8th World Congress of Biomechanics
8-12 July 2018
Dublin, Ireland

Biomechanical modeling of endovascular aortic aneurysm repair: transfer towards clinical practice

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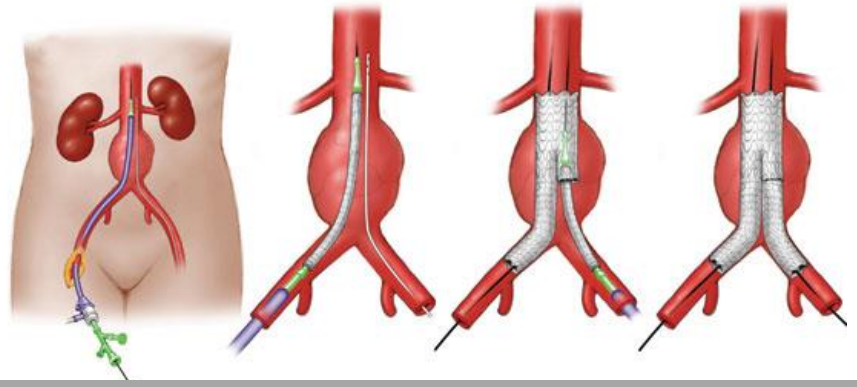
Medical context

Aortic aneurysm:

- ✓ Dilatation of the aorta which can *lead to death*
- ✓ Affects *5 to 10%* of men aged 65+
- ✓ Most common treatment: *endovascular repair* (deployment of a stent-graft within patient's aorta)



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Medical context

- ✓ Time to design and manufacture customized stent-graft
  > 2 months ➔ Possible patient's ***death before intervention***

- ✓ High complexity of the intervention
  ≥ 6h ➔ ***Radiations exposure*** **+ Risk of** ***complications***

- ✓ Post-operative complications
  15 % ➔ ***Secondary intervention***
  2 to 7% ➔ ***Death***

Risks for patient's health
+ Complex intervention for the physician
+ High costs for the hospitals

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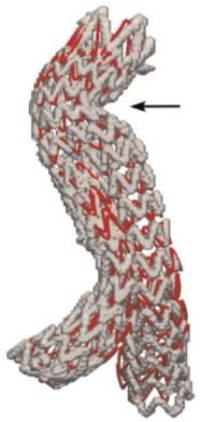
Our technology

Numerical simulation of endovascular devices insertion

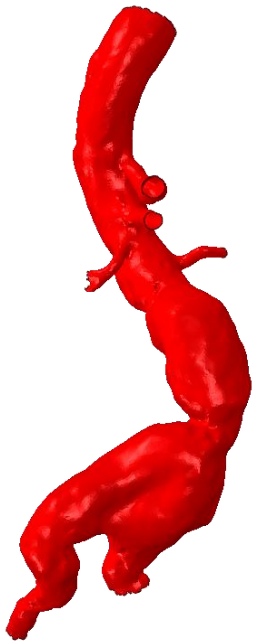


Predictive

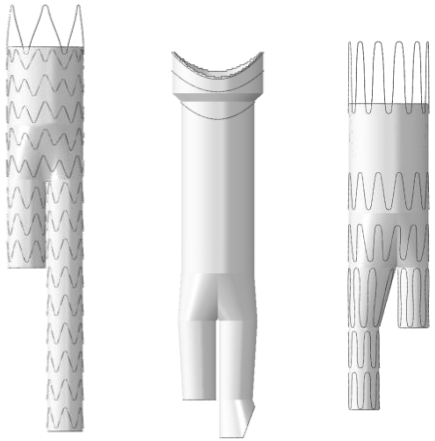
50 clinical cases

Infra-renal, complex supra-renal aortic aneurysms

Robust



Patient-specific



Device-specific

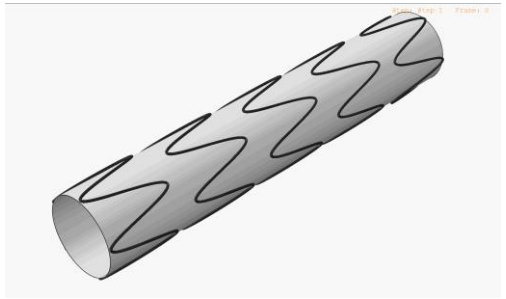
24h delivery

Cost-effective

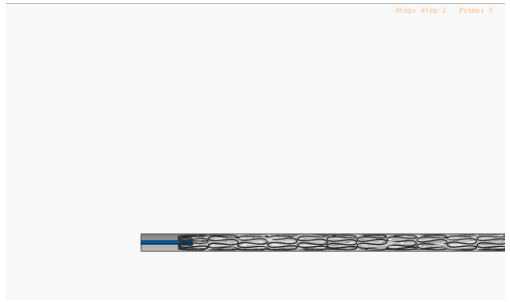
Efficient

Our technology

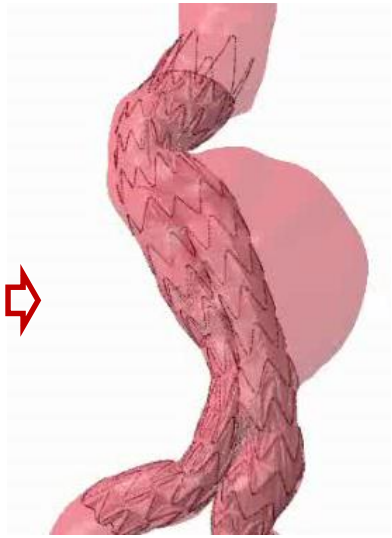
Research: from basic models to clinically relevant simulations



