14th European LS-DYNA Conference
Baden-Baden, Germany
18-19 October, 2023

Reduced Order Model for enhanced EVAR Planning and navigation guidance

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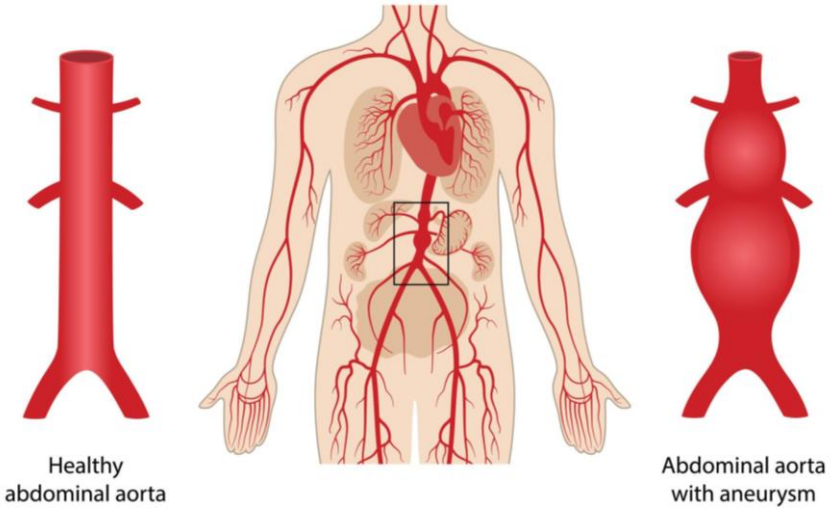
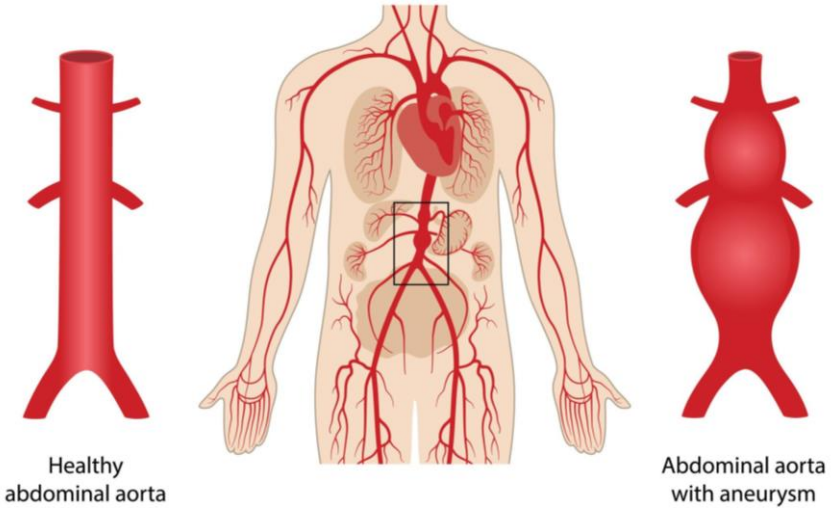
Background & Clinical Challenge



www.vascularcures.org

An abdominal aortic aneurysm (AAA) is the bulging or 'ballooning' of the abdominal aorta.

Background & Clinical Challenge



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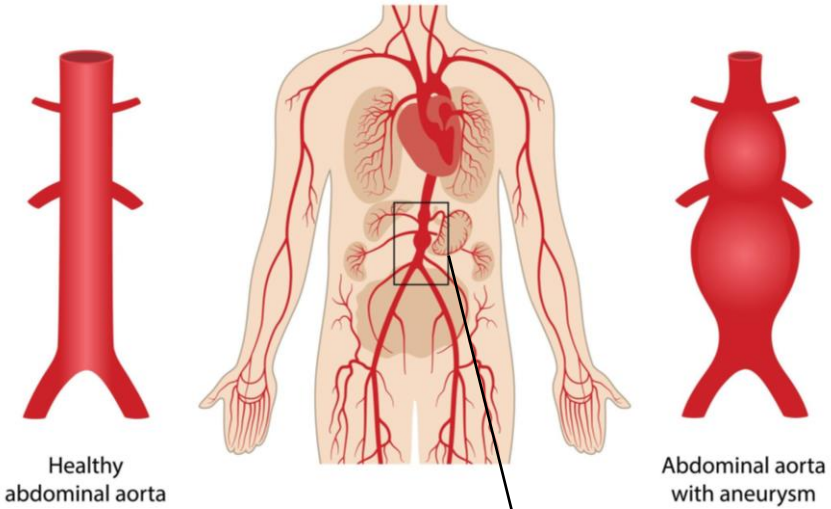
An abdominal aortic aneurysm (AAA) is the bulging or 'ballooning' of the abdominal aorta.

