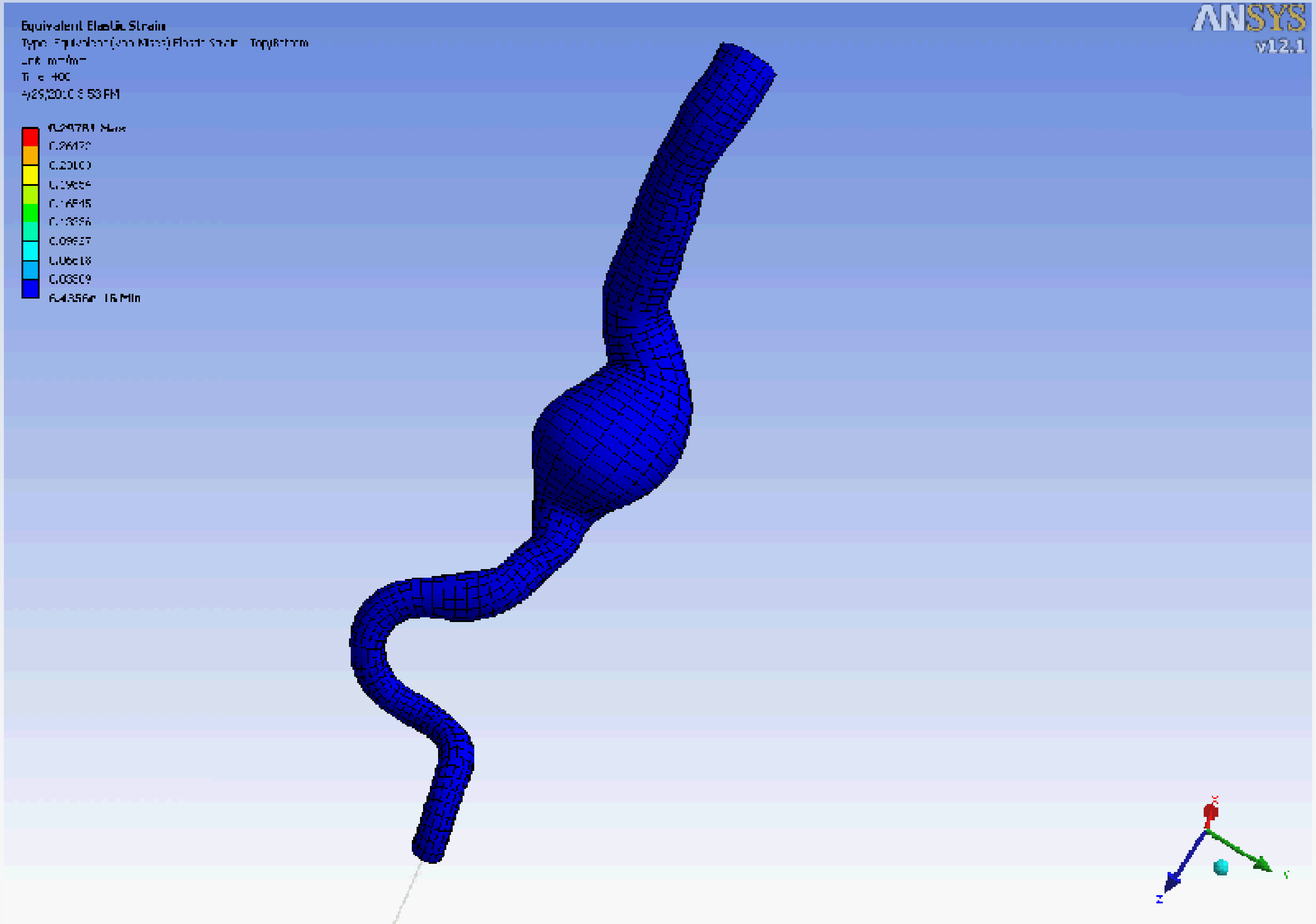


Motion Simulation



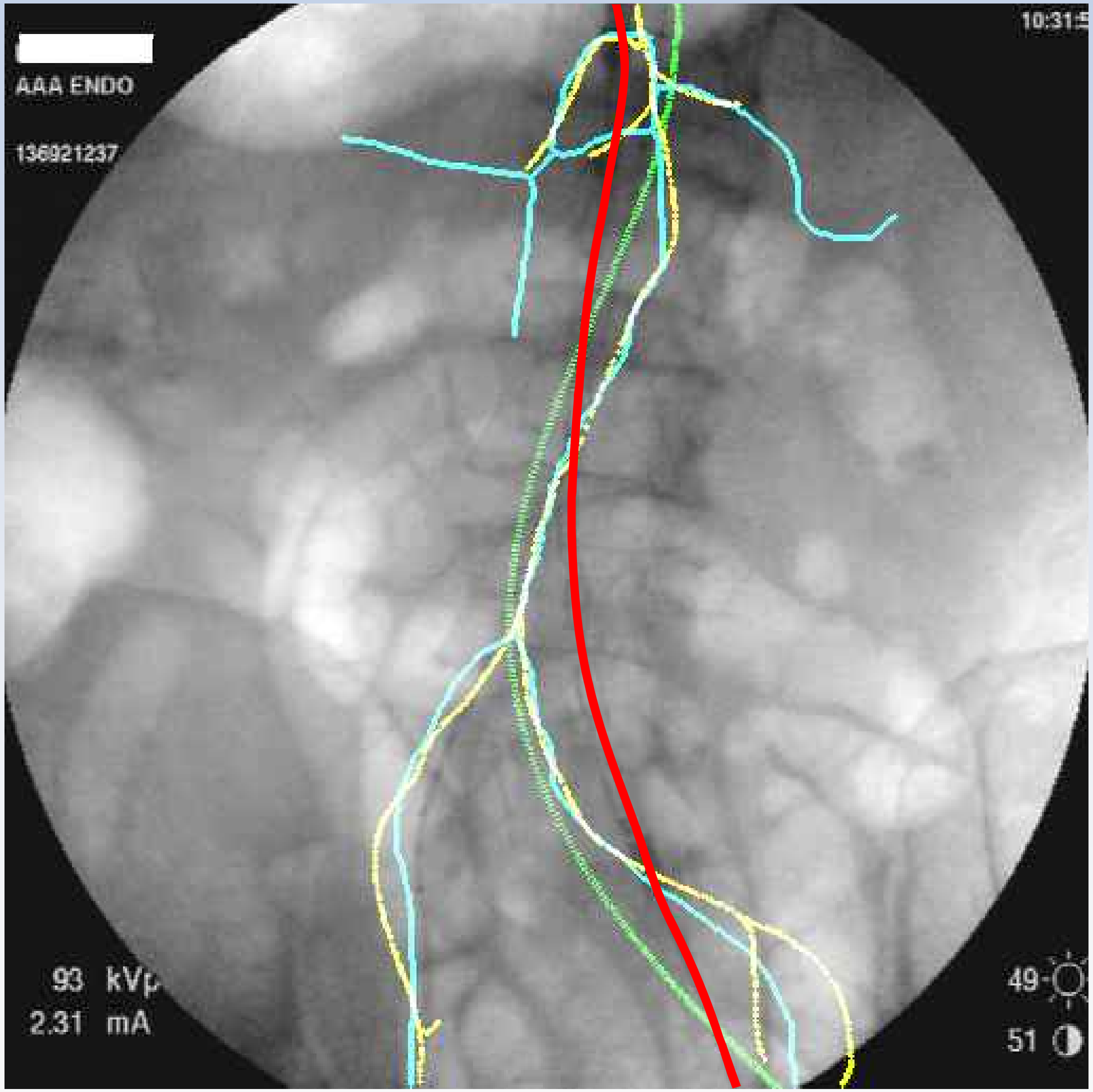
Deformation of the second iliac and the aorta under the action of the stiff guide, Ddifferent view angles

