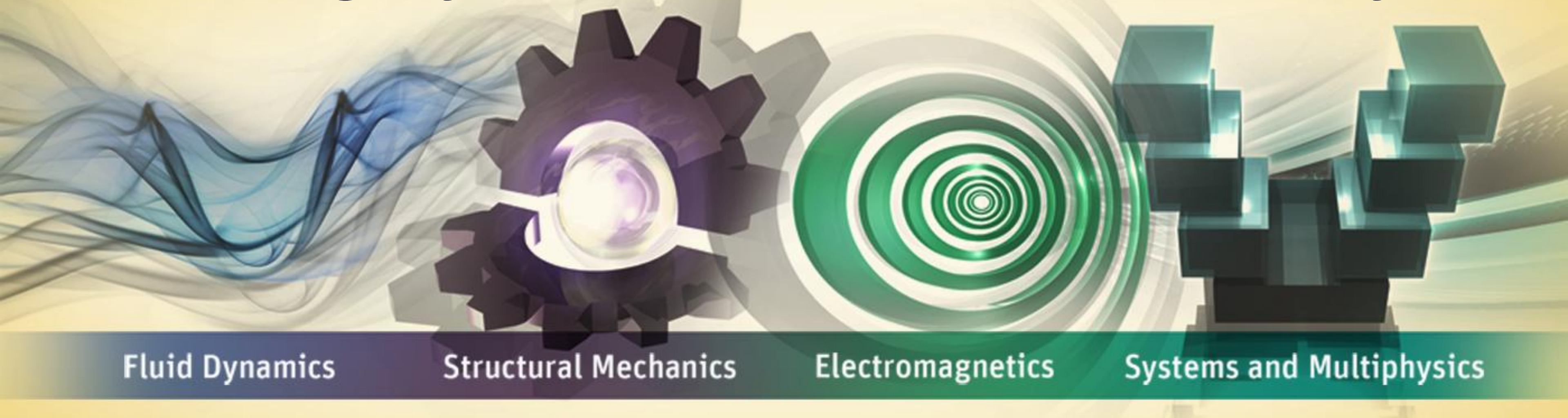
ANSYS

Realize Your Product Promise™

Predictive and patient-specific numerical simulations of endovascular surgery for aortic abdominal aneurysms

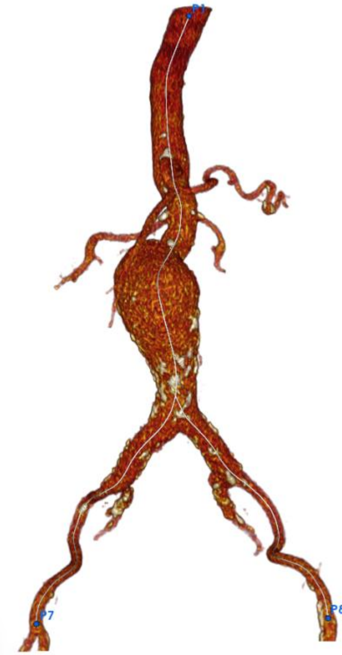


Michel Rochette

Our Partners

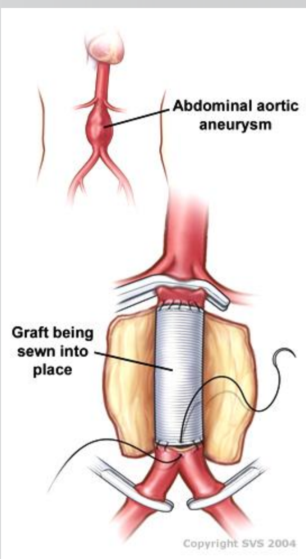
This work has been partially supported by French national research agency (ANR) through the TecSan program (project ANGIOVISION n°ANR-09-TECS-003)

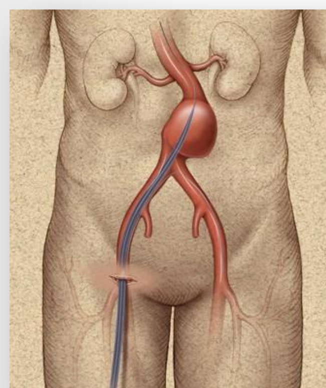
Abdominal aortic aneurysm repair

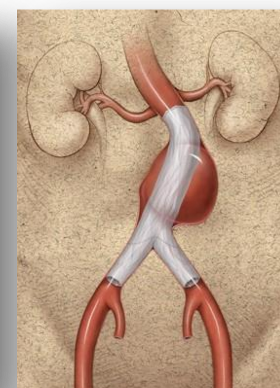


- **Definition : AAA = dilatation of the abdominal aorta**
- **Repair strategy if needed :**

Open surgical repair / Endovascular repair







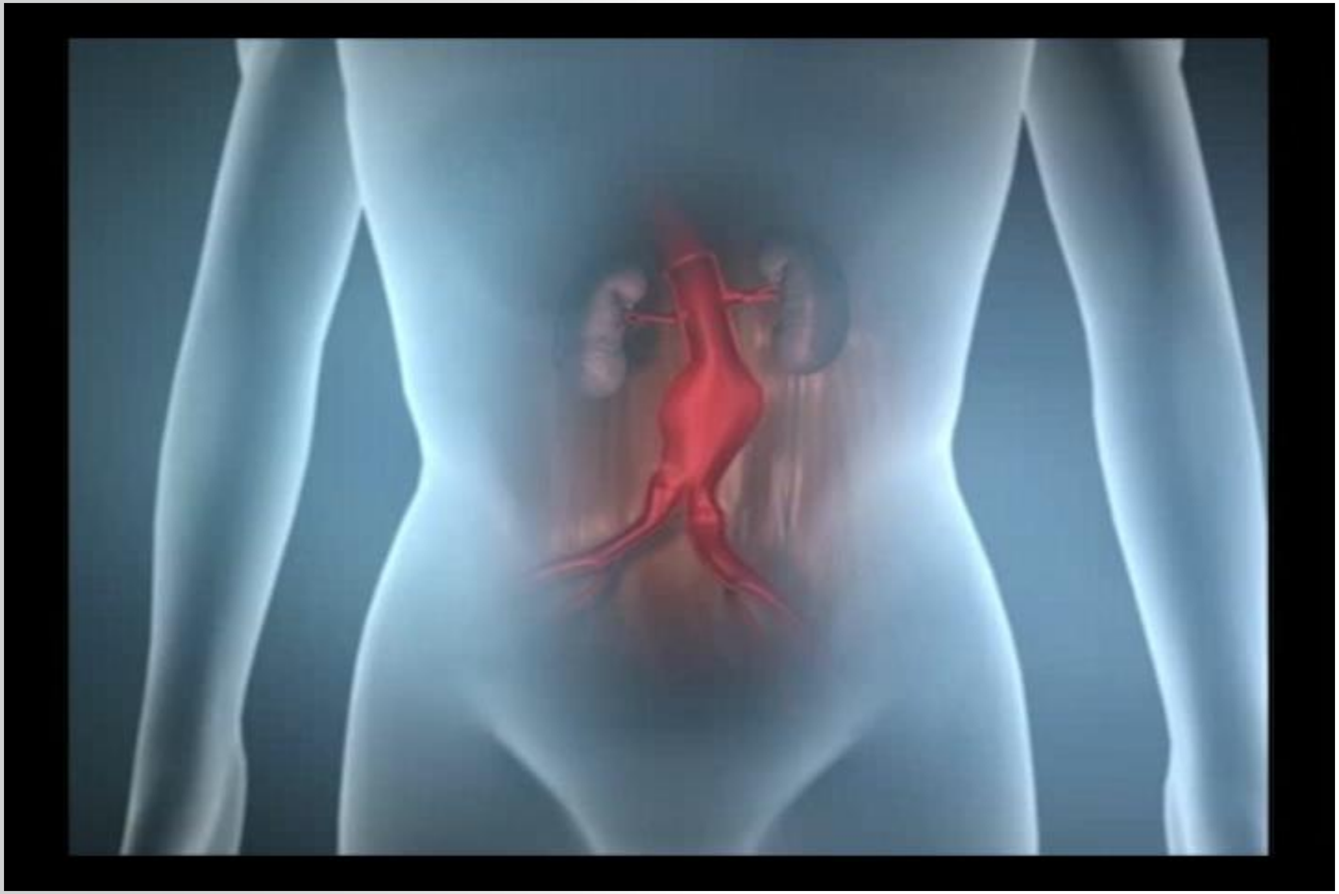
Abdominal aortic aneurysm repair

2010, Endovascular surgery :

- **80% procedures**
- **No direct access to the lesion**
- **Rx imaging interface**
- **Specific devices required**
- **Constantly changing devices (learning-curve issue)**

- **NEED FOR PLANNING & SIMULATION TOOLS**
    - **Engineering task ?**

Abdominal aortic aneurysm repair

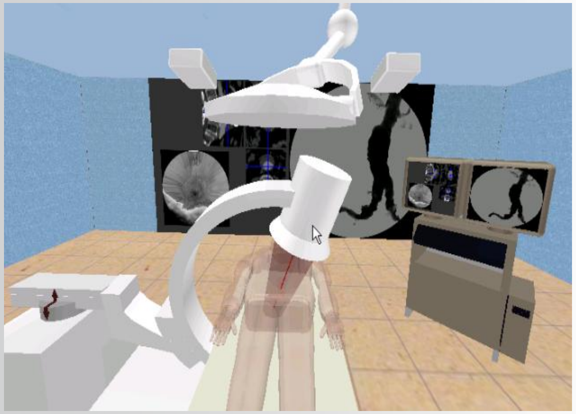


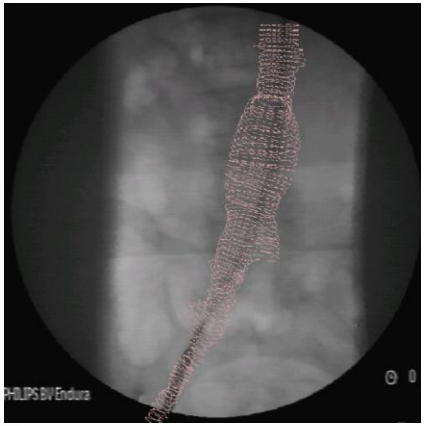
The intra-operative imaging paradox

- Pre-op CT scan => rich and precise information
- Intra-op fluoroscopy => poor but real-time

- How to enrich the intra-operative information?
- How to avoid positionning errors?