Treatment for abdominal aortic aneurysm: 10^6/year operations worldwide

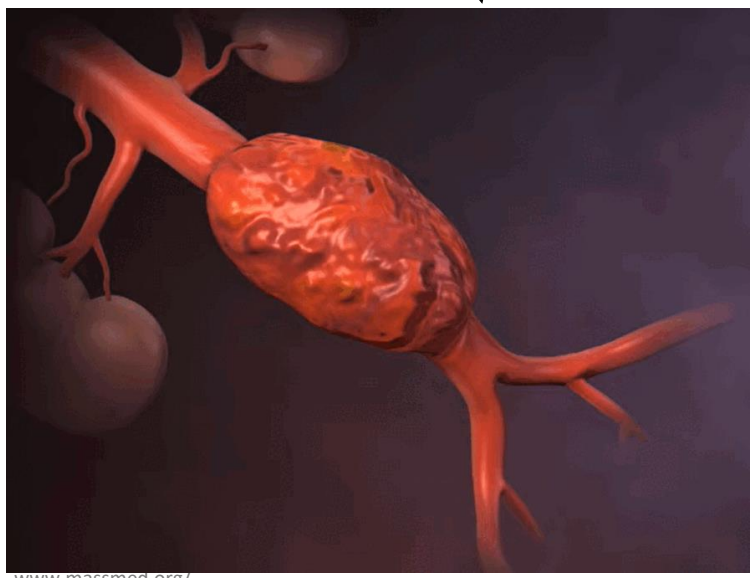
- Open surgery: 30%
- EVAR: 70%

www.massmed.org/

Background & Clinical Challenge



www.vasculararcures.org



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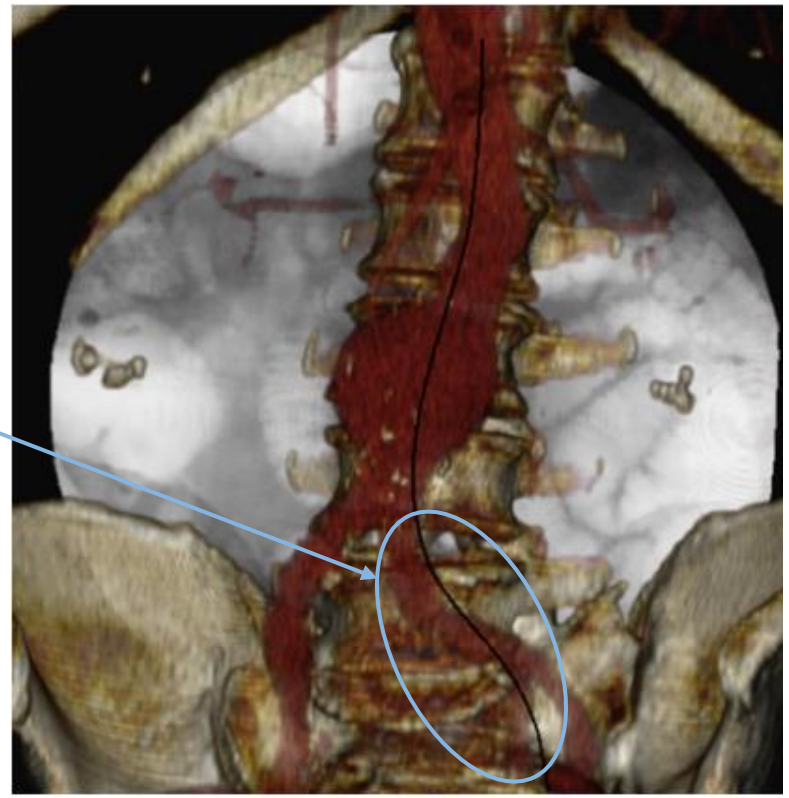
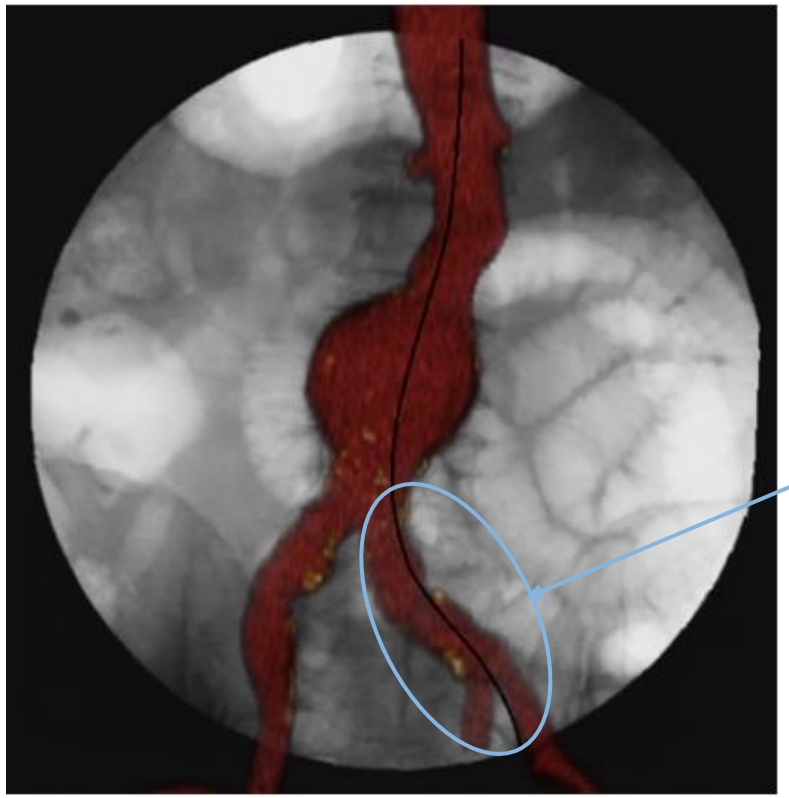
Background & Clinical Challenge