Artery Wall Stresses



Per-operative Data

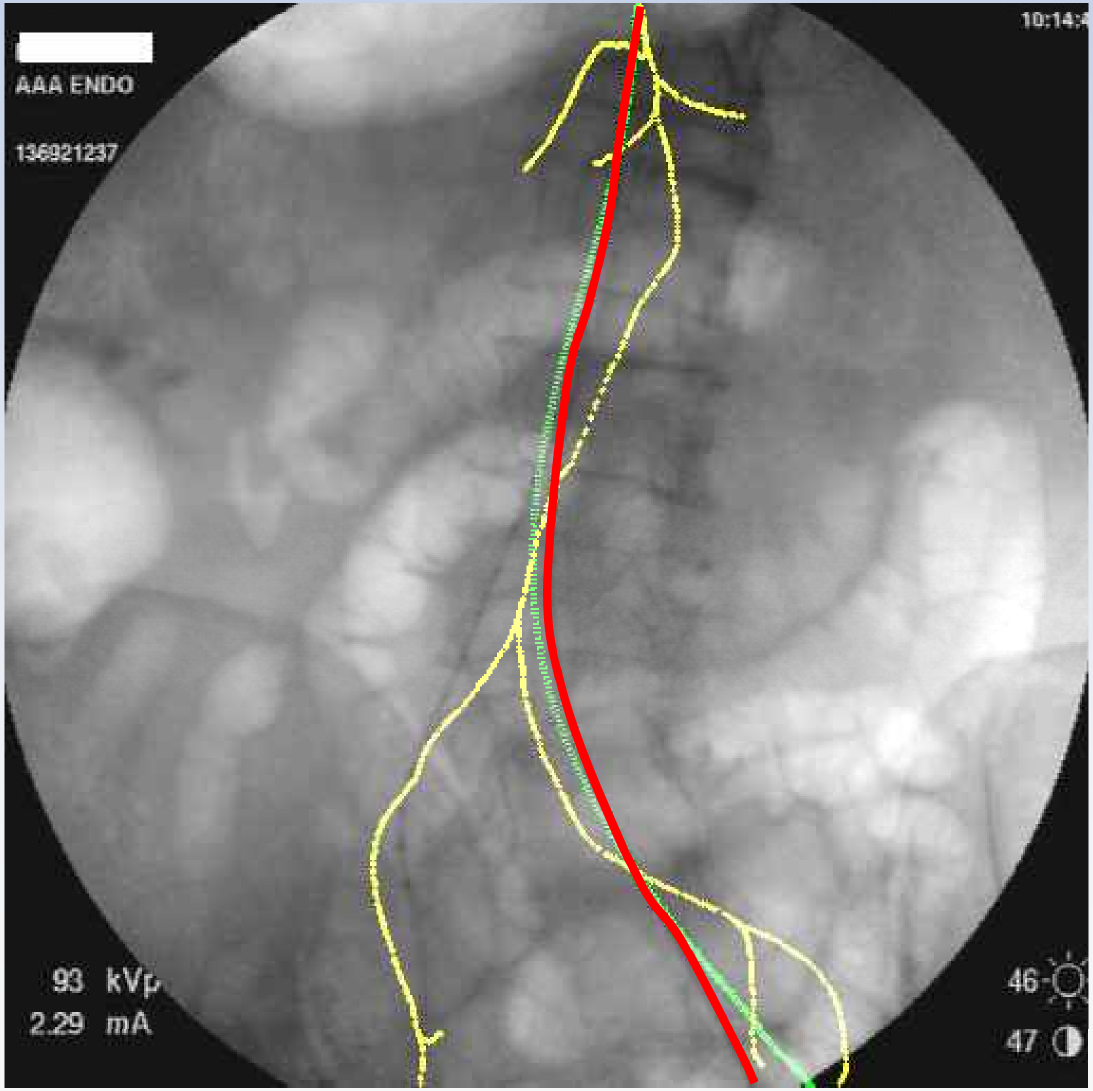
- Blue & yellow: artery centerline before endovascular treatment
- Black/Red: guidewire
- Green: First simulation (before tuning)