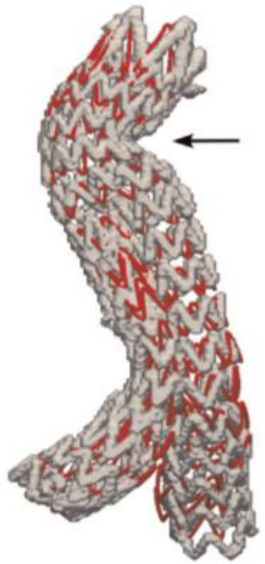
Stent-graft modelling



Generic simulation of stent-graft deployment



Patient-specific simulations



Simulation validation and assessment

Red: simulation
Grey: postoperative scan

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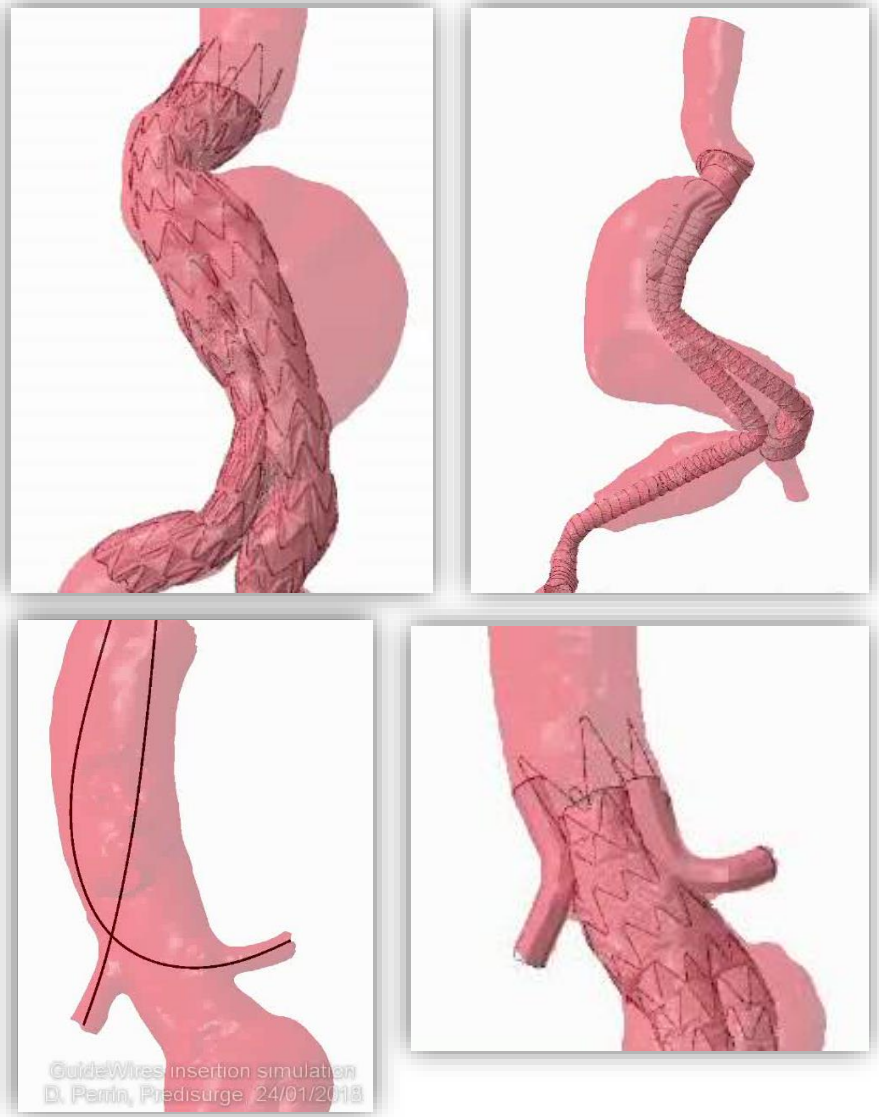
Our technology

- 2 academic theses
- 6 publications
- Patented technology
- 100+ clinical cases
- Very high interest from physicians



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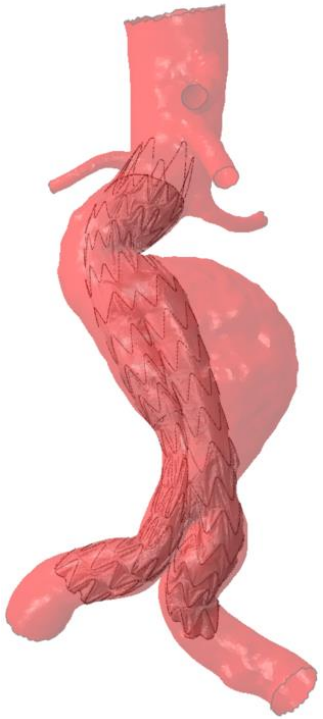
Applications

EVAR Preoperative planning

- Complex cases virtual rehearsal
- Anticipating operative difficulties
- Support to strategy and stent-graft (SG) choices



EVAR interventions

- 3D visualisation
- Less X-rays and contrast product dose
- Faster and secured interventions

Support to new SG designs

- Digital prototyping
- Numerical clinical studies on real anatomies database
- Analysis of potential SG failures

Digital predictive solutions for medical device interventions

bpifrance

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Software solutions assisted by numerical simulation

Optimize design, preoperative planning and implantation of medical devices

ompany founded in May 2017

- Primary focus on endovascular repair (EVAR)
- Backed-up by:
  - **10 years** academic research
  - Aortic Biomechanics Research Center
    - **25** full-time researchers and students
  - Regional Aortic Unit
    - **300 standard** and **70 complex** EVAR per year

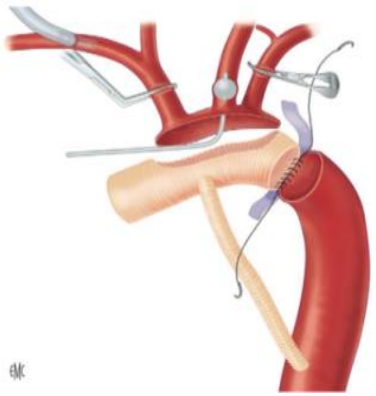
Recent extensions to TEVAR

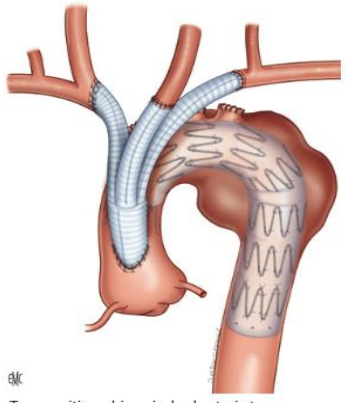
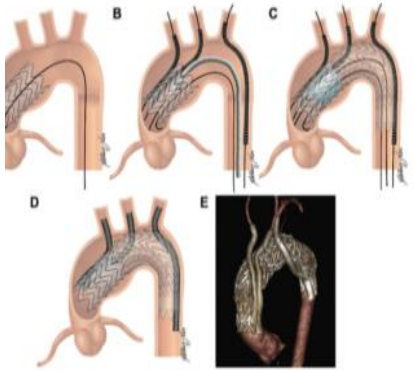
Pathologies of the aortic arch (aneurysm, dissection…)
Rare condition but high risk of mortality

Various treatment options
Complex operative procedure with significant morbidity and mortality rates
30-day mortality: until 15% Stroke: about 10%