Preoperative volume

Deformed volume

Stiff guidewire outside of the aortic boundaries.





Stiff guidewire within the aortic boundaries.

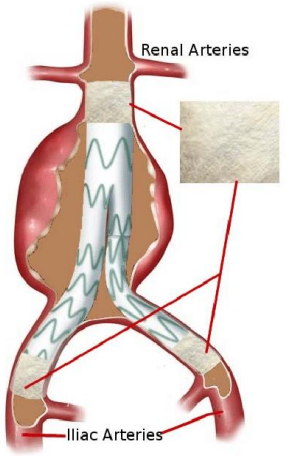
Kaladji A, et al., Comput Med Imaging Graph. 2013

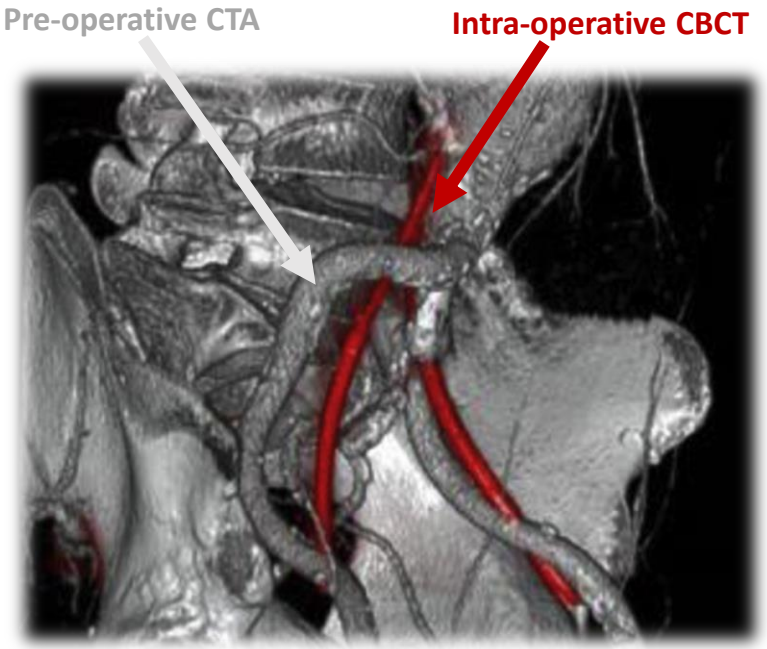
Background & Clinical Challenge

Issue: Difficulty in the estimation of guidewire-induced deformations

Challenge: Provide clinicians with a fast and accurate tool for predicting guidewire-induced deformations