X-ray using one single incidence

Model Tuning

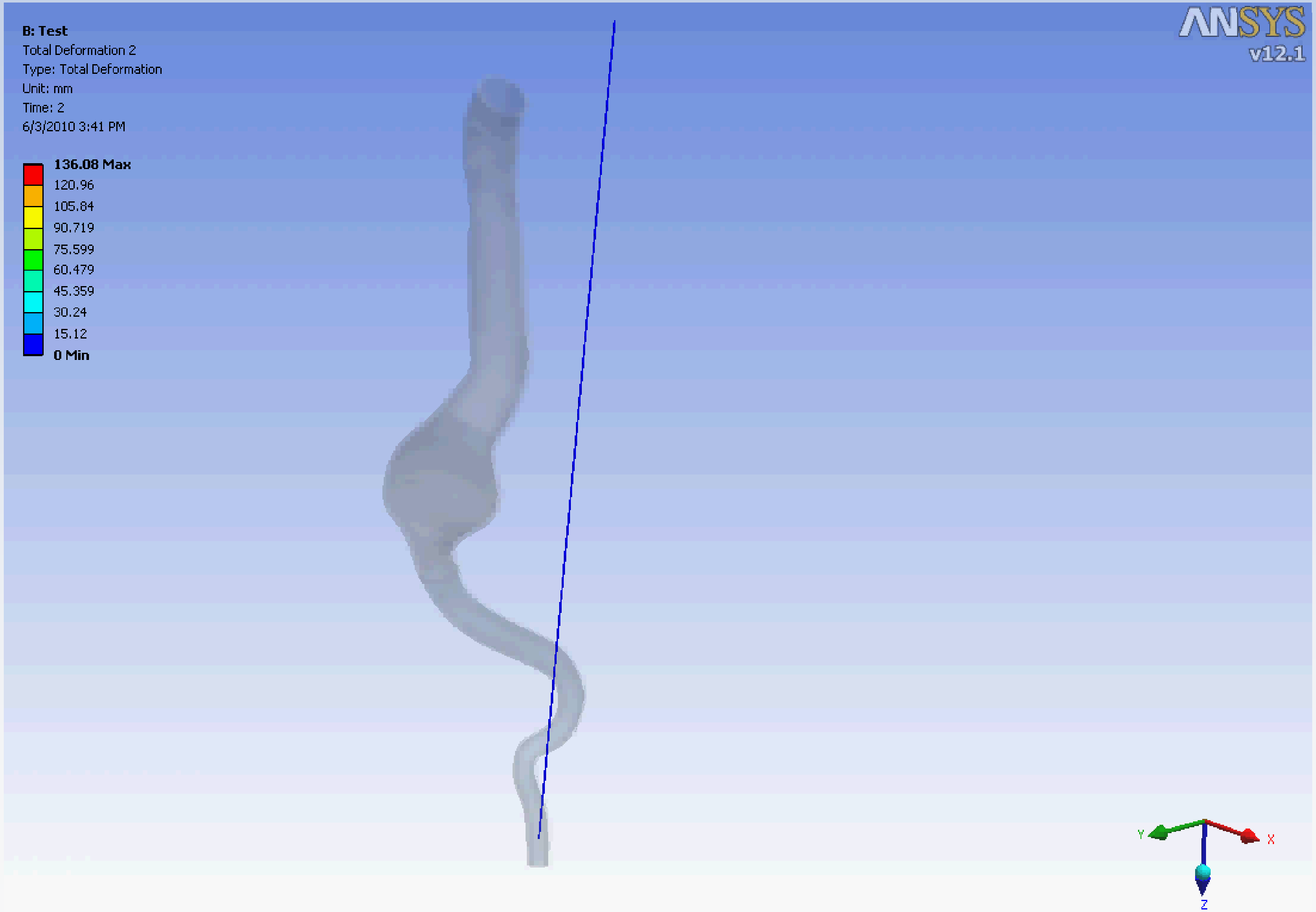
- Yellow: artery centerline before endovascular treatment
- Black/Red: guidewire
- Green: simulation with tuning
- Tuning Parameters:
  - Artery wall thickness
  - Second Iliac Link
  - Elastic support between upper aorta and spine
  - *Hyperelastic material law (more flexible iliac artery)*
  - *More accurate artery geometry*