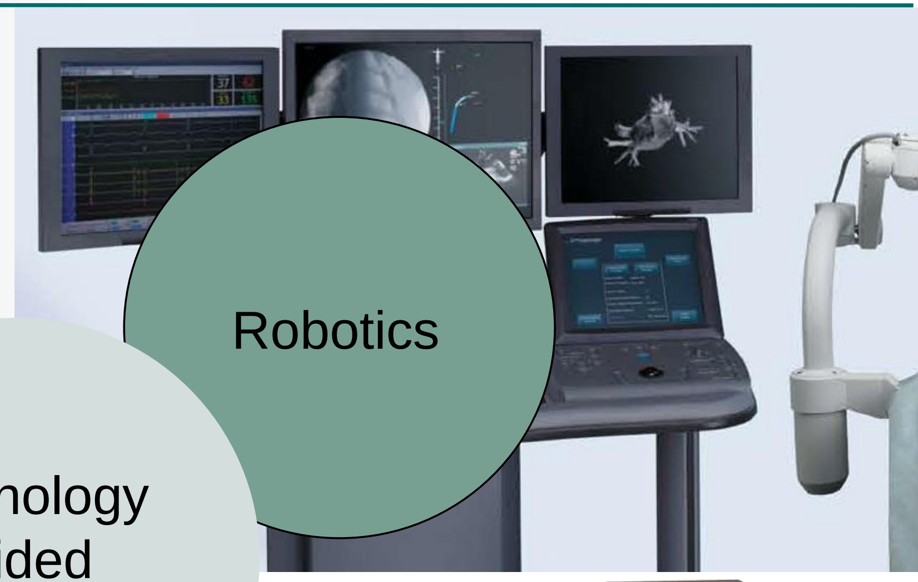
Augmented Reality (AR) = the art of merging heterogenous information