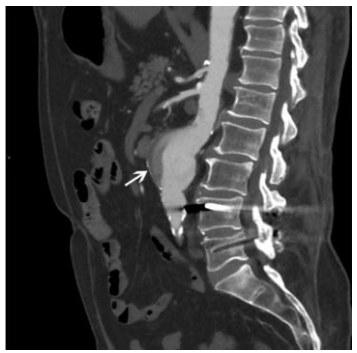
- Radiations and contrast ↑
- Risk of failure ↑
- Post-operative complications ↑



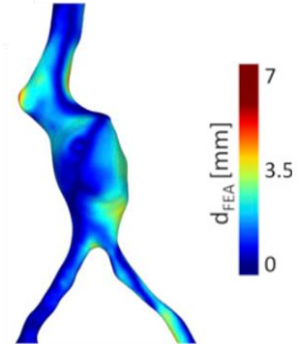


Koutouzi et al., Eur. J. Vasc Surgery, 2019

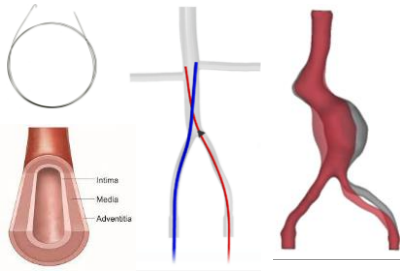
Adopted Workflow



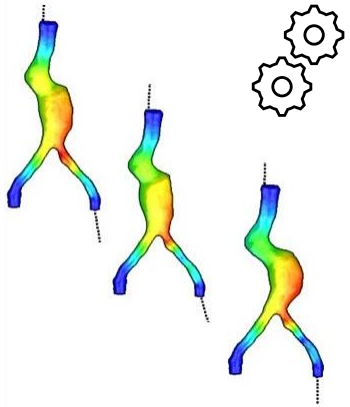
CT scan



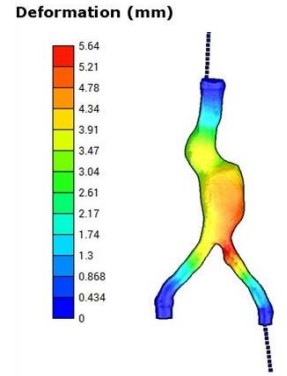
Baseline FE case



Morphological, clinical, mechanical parameterization

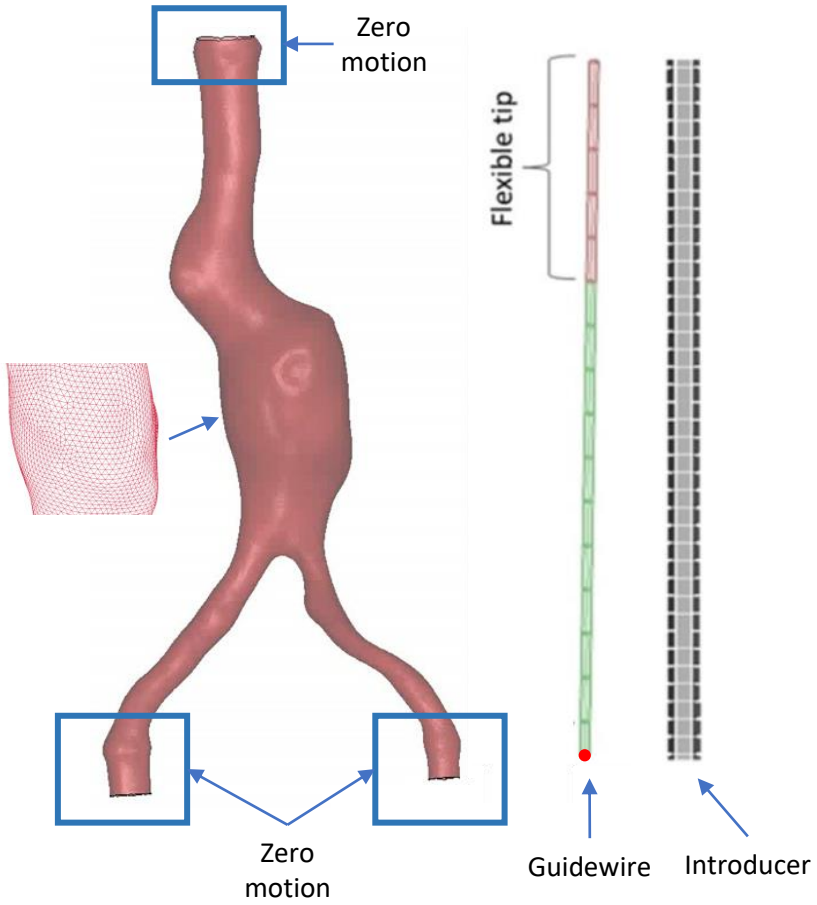


ROM Build-up



ROM exploitation

Materials and Methods – LS-DYNA set-up



Discretization:

	Aortic wall	Guidewire	Introducer
Element type	Shell	Beam	Shell
Element size (mm)	1.4	4	1

Details:

- Aortic wall mesh: C^0 triangular shell elements with 2.5 mm thickness
- Guidewire: Beam elements Hughes-Liu with cross-section integration
- Flexible tip: gradually decreasing elastic modulus, ranging from 1 to 50 GPa.

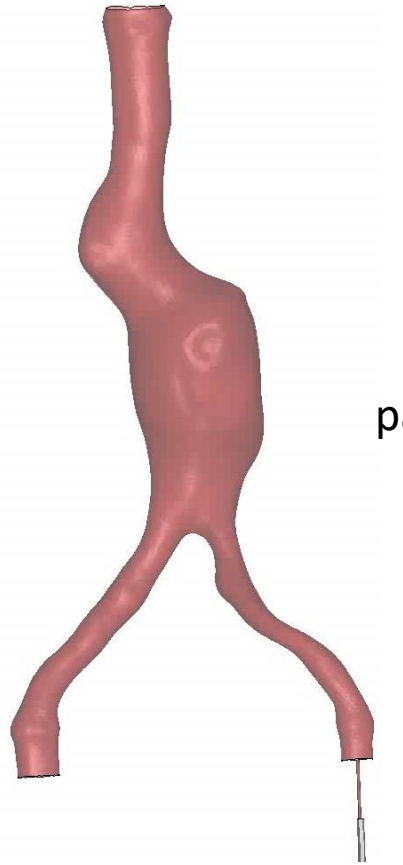
Numerical set-up:

- Central difference time integration scheme
- Dampers with a damping coefficient of 10^{-7}
- Time step size of $5*10^{-6}$ s

Boundary Conditions:

- Imposed velocity $v(t)$ to the most distal node of the guidewire
- Frictionless contact algorithm (Automatic beams to surface LS-DYNA type) between the guidewire and the vessel
- standard penalty formulation contact type between the guidewire and the introducer