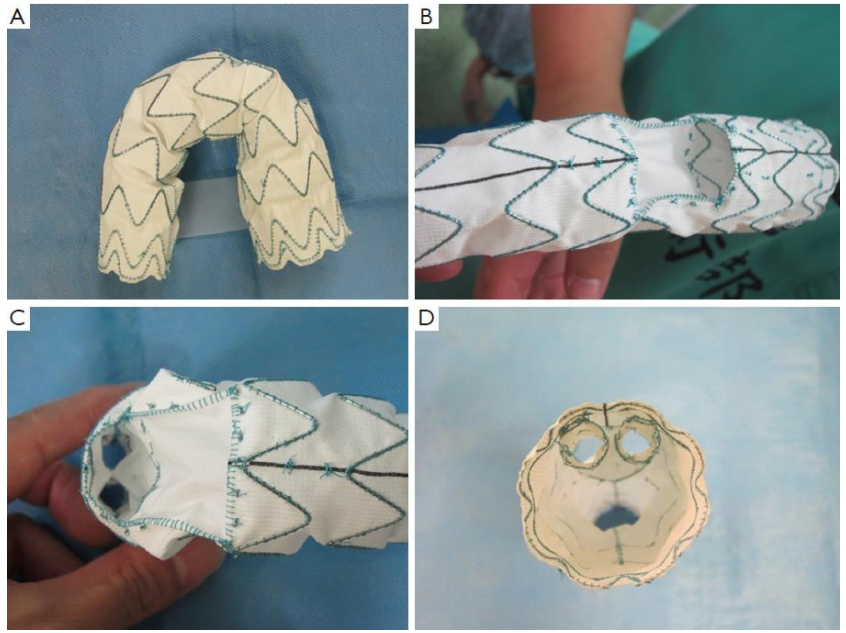
Erbel R et al. 2014
Maurel B et al. 2015
Cao P et al. 2012
Tian DH et al 2013

A significant proportion of patient population = high-risk patients deemed unfit for open surgery



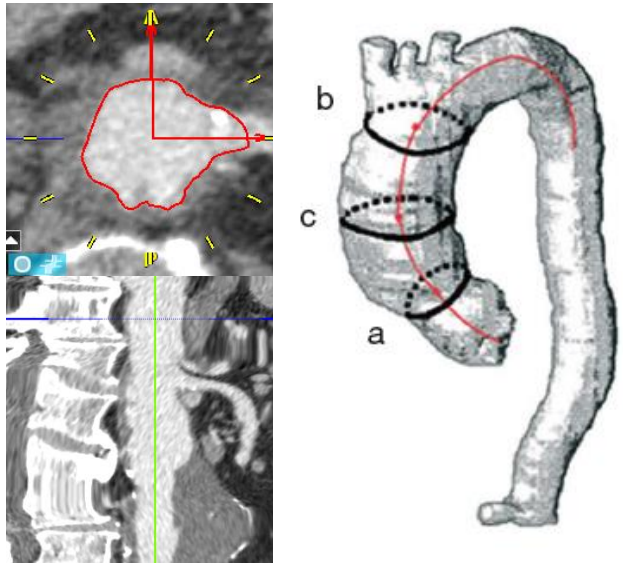
Various options: arch branched devices



Double Branch endograft Bolton Relay®

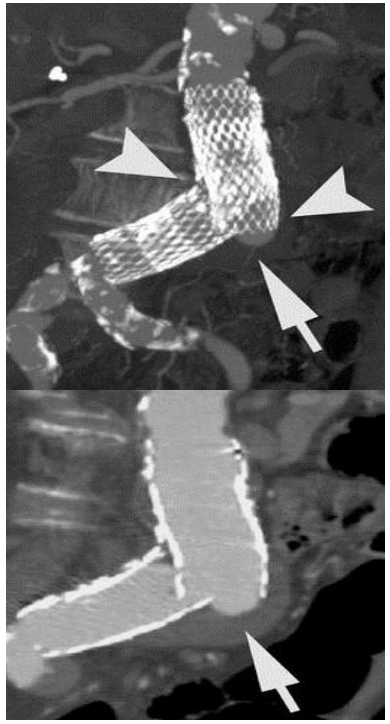
Custom-made device

TEVAR challenges



Custom-made device
Measures on preop CT

Device alignment
Secure device



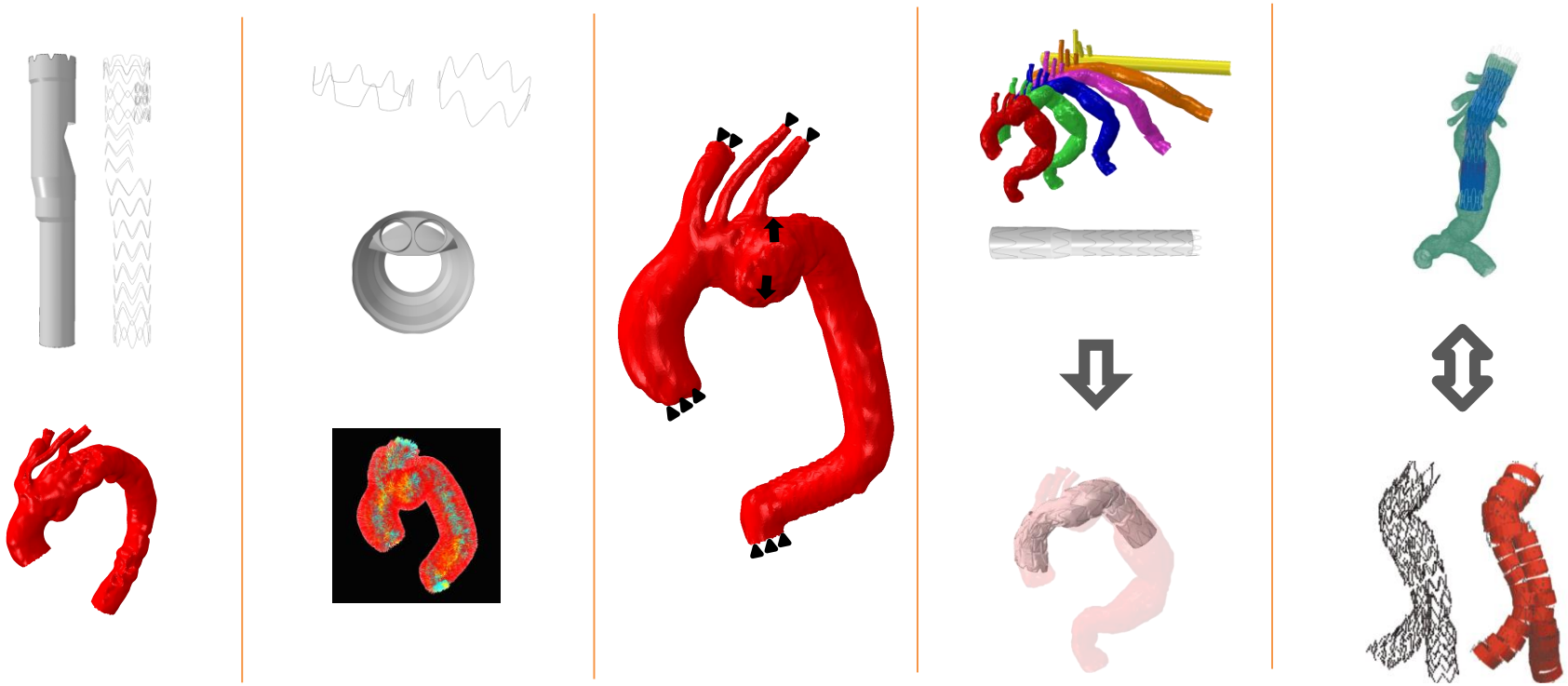
Device durability
New set of physiological loads