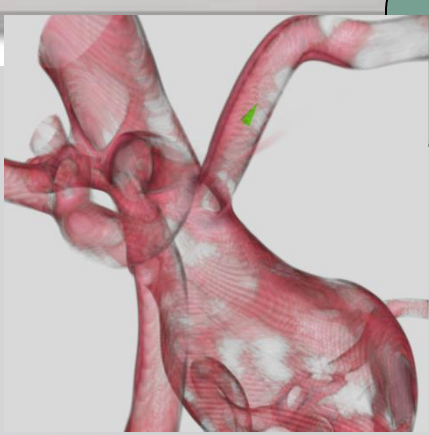




Challenge : Flexible devices within soft tissues

New technological landscapes





Medical Imaging

Robotics

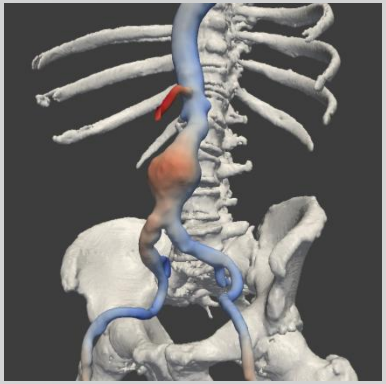
Technology Guided Surgery

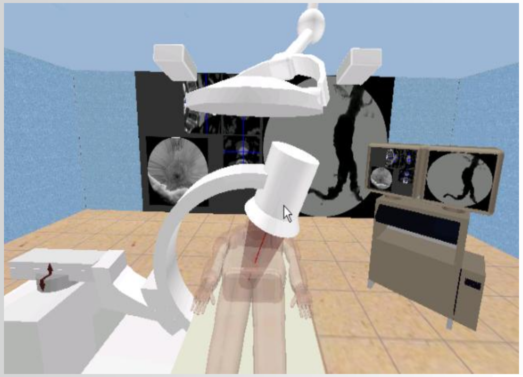
Micro-Technologies

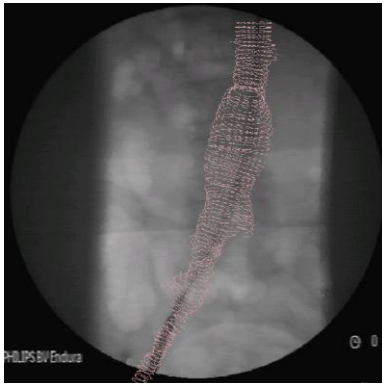
Computer Graphics & Modeling

Our approach

Three stages







CT Analysis and Sizing

Geometrical description, vessel wall information

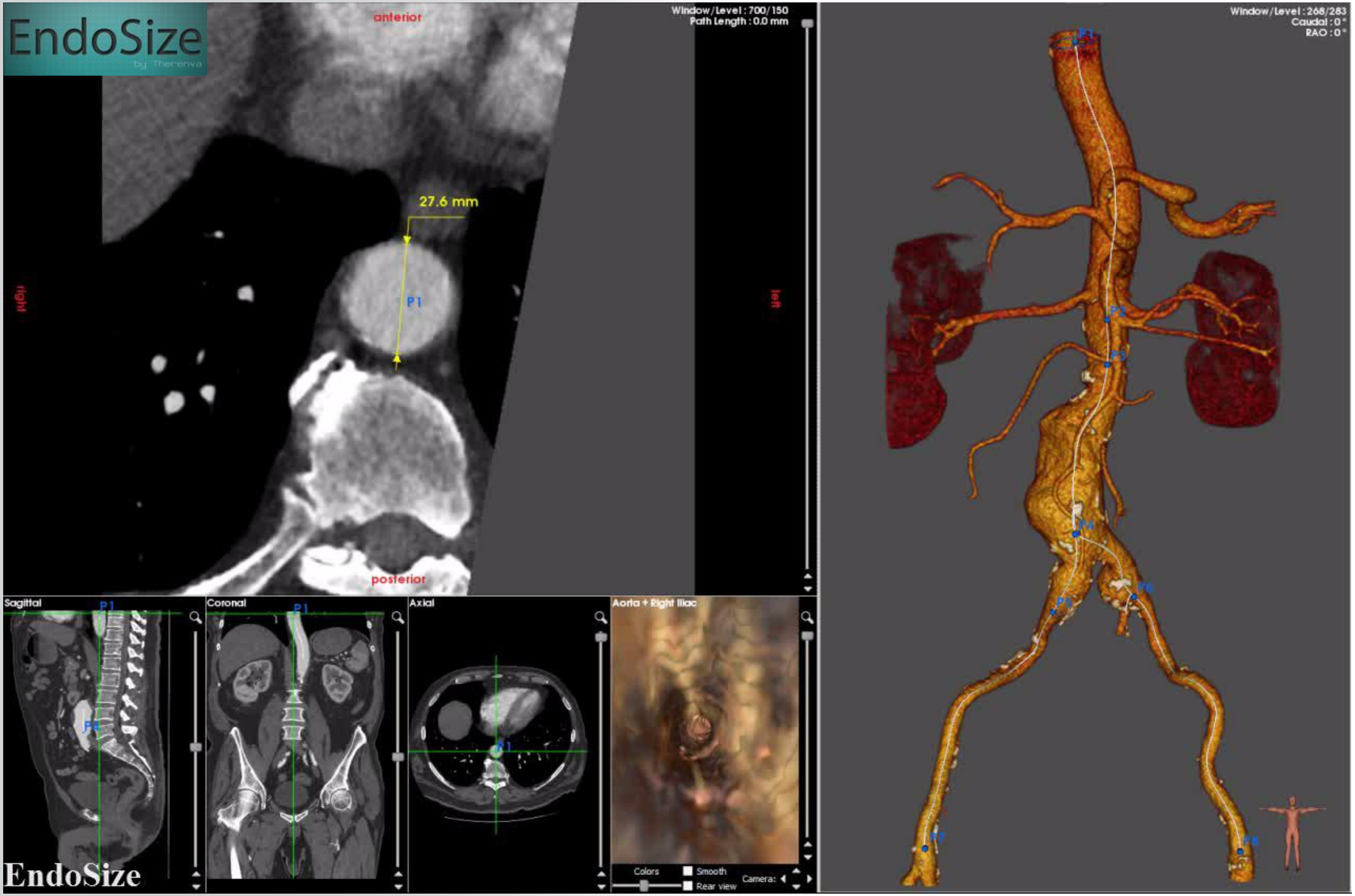
Planning

Simulation, deformation prediction, optimal device selection

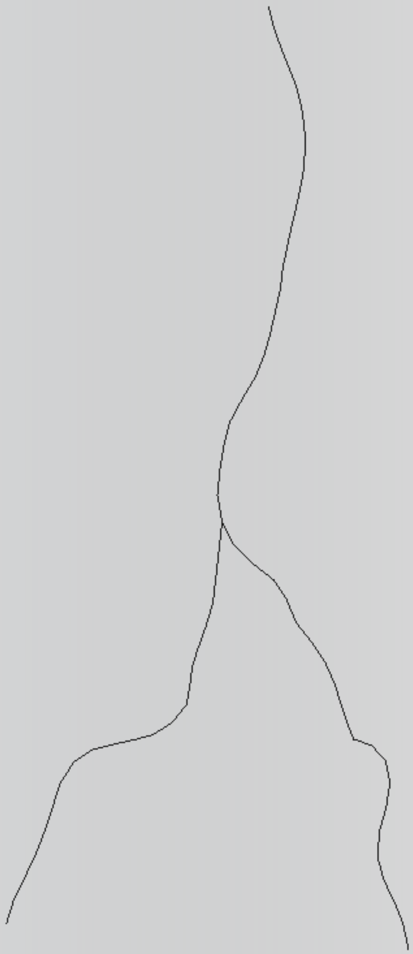
AR Guidance

3D device positioning control, data fusion

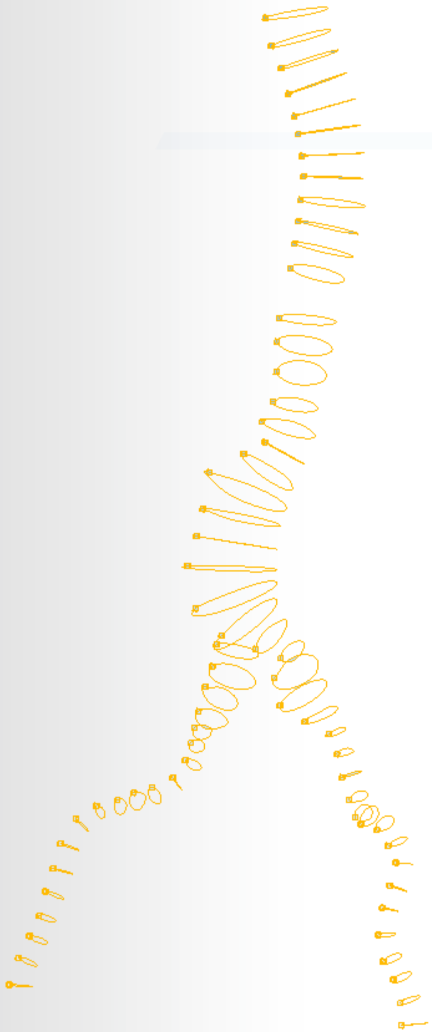
CT-scan data analysis with Endosize



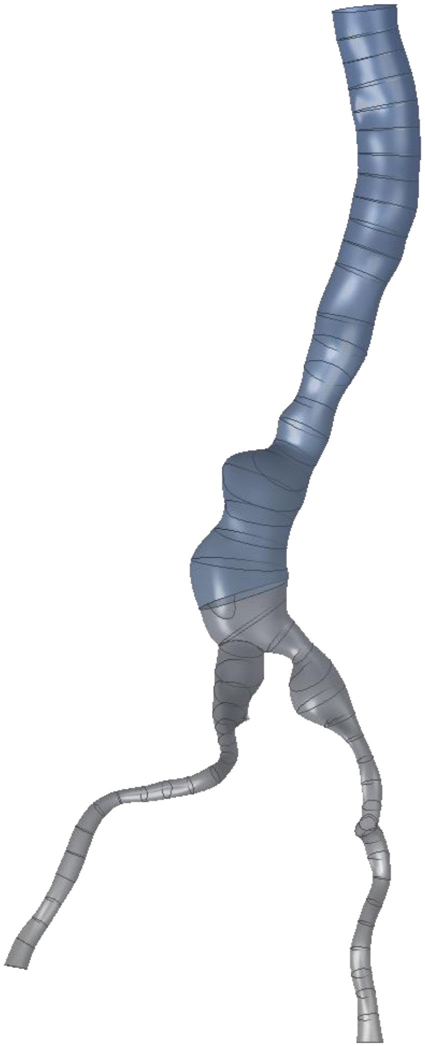
Automatic geometry reconstruction



- **Centerlines**

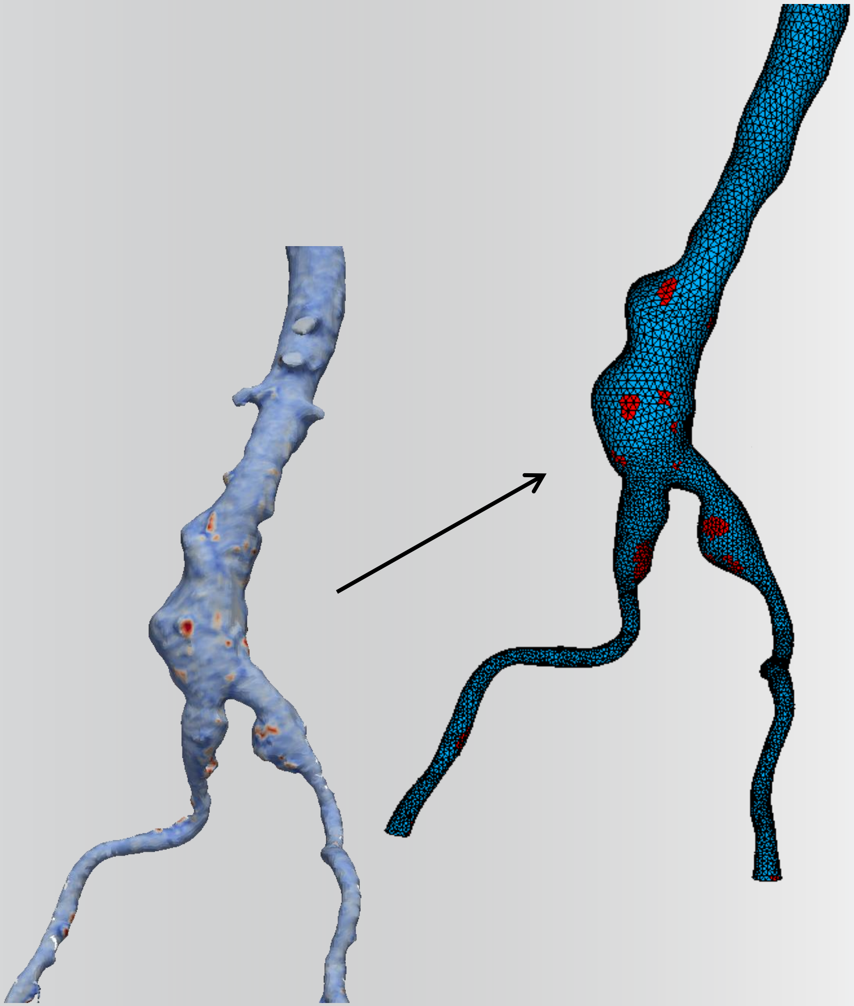


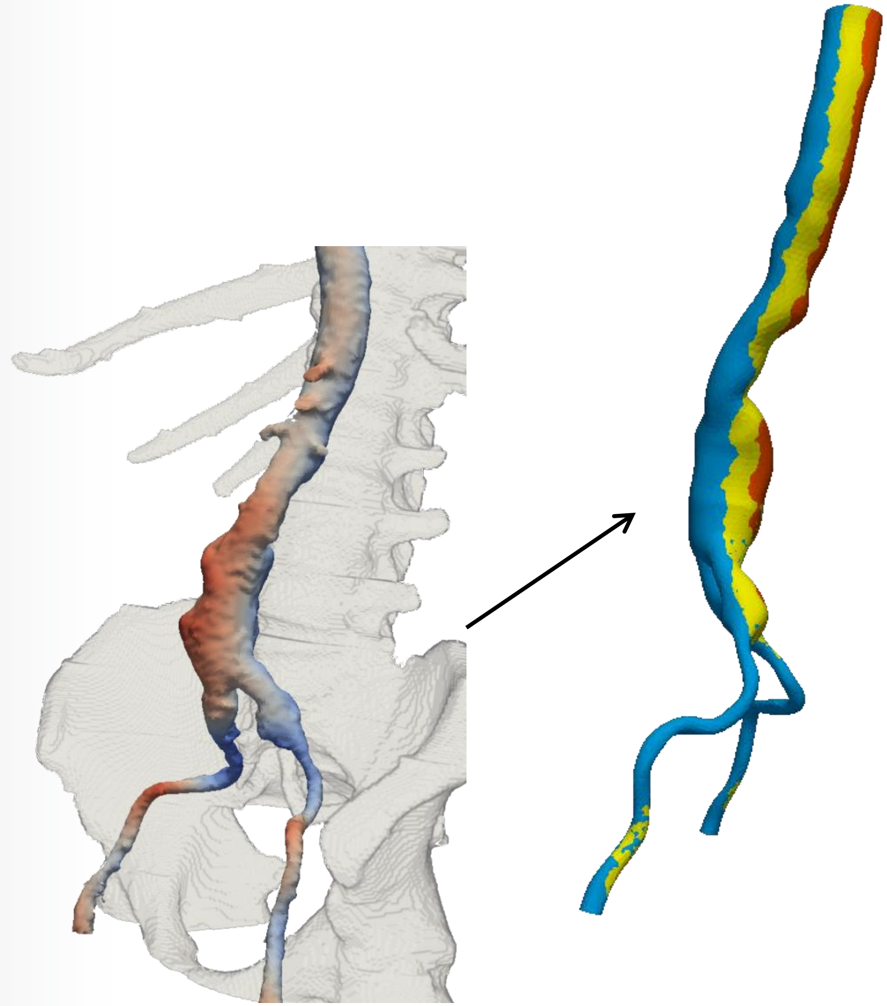
- **Contour splines**



- **Surface**

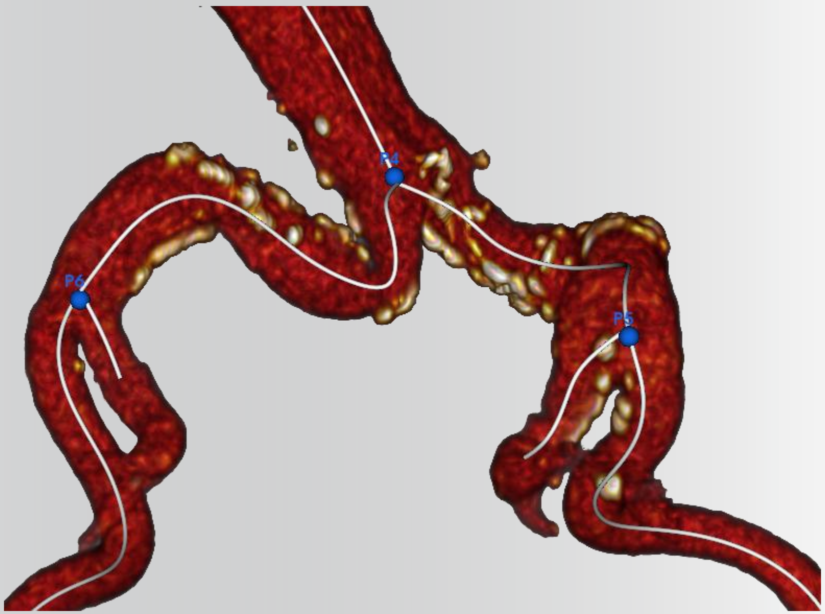
Extracting patient-specifc data for FE modeling





- **Vascular wall calcification level for material properties**