Materials and Methods – Parametric Modeling



High–fidelity Finite Element simulation

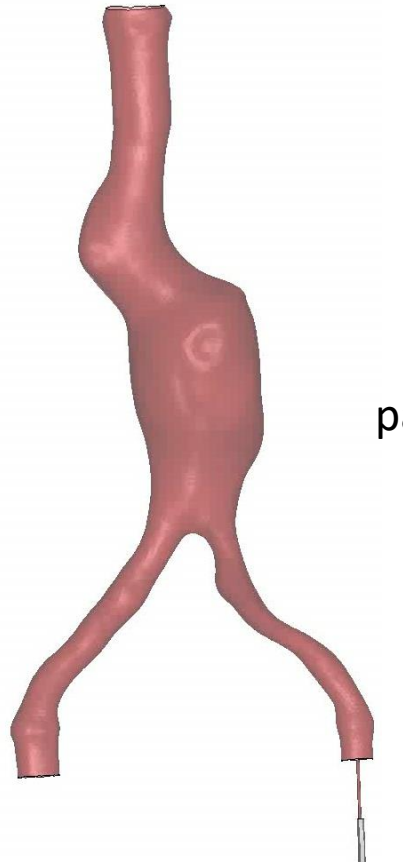
Problem parameterization

Mechanical parameters
Aortic elasticity
Guidewire's stiffness

$0.8\ \text{MPa} \leq E_{aorta} \leq 3\ \text{MPa}$

$60\ \text{GPa} \leq E_{wire} \leq 200\ \text{GPa}$

Materials and Methods – Parametric Modeling



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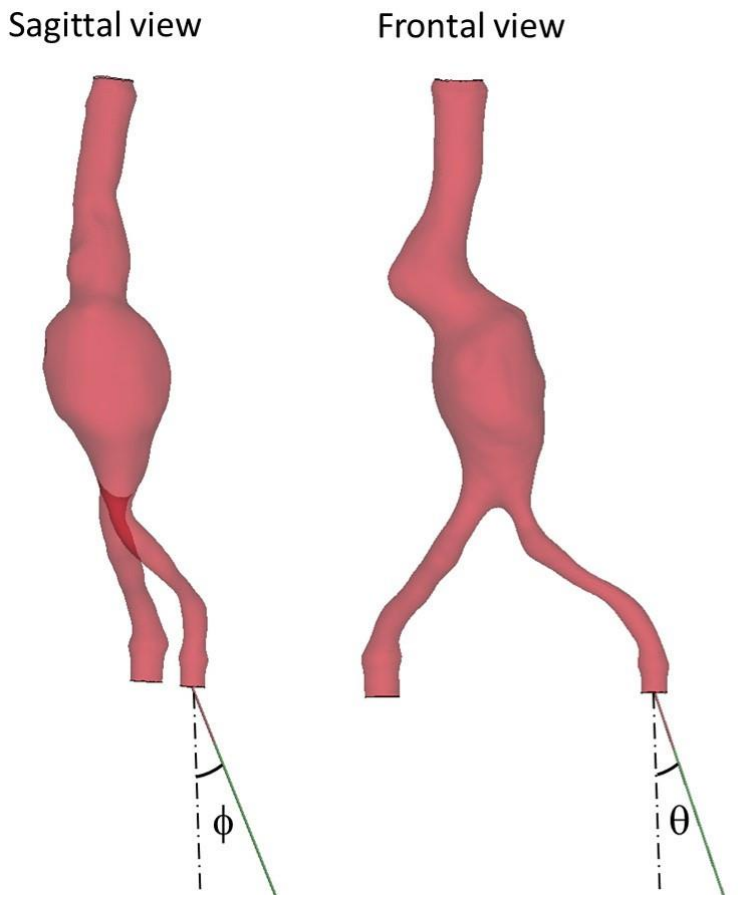
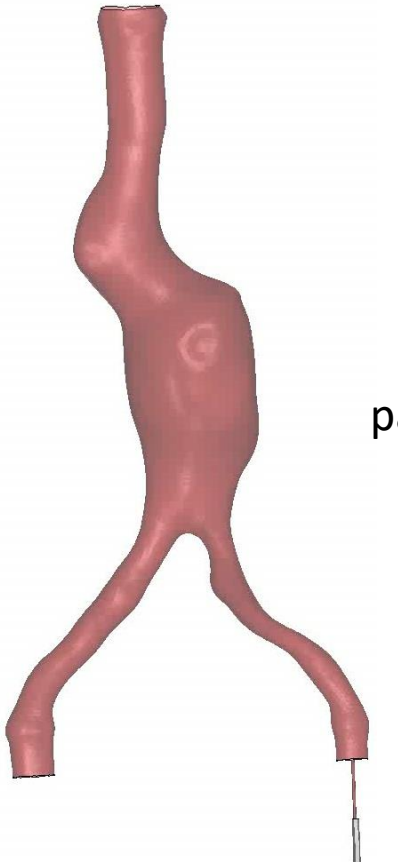
Clinical parameters

- Insertion angles



$-25^o \leq \varphi \leq 0^o$ $0^o \leq \theta \leq 20^o$

Materials and Methods – Parametric Modeling



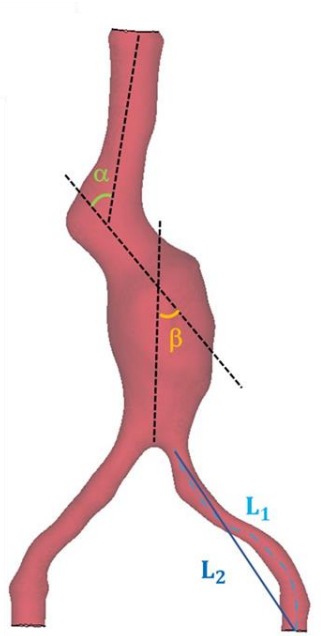
High–fidelity Finite Element simulation

Problem parameterization

Mechanical parameters
Aortic elasticity
Guidewire's stiffness

Clinical parameters
Insertion angles

Morphological parameters
Supra-renal neck angle α
Infra-renal neck angle β
Left iliac artery tortuosity τ