Tools are needed for planning to help the practitioner and to improve the device properties

Computational analysis: promising tool

Methodology

Geometry → Material → BC → Simulation strategy → Validation



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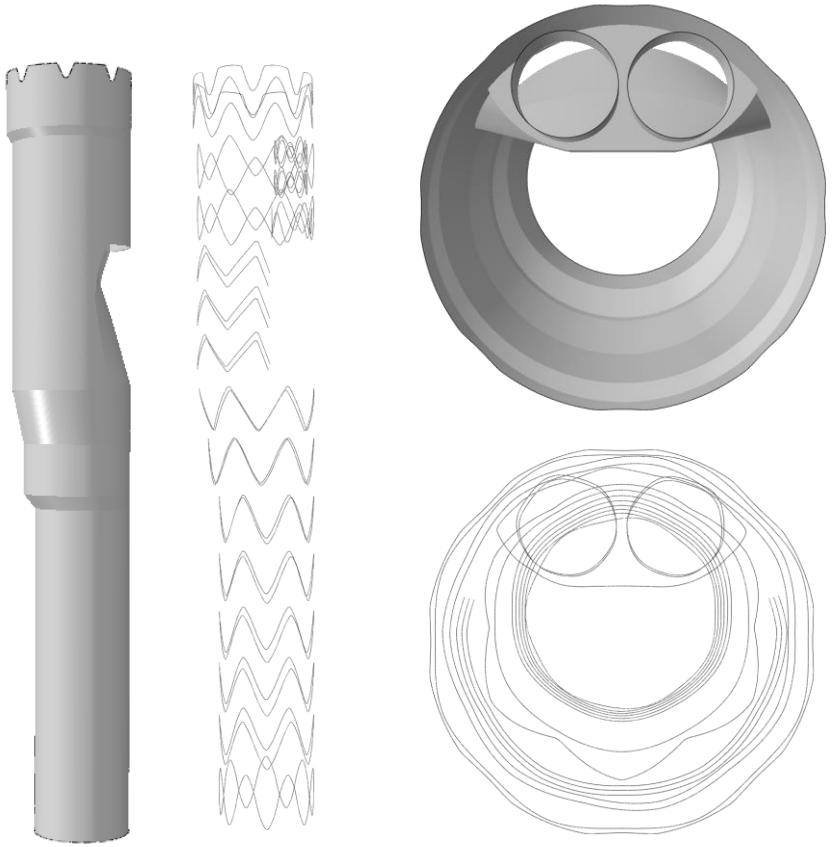
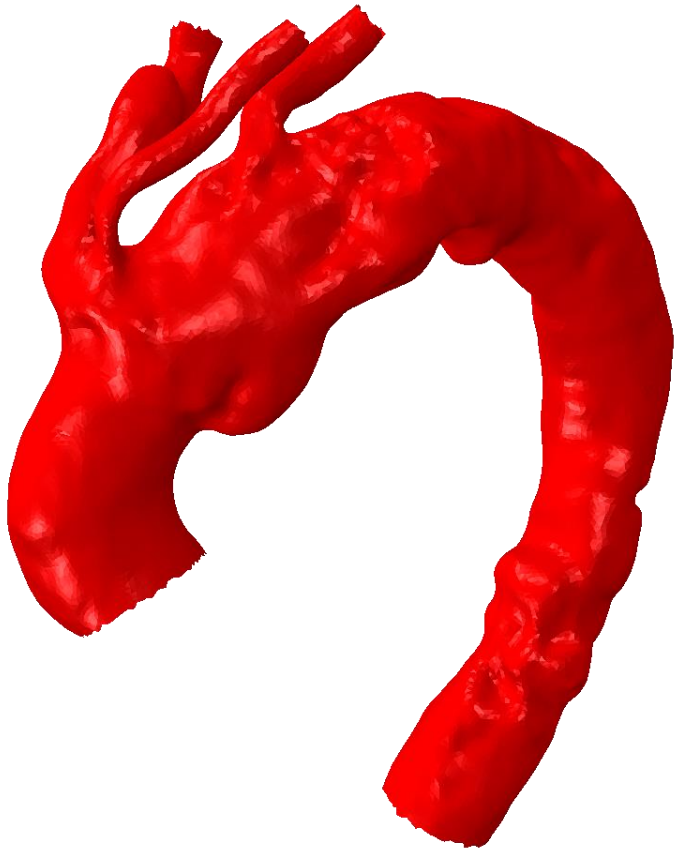


Personalised
Mesh
Graft: quad, 0,5 mm
Stent: beam, 0,3 mm



Personalised
- **Aortic segmentation**: preop CT
- **Mesh:** shell, 1,5mm

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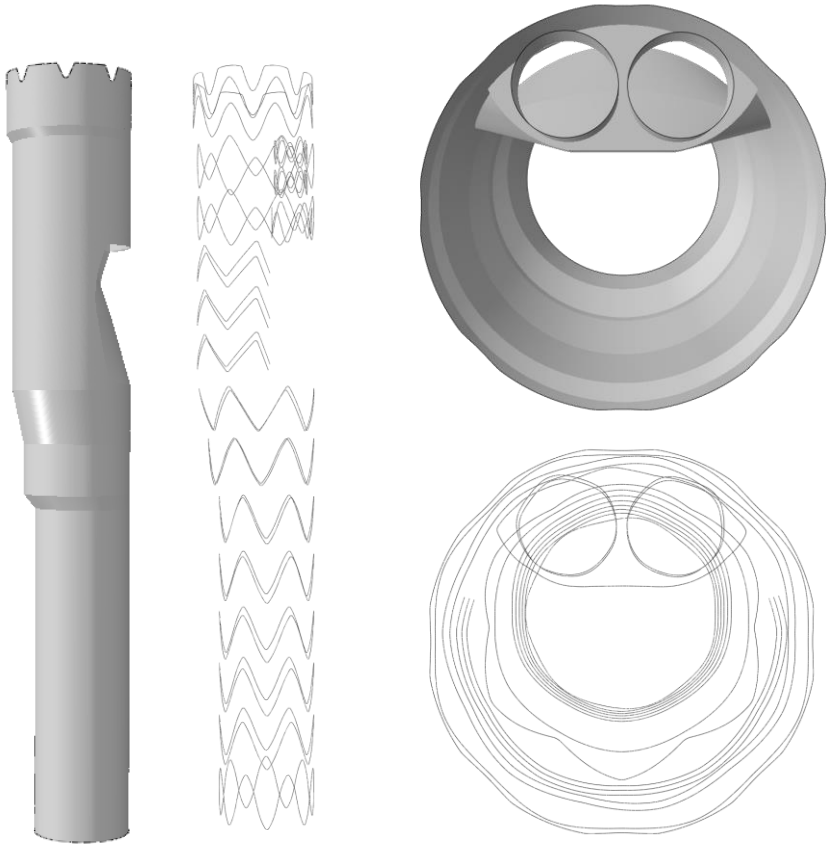