- **Artery-Spine distance for boundary conditions**

Extracting patient-specifc data for FE modeling



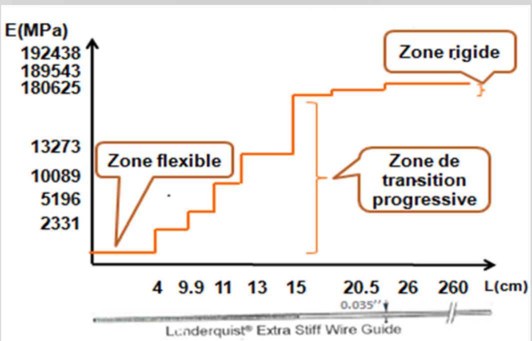
- Endosize centerlines

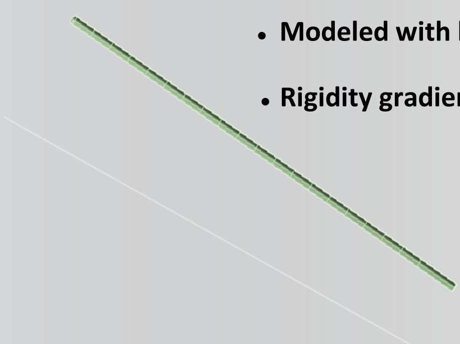
- Local additional elastic support

- **Collateral arteries support modeling**

Tools modeling

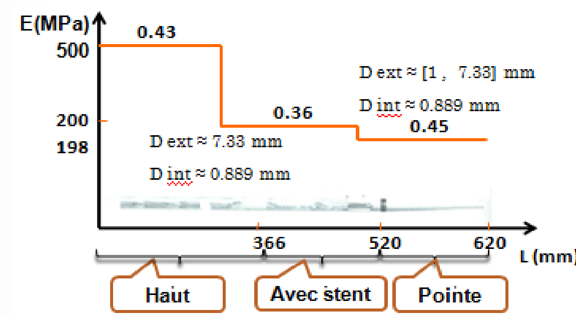
Lunderquist® Extra Stiff Wire Guide (Cook ®)



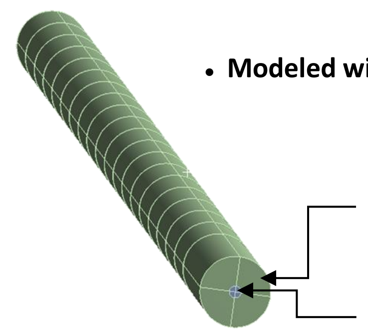


- Modeled with beam elements
- Rigidity gradient

Xcelerant hydro delivery system (Medtronic ®)



- Modeled with 3D solid elements



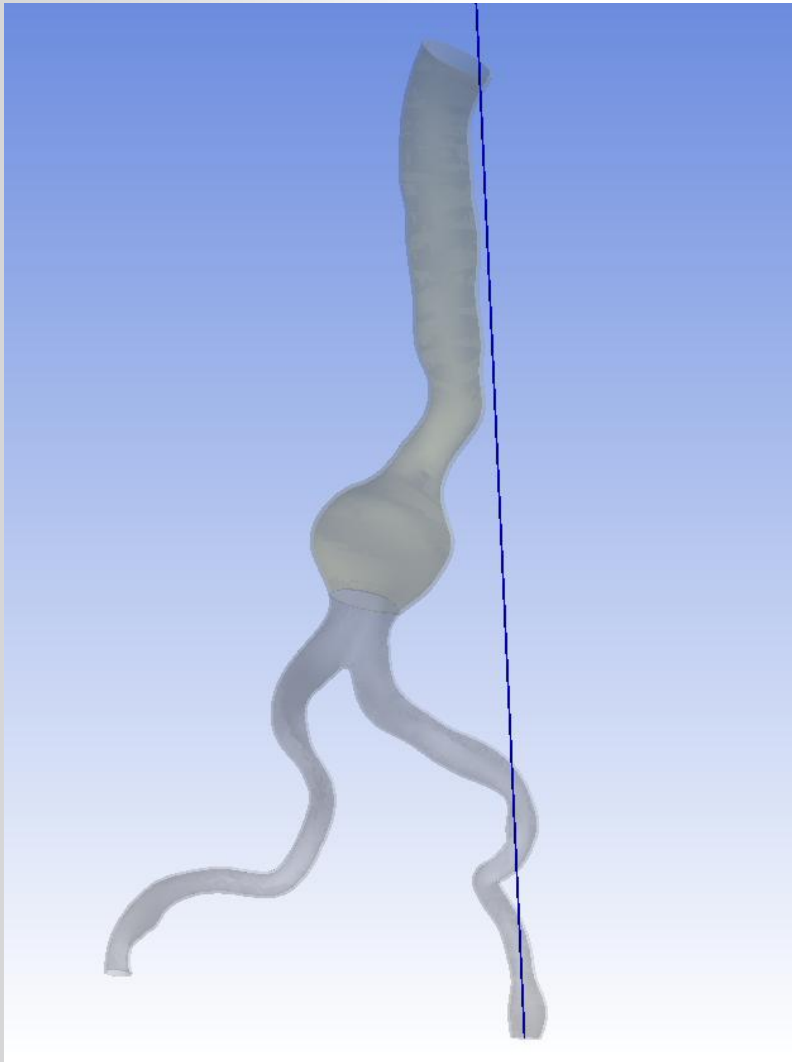
Therenva
Share medical innovation

Quick Implicit Solution

- First approach historically considered (Angiovision project, 2010 – 2011)
- Validated on 18 patients
- Strengths:
  - Quick results (Implicit method)
- Weaknesses
  - Lack of robustness for tortuous patients
  - Show the final results but not the navigation
- Applications
  - Numerous virtual prototyping of medical device
  - Preliminary validation on “standard” client
  - Design of Experiments