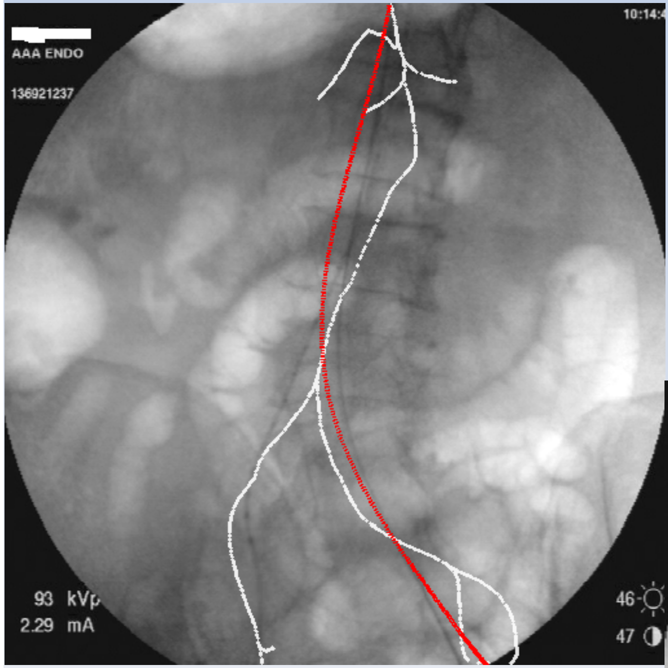
Necessary Clinical Output

- **Transient progression of stiff wire :**
  - Nice to look at
  - Time consuming
  - Not really necessary for clinical purpose
- **Valuable clinical information:**
  - Deformed arteries
  - Induced stress
  - Getting quick results to test various configurations and devices
- **Solution**
  - Direct calculation of final position
  - No transient modeling