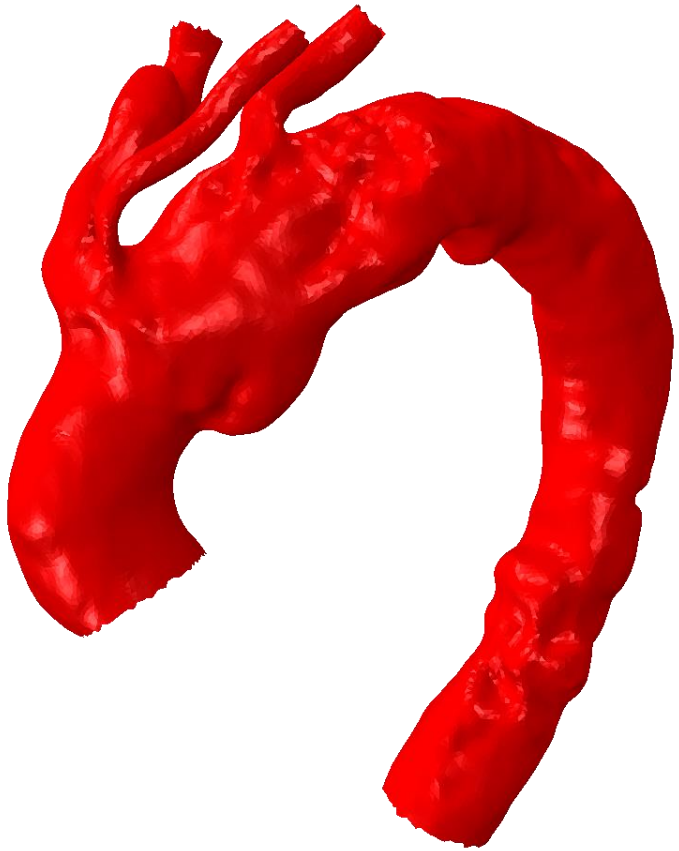

Stent: nitinol, linear elastic

Perrin et al 2015b
Perrin et al 2016

Graft: PET (polyethylene terephtalate), orthotropic elastic

De Bock et al 2012
Demanget et al 2012 & 2013
Perrin et al 2015b

Isotropic elastic E=2 MPa ; ν=0,4
Homogeneous
Thickness 1,5 mm / 1 mm

Gasser et al 2006
Perrin et al 2015b

Geometry → Material → **Simulation strategy** → BC → Validation

Pre-stressed → Deployment → Morphing → Mechanical equilibrium

Stentgraft pre-stressed
- oversizing: tie constraint
- radial compression

Ties

Radial compression

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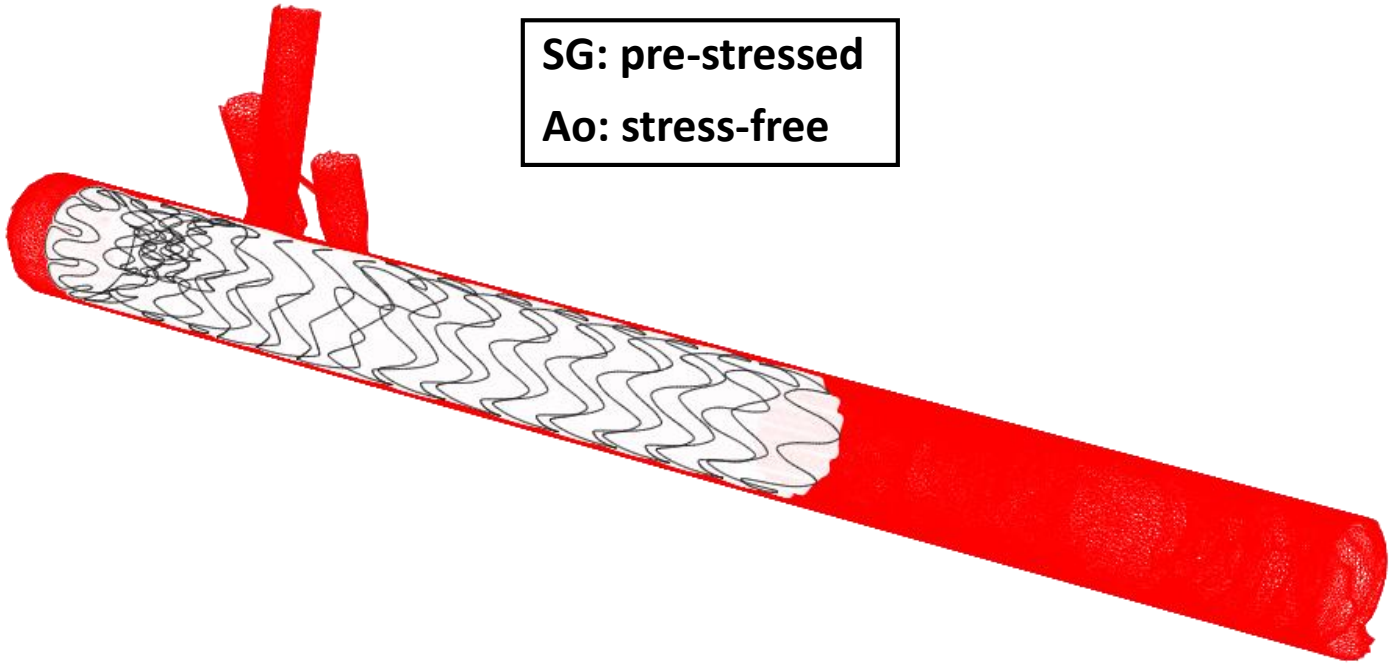
Geometry → Material → **Simulation strategy** → BC → Validation