Implicit Modeling: Final equilibrium state computation

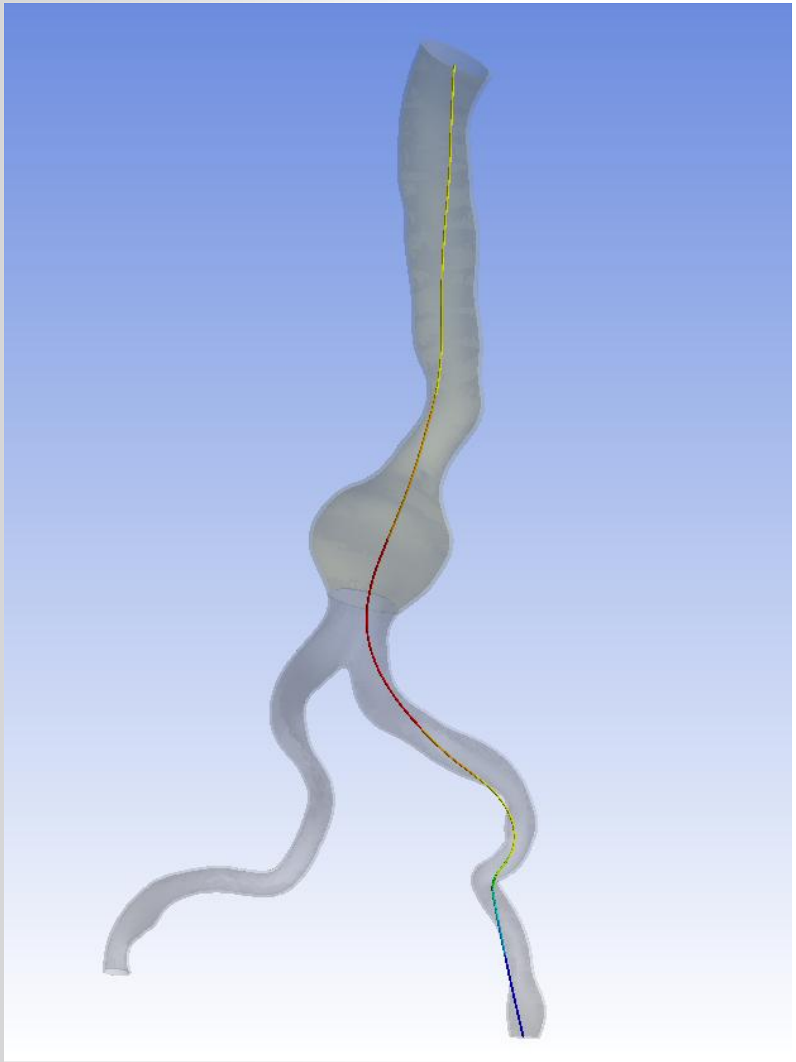
- **Initial state**



- **Guidewire simulation process**

Implicit Modeling: Final equilibrium state computation

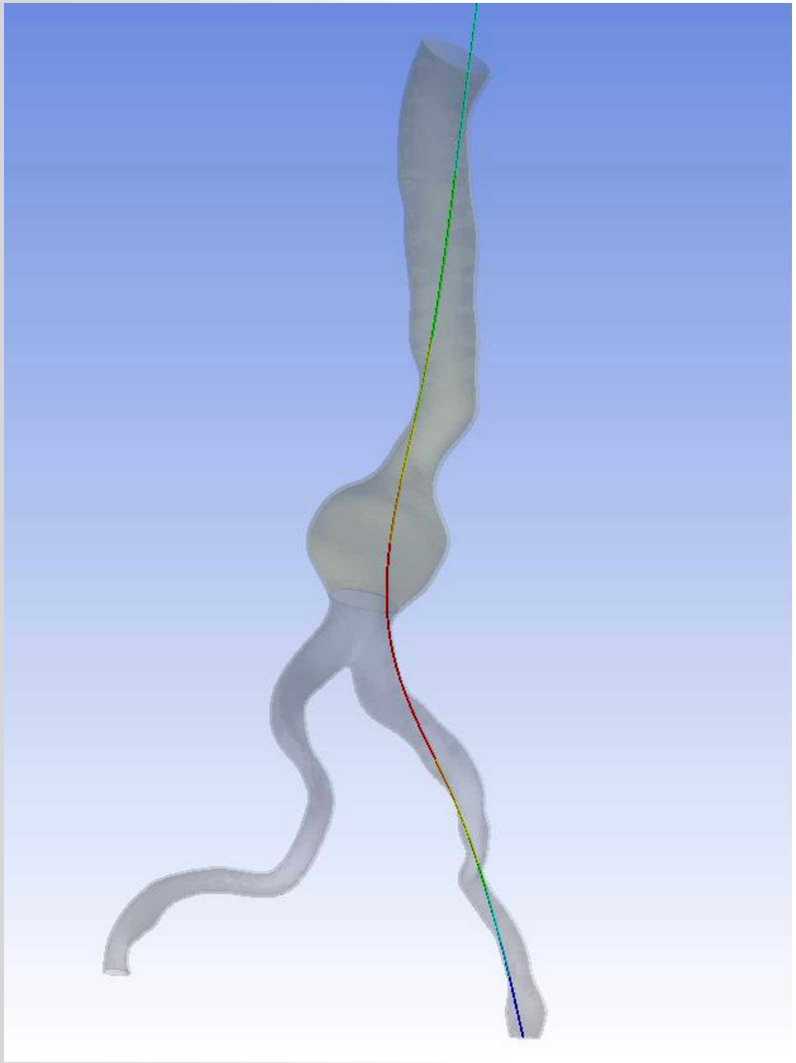
- **Guidewire initialization**
- **Contact activation**



- **Guidewire simulation process**

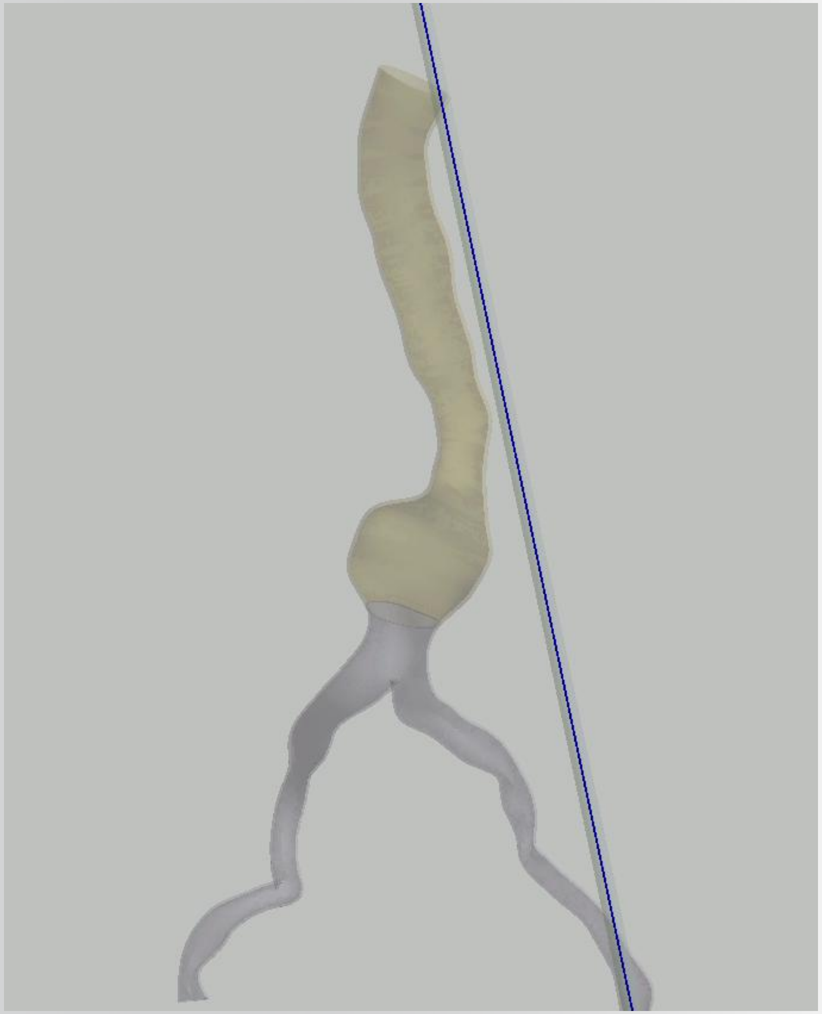
Implicit Modeling: Final equilibrium state computation

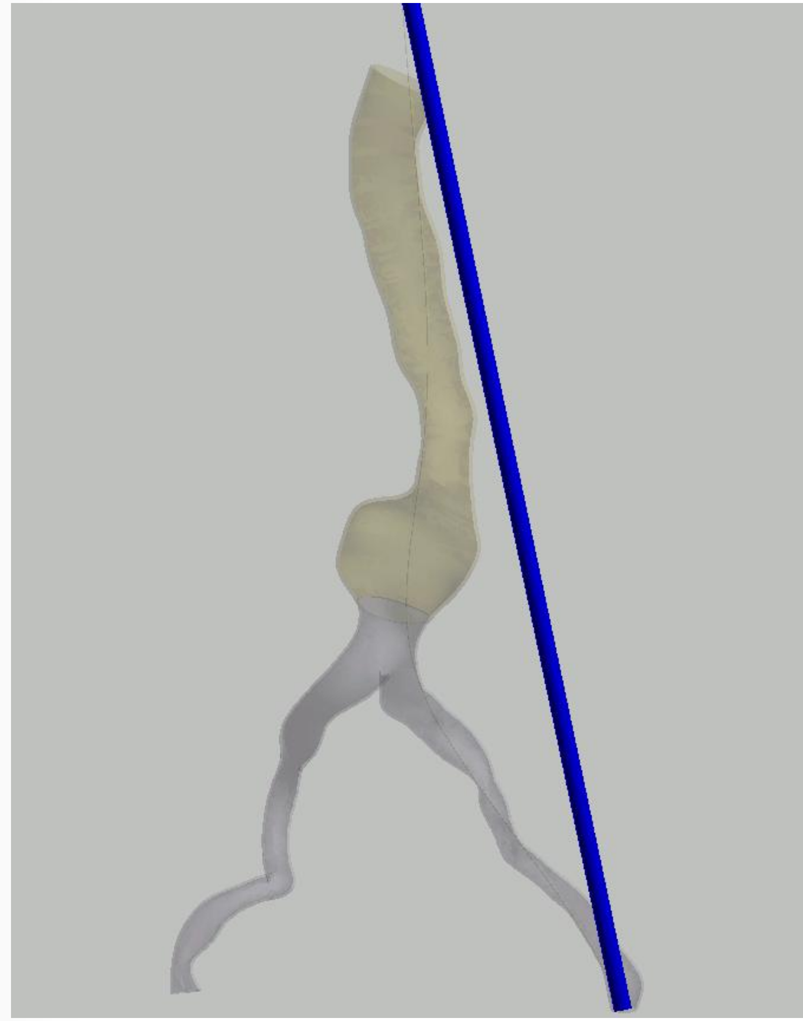
- **Guidewire relaxation**
- **Artery deformation**