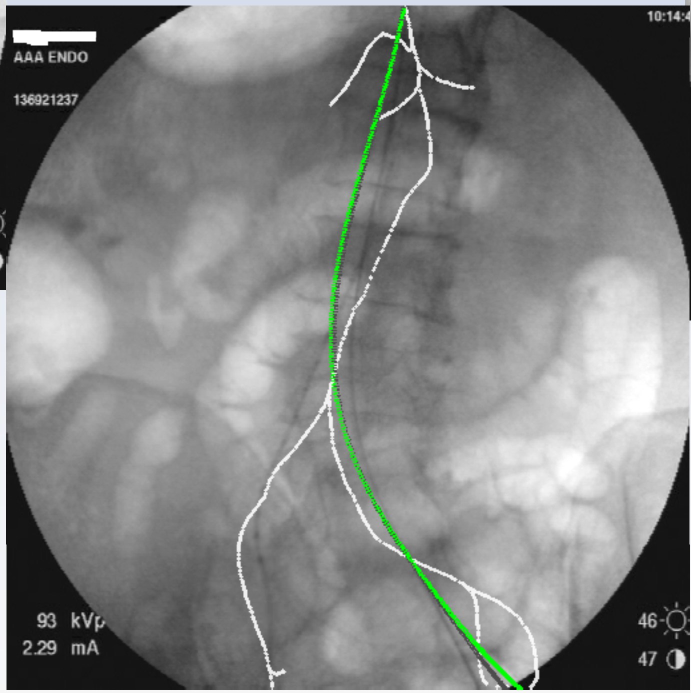
Direct Final Position



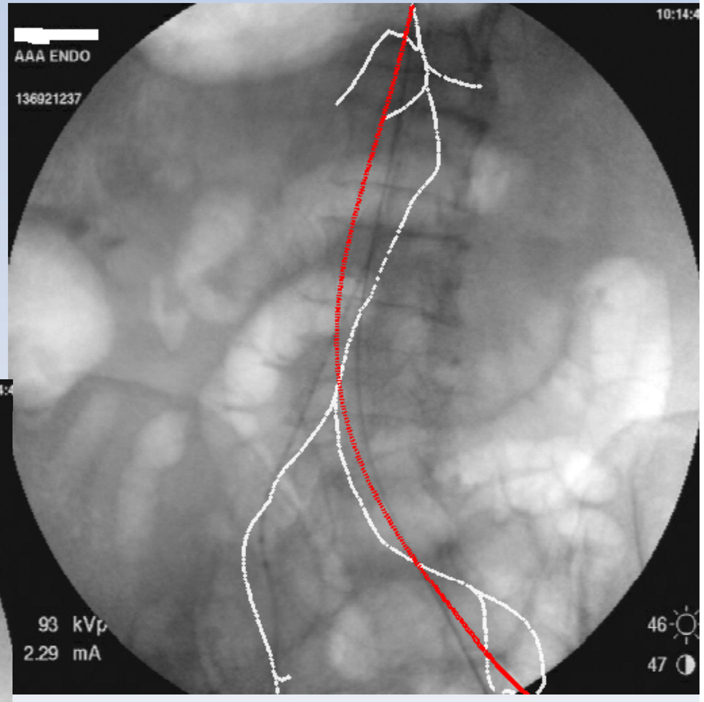
Comparison between the 2 End Results



Motion Simulation

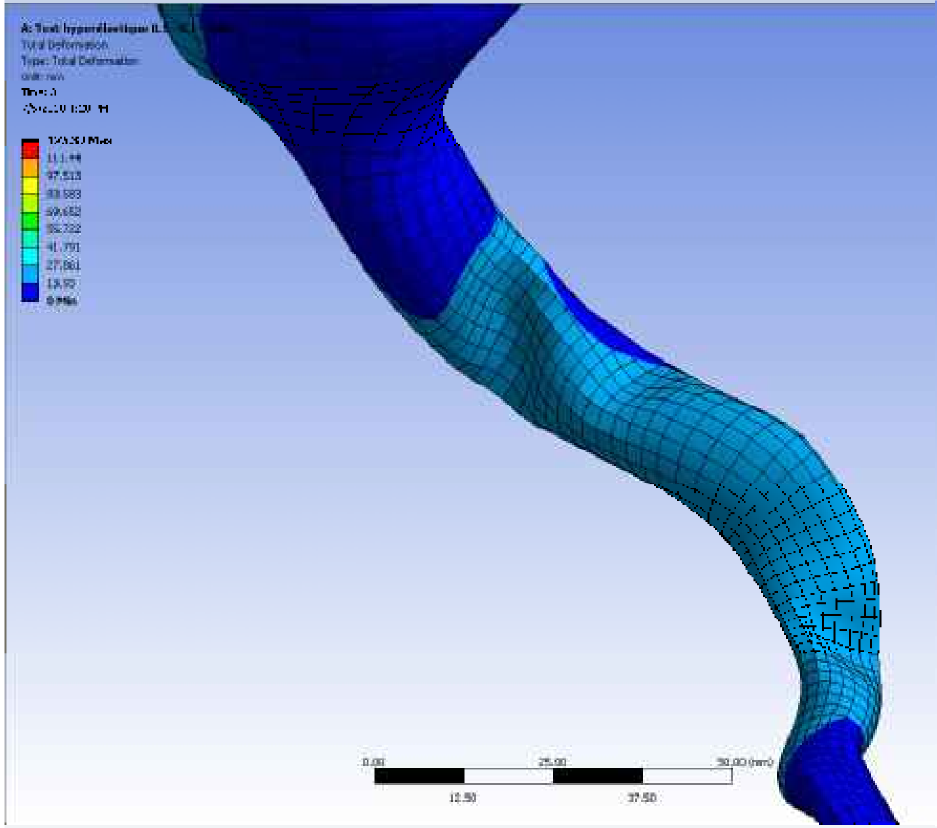


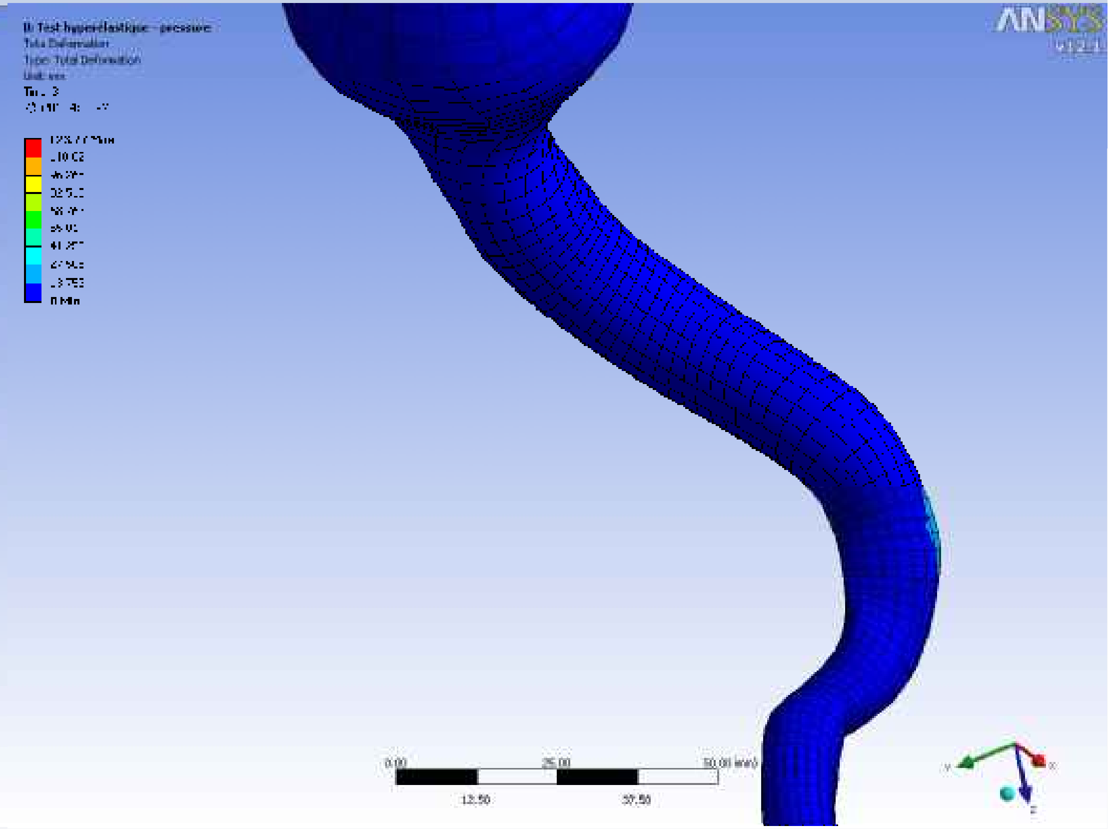
Comparison (Black (transient), Green (Direct))



Direct Final Position Simulation

Blood Pressure





Simulation without blood pressure

Simulation with blood pressure

Endovascular Simulation:

Its Value, its Future

Benefits of Endovascular Simulation

- **Clinical Applications**
  - Treatment Planning
    - All treatment steps can be simulated using patient specific data
    - Verification of stresses of the calcified artery parts during rigid guidewire insertion to control risk of rupture
  - Surgeon Training on Patient Data
    - Endovascular simulation as an education tool
    - Interactive computation of artery deformation, stent deployment, stresses on artery wall, reaction forces …
- **Industrial Applications**
  - Design and certification of endovascular tools
  - Virtual Experimentation and Virtual Planning
    - Targeting Smart Products and Product Integrity
    - Contribution to **V**irtual **H**uman **L**aboratory (VHL)