Pre-stressed → **Deployment** → Morphing → Mechanical equilibrium

SG: pre-stressed

Ao: stress-free



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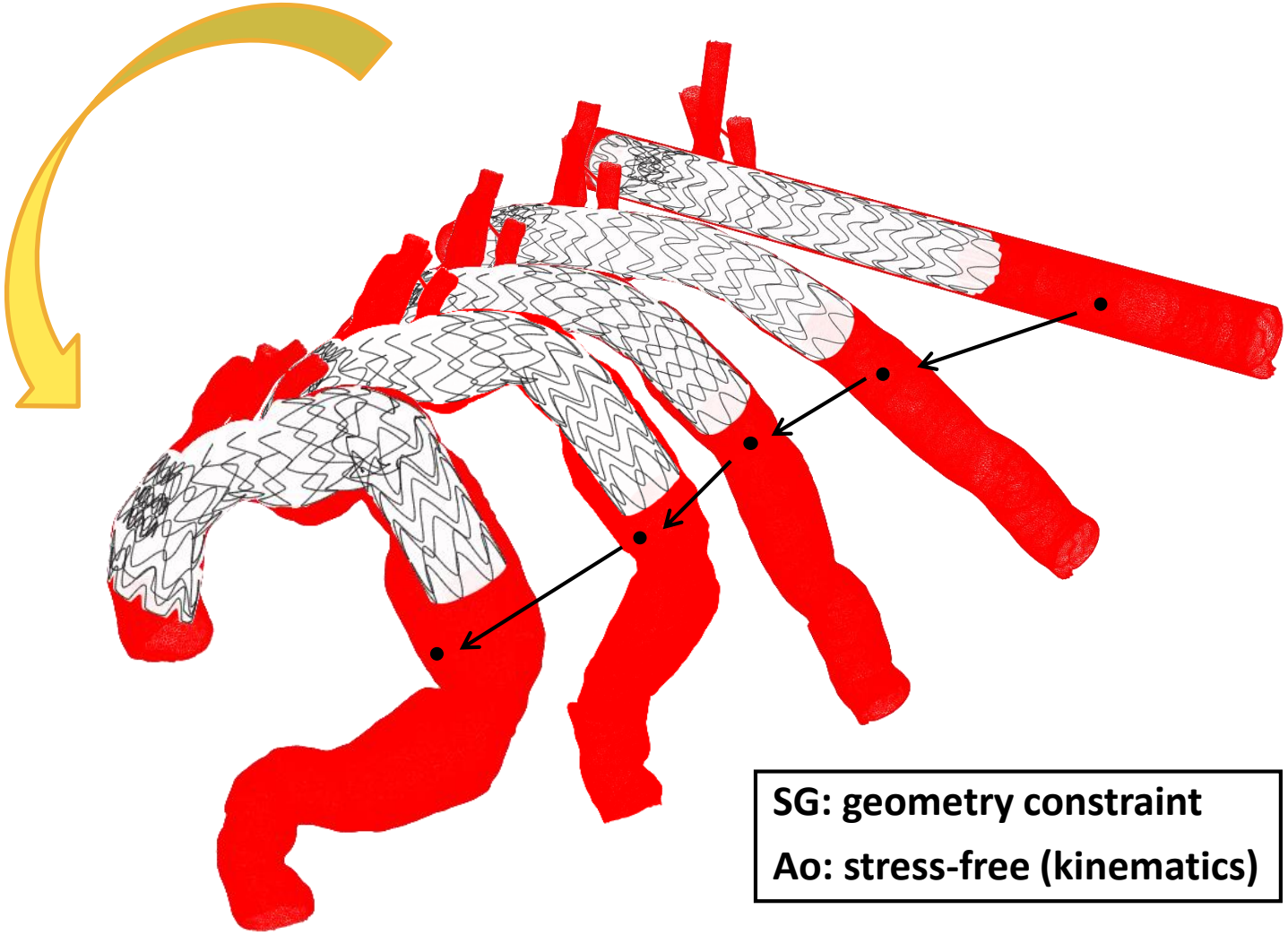
Geometry → Material → **Simulation strategy** → BC → Validation

Pre-stressed → Deployment → **Morphing** → Mechanical equilibrium



SG: geometry constraint

Ao: stress-free (kinematics)

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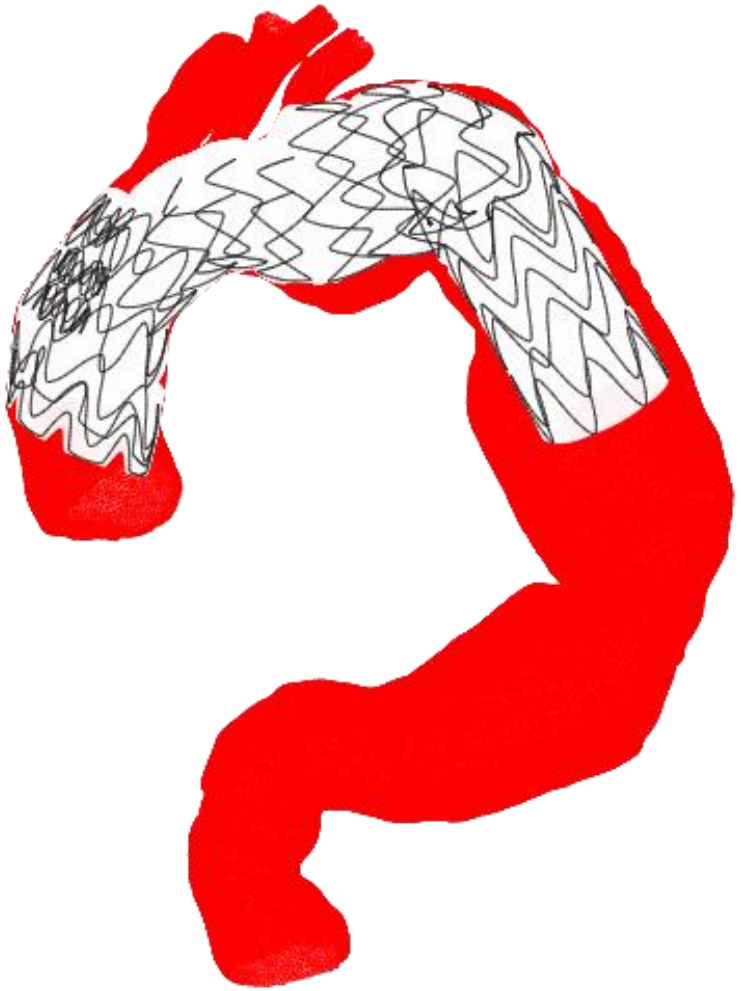
Geometry → Material → **Simulation strategy** → BC → Validation