- **Guidewire simulation process**

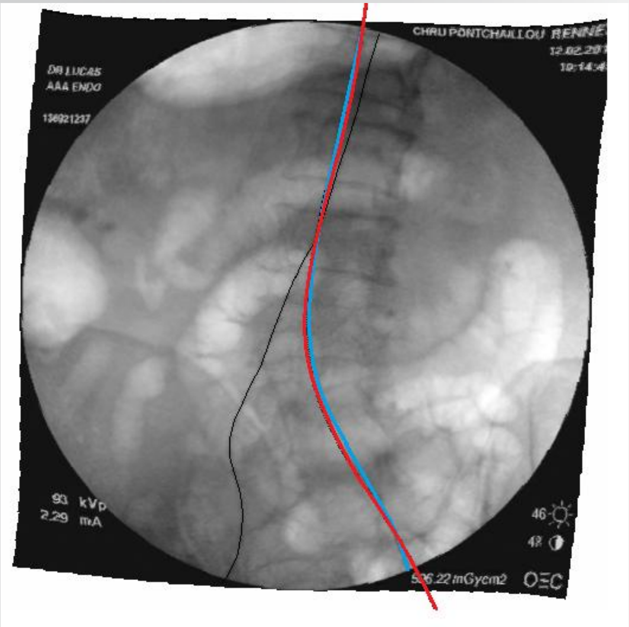
Implicit Modeling: Results

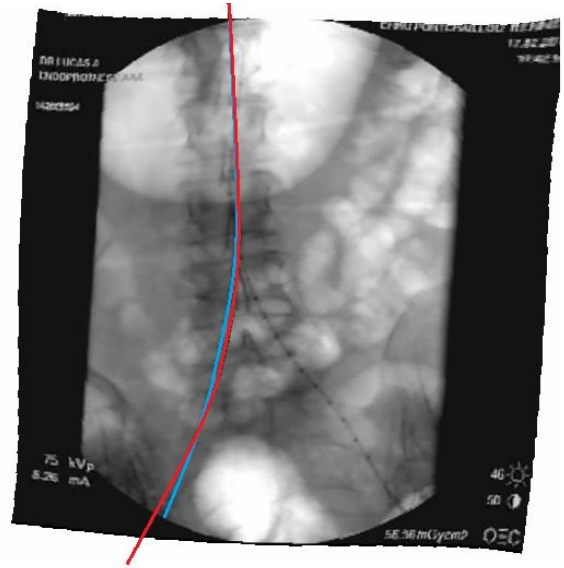




Implicit Modeling: Results

- Qualitative evaluation of simulation results based on comparison of real guidewire and simulation guidewire final positions





- Quantitative evaluation based on distance mapping between the two guidewires
  - Registration error
  - Simulation error : distance entre les deux guides

Implicit Modeling: Results

<u>Model parameterization</u>

- Step 1 : Model parametrization on a first group of patients. Independently for each patient

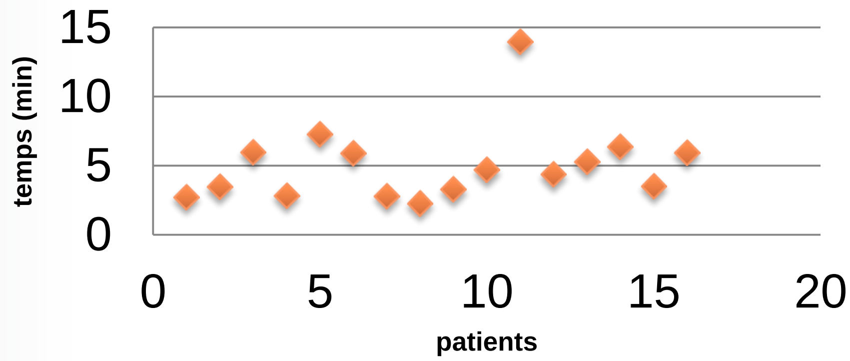
- Step 2 : Determination of laws to relate imaged-base patient-specific data to biomechanical data (polynomial regression)

  $\Rightarrow$ a single patient-specific parametrized model

- Step 3 : Evaluation of the model on a second group of patients

Implicit Modeling: Results

- **35 patient data sets**
  - Preoperative CT-scan
  - Intra-operative images
  - Post-operative CT-scan
- **18 simulations**
- **18 intraoperative comparison**



	Total (n=18)	Group A (n=10)	Group B (n=8)
Registration error (mean ± SD)	1.54 ± 0.45mm	1.61 ± 0.35mm	1.46 ± 0.39mm
Simulation error (including registration)	2.52 ± 0.91mm	2.32 ± 0.62mm	2.79 ± 0.58mm

- **Article published in TBME** :

Finite element-based matching of pre- and intra-operative data for image-guided endovascular aneurysm repair

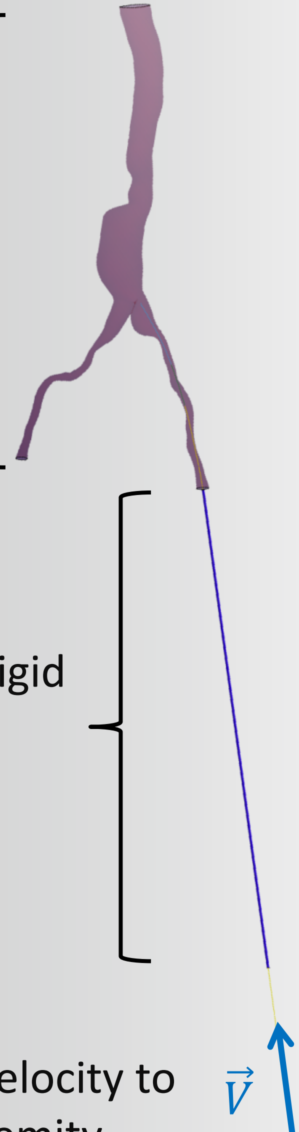
ANSYS

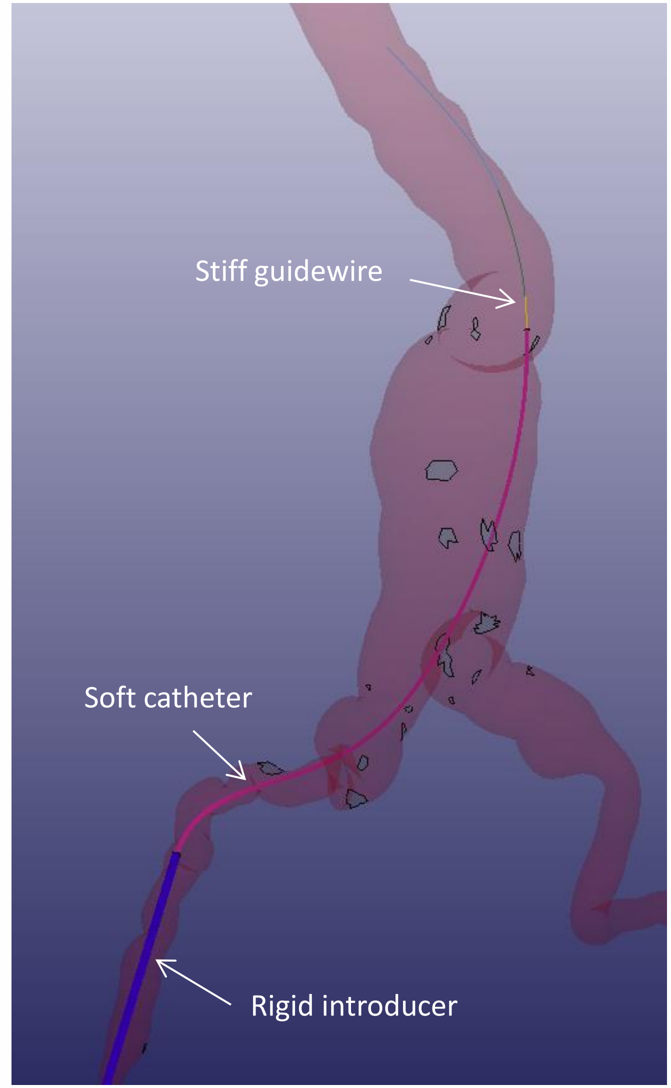
Detailed Explicit Modeling

- Second approach addressing the weaknesses of the implicit method
- Validated on 20+ patients
  - Including challenging cases of the implicit method
- Strengths:
  - Work on all patients (so far)
  - Illustrates the transient navigation process
- Weaknesses
  - Time consuming (few hours)
- Applications
  - Final validations, including tortuous case
  - Surgery planning
  - Surgery training