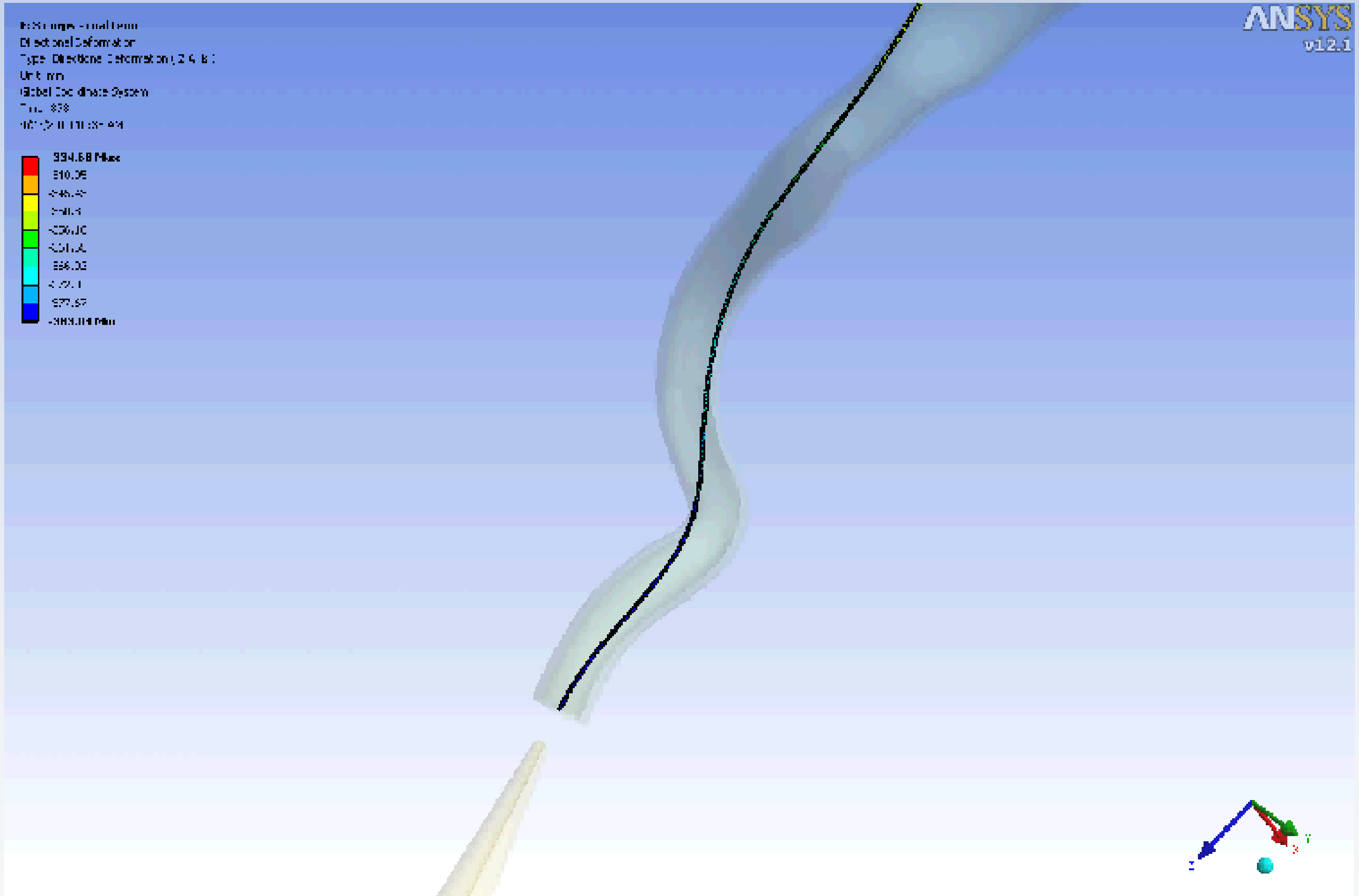
Conclusions & Next Steps

- **Automated process from patient specific data to personalized endovascular simulation**
  - Cohort of patients (20+) from our 2 hospitals (Rennes and Creteil)
  - Fully automated process with segmentation, boundary conditions, simulation and visualization of results
  - Simulation speed up and robustness
- **Fine tuning between endovascular simulation and per-operative patient data**
  - Second incidence angle for a full 3D verification
  - Validation on several patient data
- **Adoption and deployment of this solution amongst leading biomedical companies**

Acknowledgement

- **CIC-IT & HMN Hospitals**
- **Treatment of medical images:**
  - LTSI
  - Therenva
- **Material Properties:**
  - LAMCOS

Thank you



Insertion of medical devices along stiff wire