Pre-stressed → Deployment → Morphing → **Mechanical equilibrium**



SG: stressed

Ao: stressed

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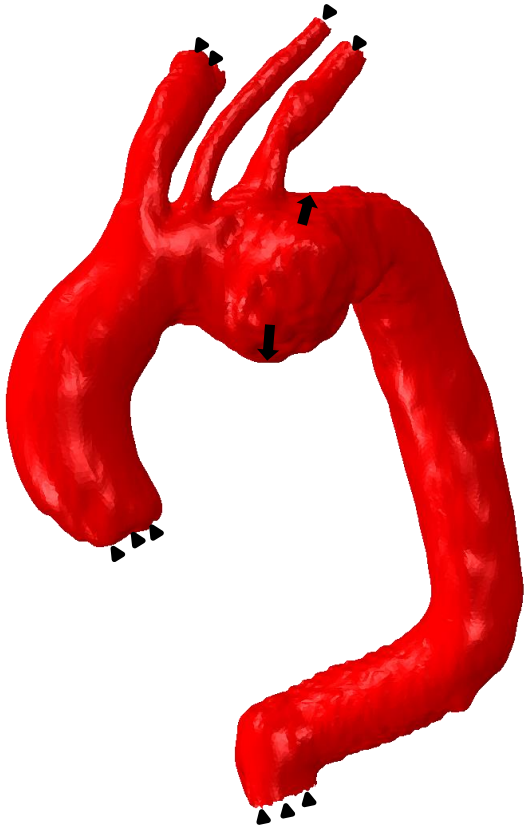


- **Blood pressure**= 30 mmHg (on SG)
- **Friction** SG/Aorta = 0.4

De Bock et al 2012
De Bock et al 2014
Perrin et al 2015a & b
Perrin 2016

- **Nodes** were kinematically driven during morphing step
- **Aortic extremities** were fixed during the last step

Results

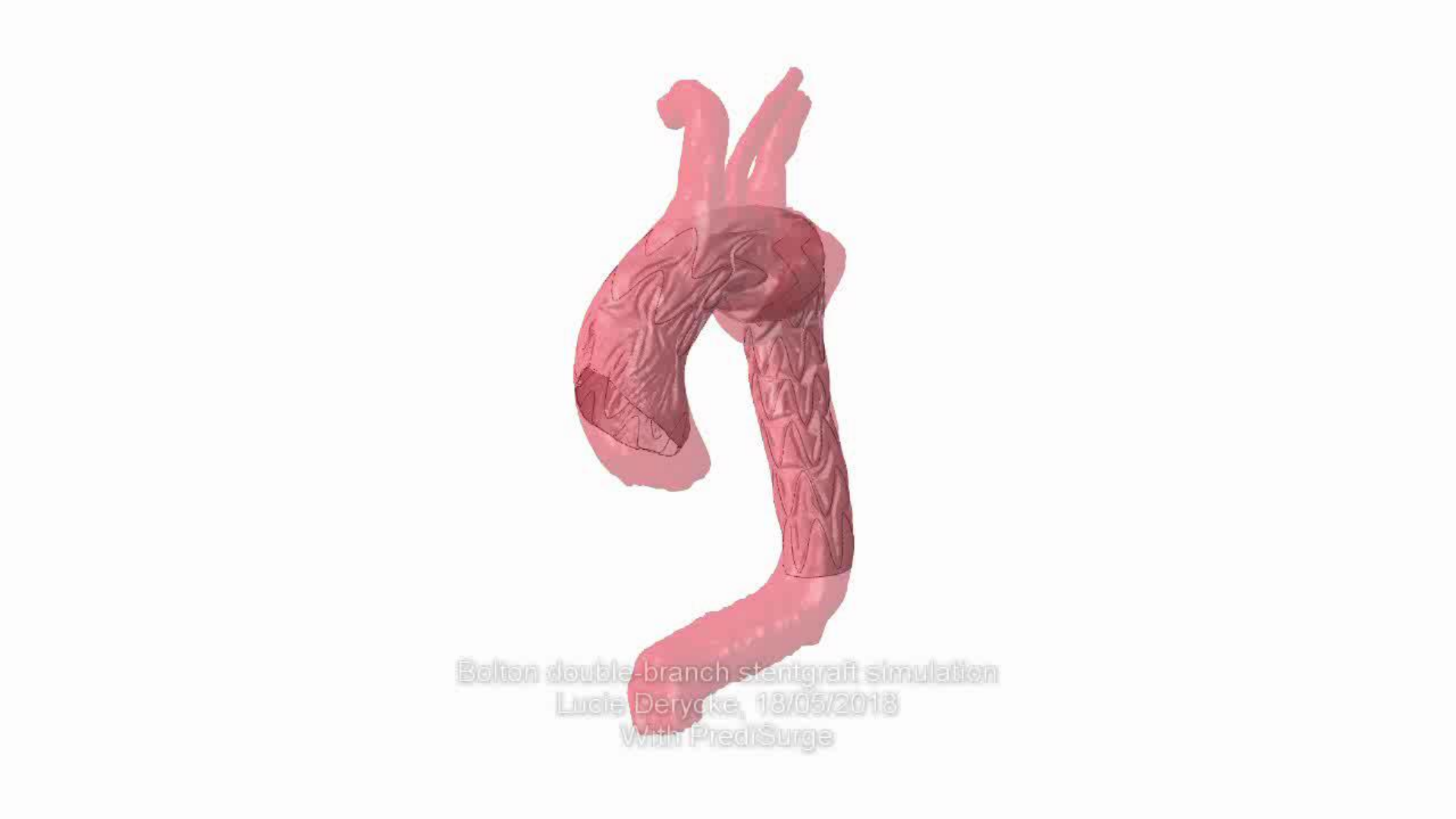
Case 1

Case 2

Case 3

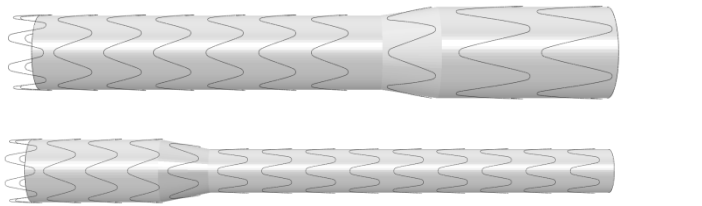
Case 4

Results

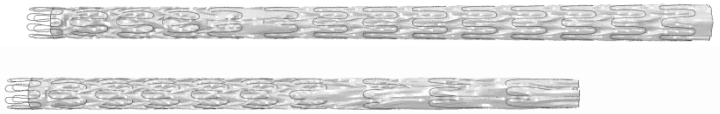

Bolton double-branch stentgraft simulation
Lucie Derycke, 18/05/2018
With PrediSurge