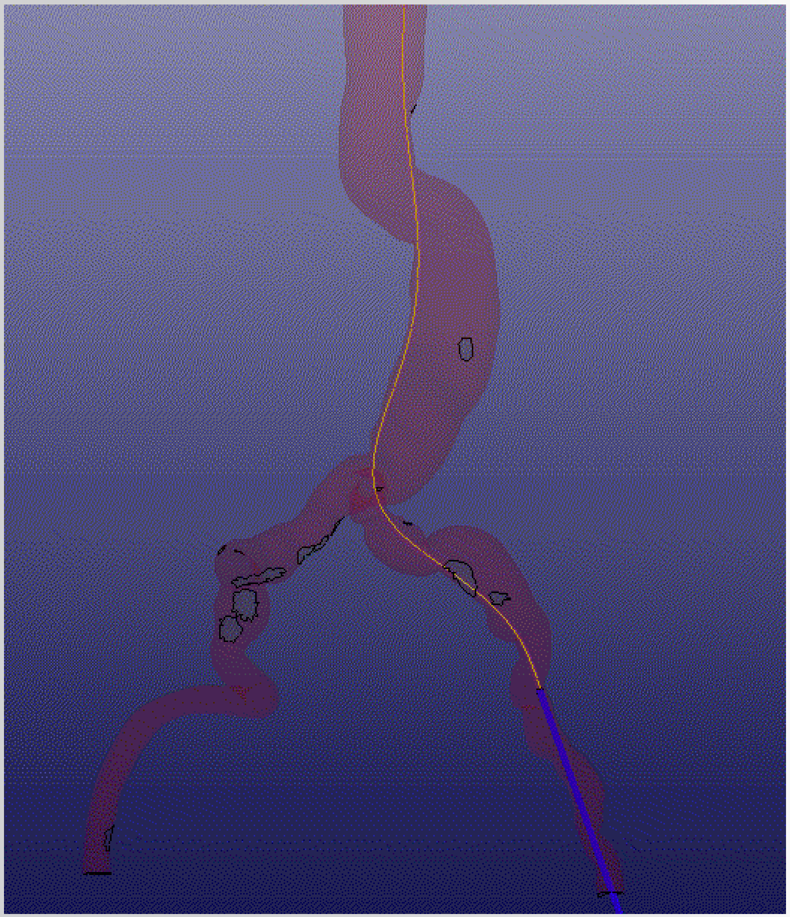
Explicit Modeling: progressive insertion modeling

- Inside artery: free + internal wall contact
- Outside artery: inside rigid tube (avoid buckling)
- Imposed velocity to lower extremity





Explicit Modeling: example of guidewire insertion simulation

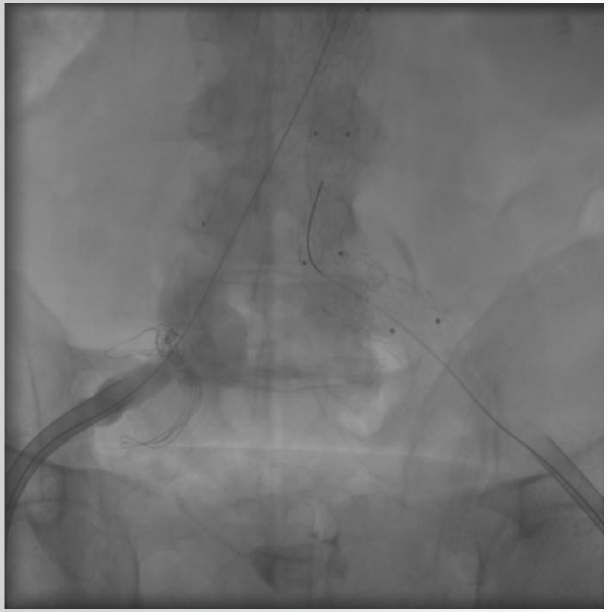


Explicit simulation

Intervention video capture

Qualitative comparison artery deformation

- Right



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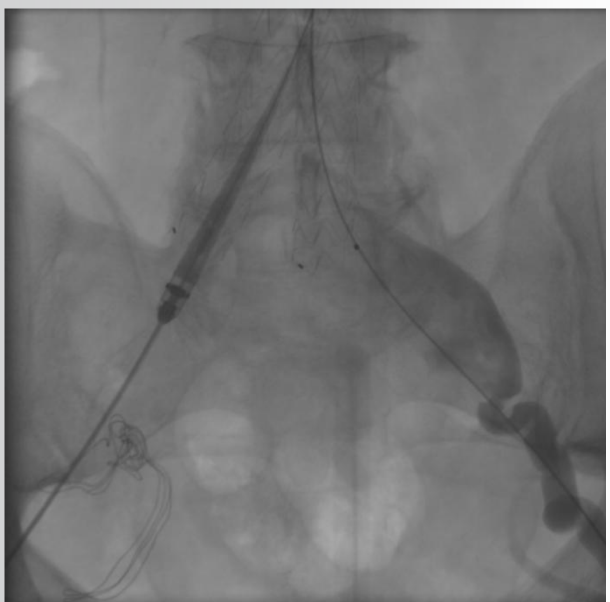
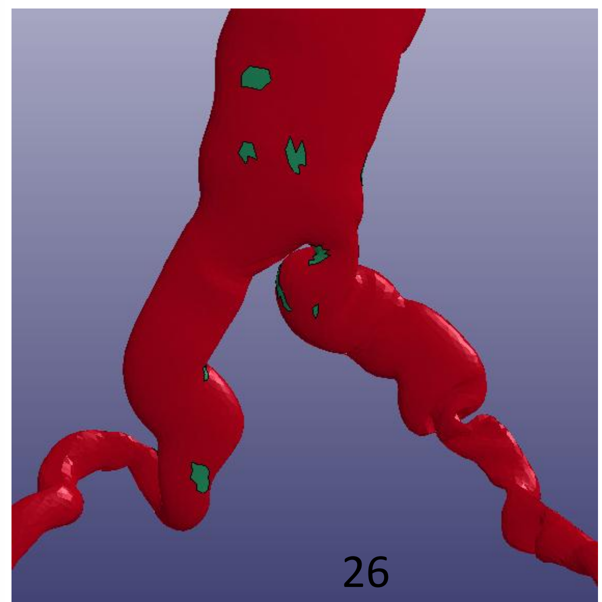




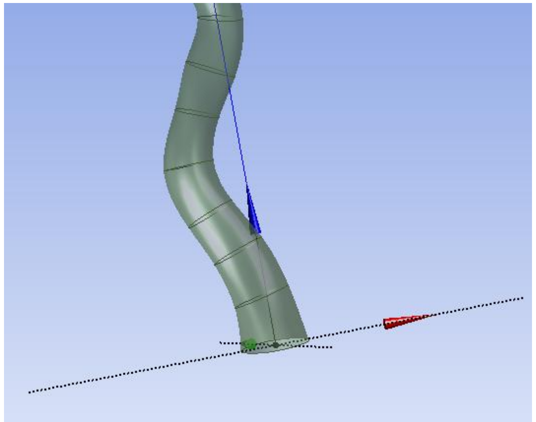
Explicit Modeling: Parameters tuning

- Patient-dependant parameters (that can be known in advance) :

  - Material properties
  - Artery external support
  - Collateral artery support
  - Arterial pressure

- Intervention-dependant parameters (that can not be known in advance) :

  - Tools angle and position of insertion



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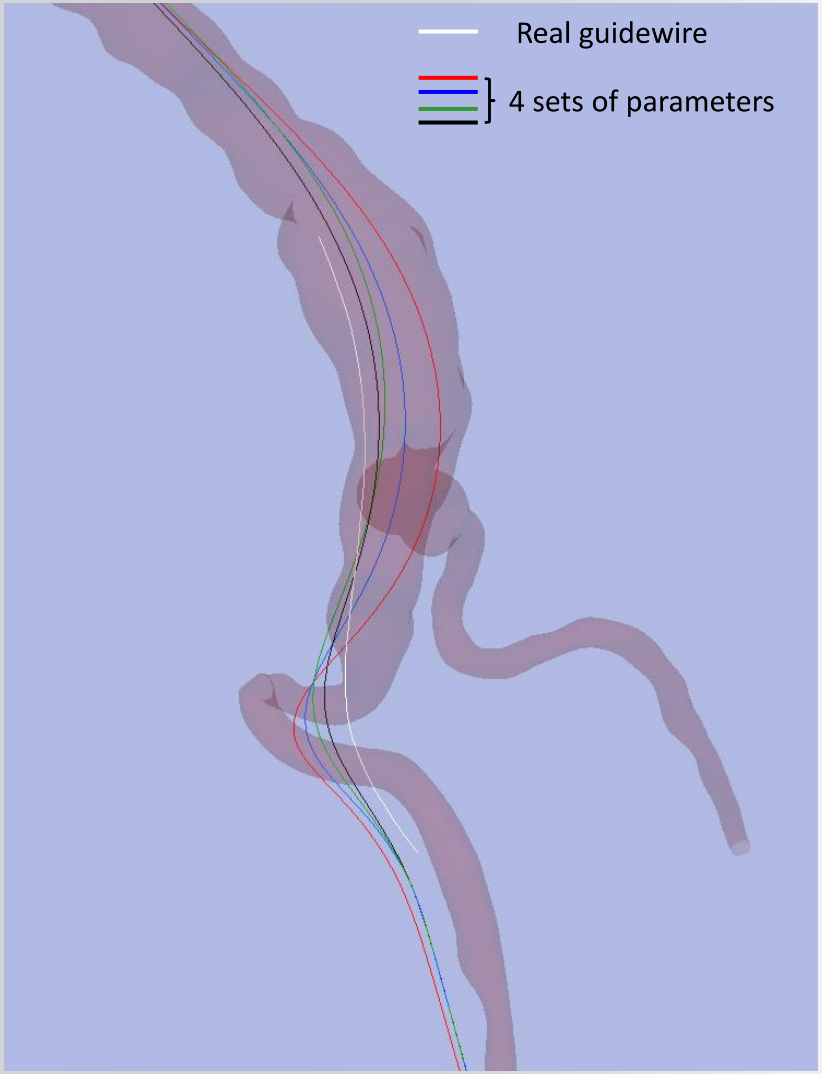
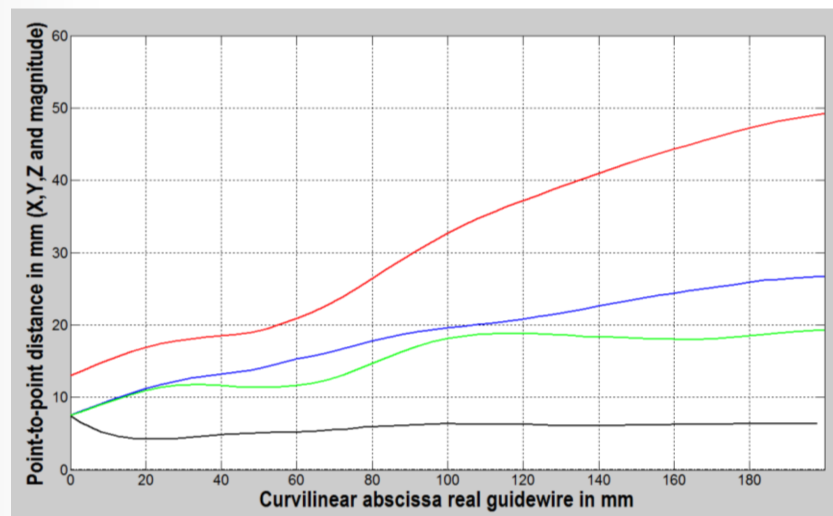
Explicit Modeling: Comparison to 3D data

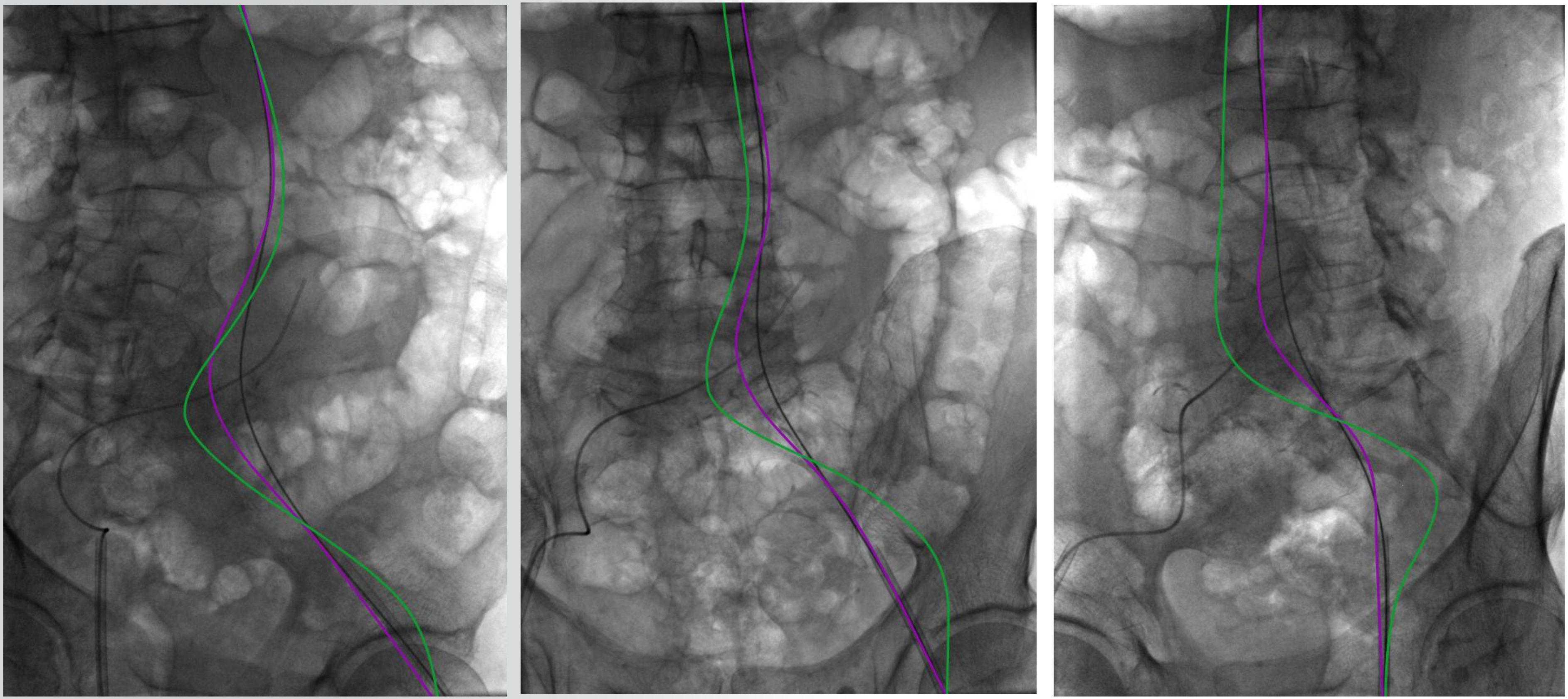




Comparison for 3 parameters sets

Point-to-point error magnitude

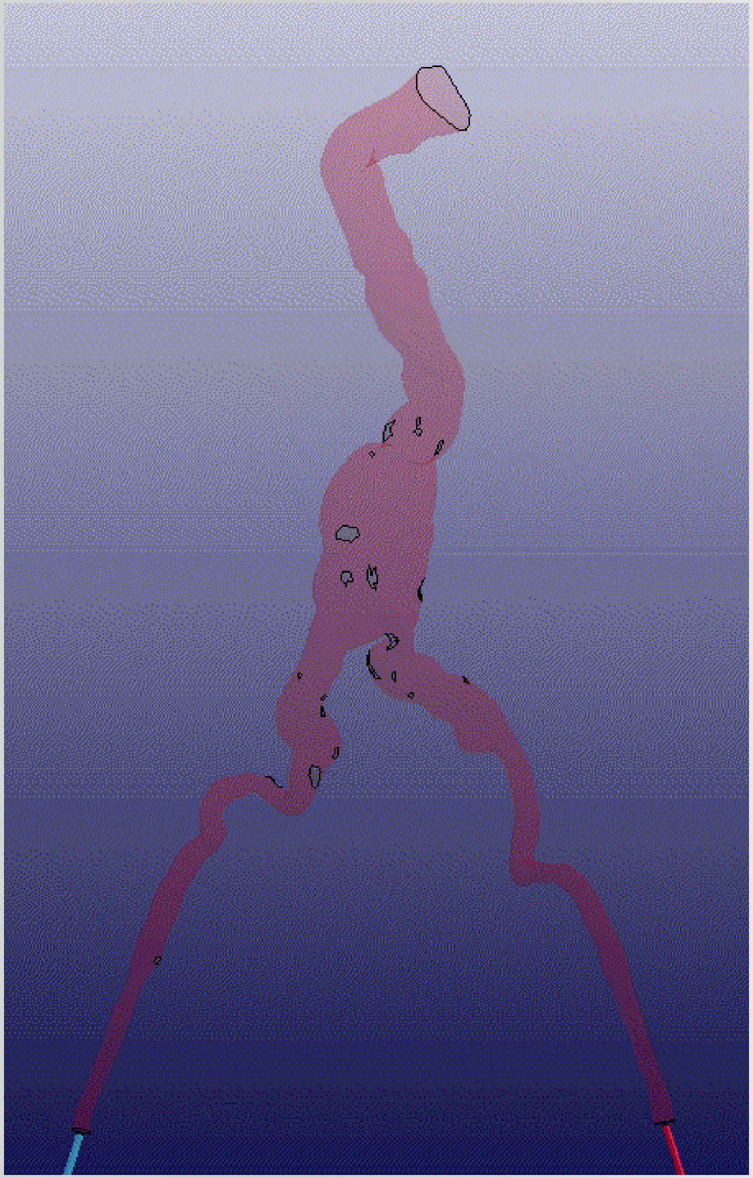
Explicit Modeling: Comparison to 2D data



30° LAO **Front** **30° RAO**

→ Example of simulation results for 2 sets of parameters

Challenging Navigation?



ANSYS in the operating room

"I don't understand why simulation is used so much in automotive and aeronautic applications and so little in the medical world, where we directly impact a patient's life. As surgeons, we are spending years to acquire enough know-how and experience to learn how to react quickly when the patient is lying on the operating table; but simulation is giving us the luxury to examine the situation when we still have plenty of time to think through more quietly. I trust that simulation will be used increasingly in the clinical world in the near future."

Dr. Antoine Lucas
Cardiovascular Surgeon
University Hospital of Rennes

ANSYS

Upcoming Planning Tools

Therenva

- **EVAR applications** **EndoSize *Sim+***
  - **An accurate tool for stent sizing taking into account the artery deformation induced by endovascular devices**
  - **Endovascular simulation results to make surgery safer.**
    - Using endovascular simulation validated on a population of patients, clinicians will get access to virtual but reliable post-implantation 3D image during the surgery planning phase
  - **Identify difficult cases (e.g. excessively calcified arteries), where endovascular surgery is challenging, early in the surgery planning process and test alternative solutions**
- **EVAR – TEVAR - TAVI applications**
  - **Femoral access simulation taking into account tortuosity and calcifications of iliac arteries**