Current work

Additional stentgrafts



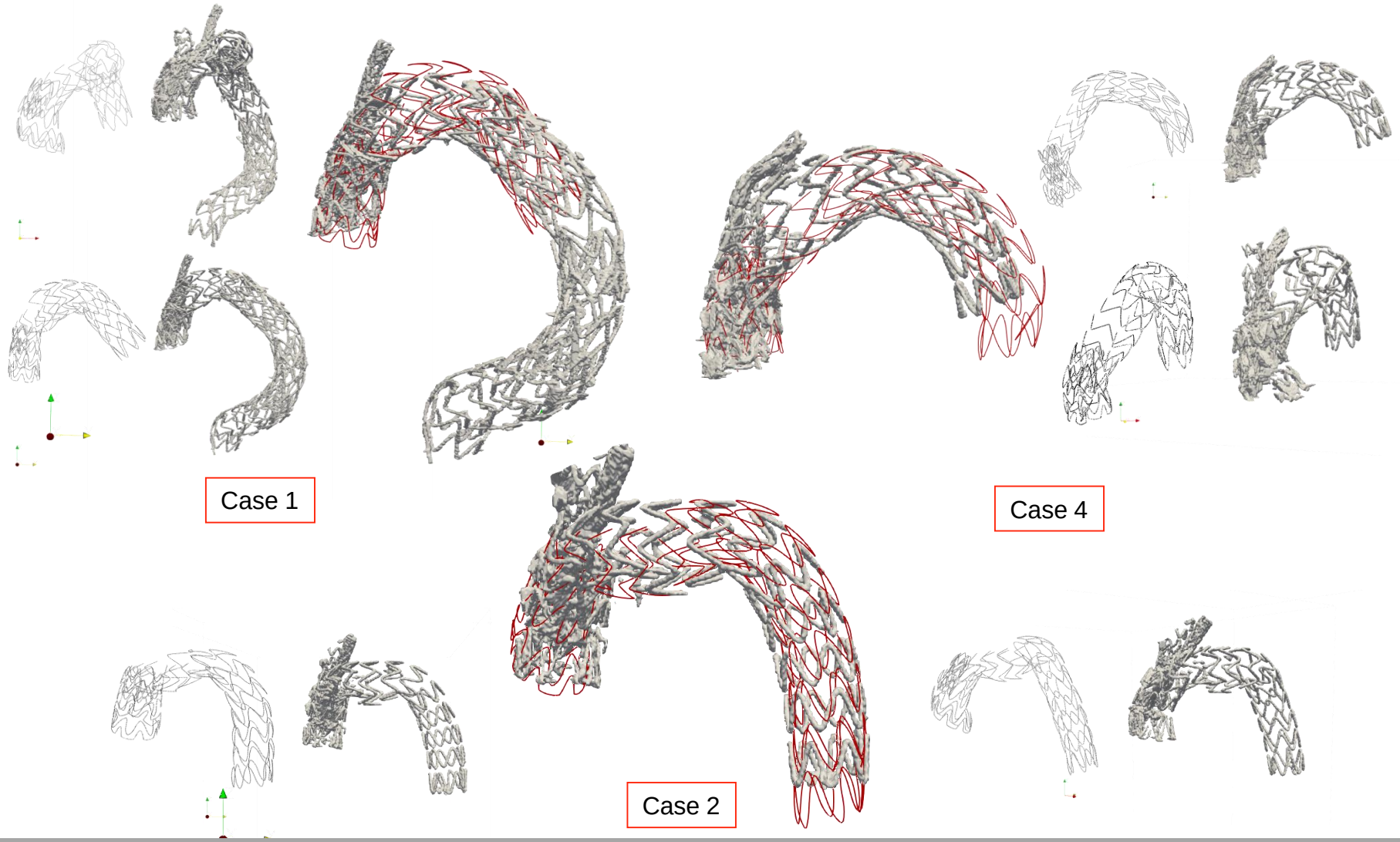
- Limbs



- Limbs after crimping

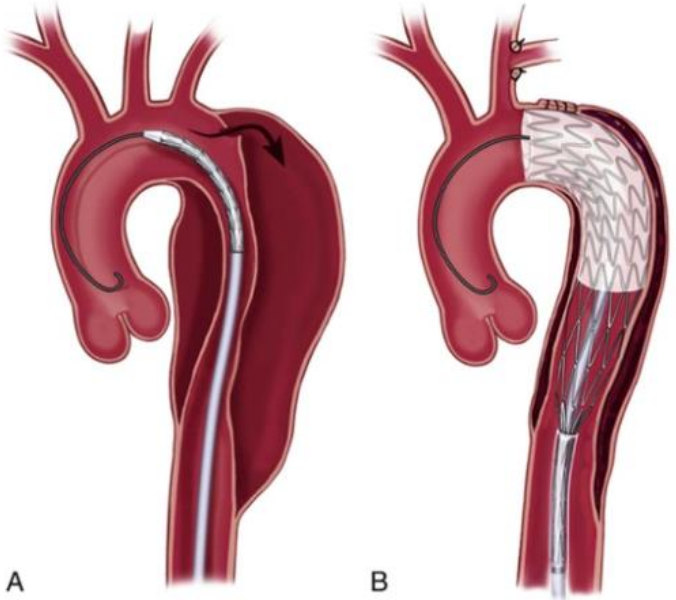
To develop an algorithm to guide the limbs in the supra-aortic vessels before the deployment

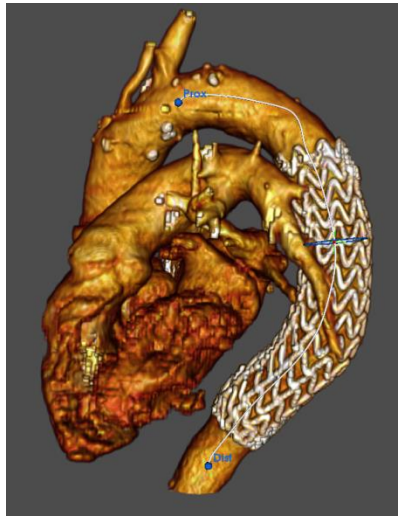
Validation

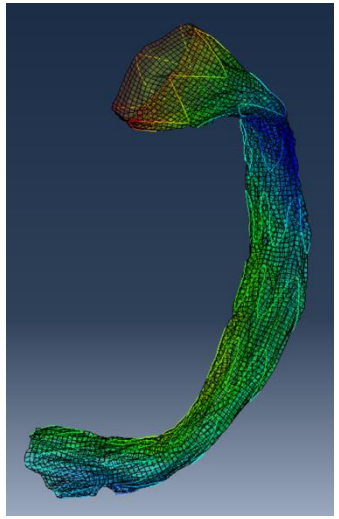


Conclusion & future directions

- Real-time simulations
  - Personalized image-guided EVAR
- Extensions to TEVAR
  - FSI modelling
  - Mechanobiological modelling
- Functional stent-grafts
  - Drug-coated
  - Smart textiles







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