$30^o \leq \alpha \leq 55^o$

$25^o \leq \beta \leq 60^o$

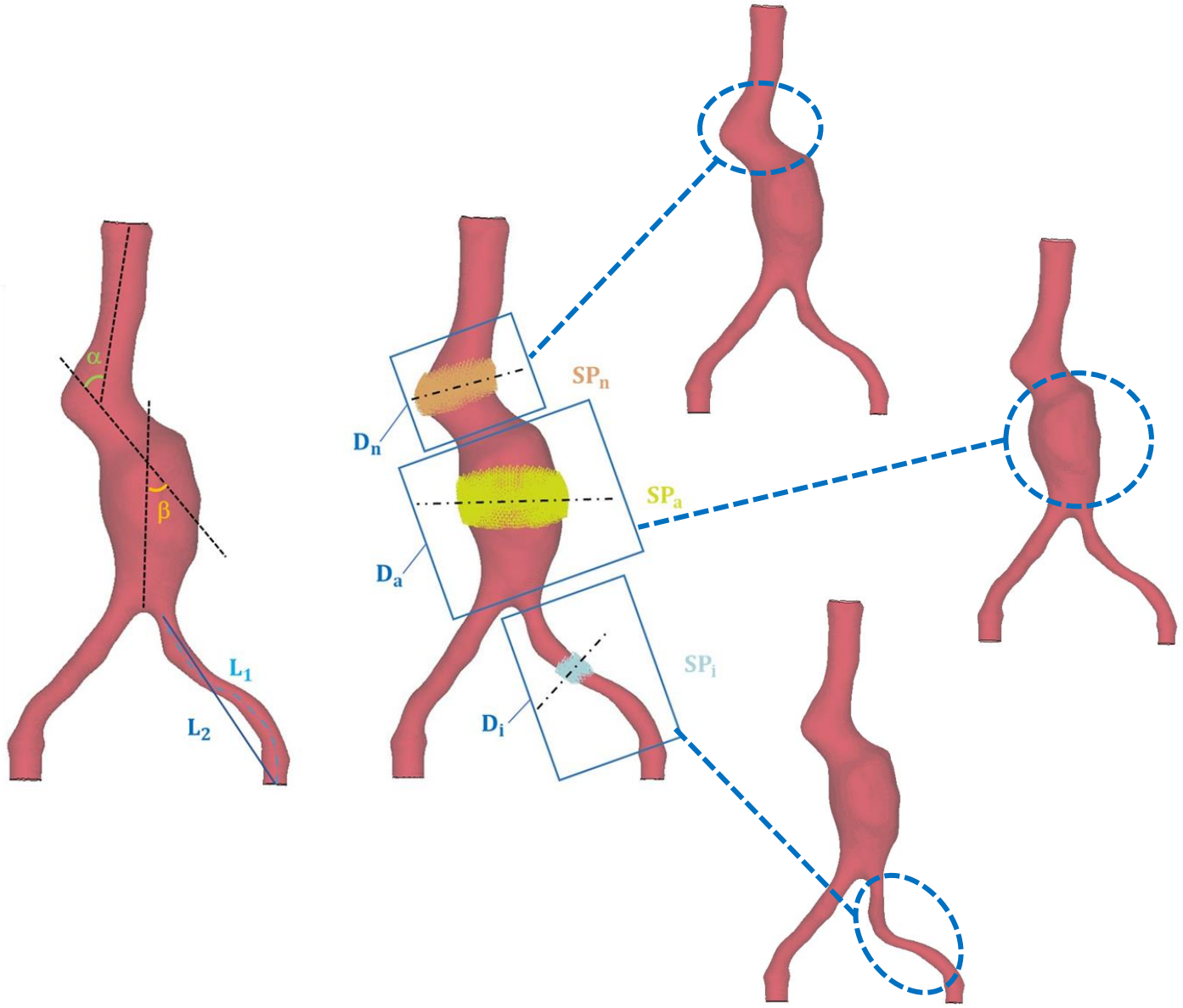
$0.09 \leq \tau \leq 0.15$

$$\tau = \frac{L_1}{L_2} - 1$$

Materials and Methods – RBF Shape Modifiers

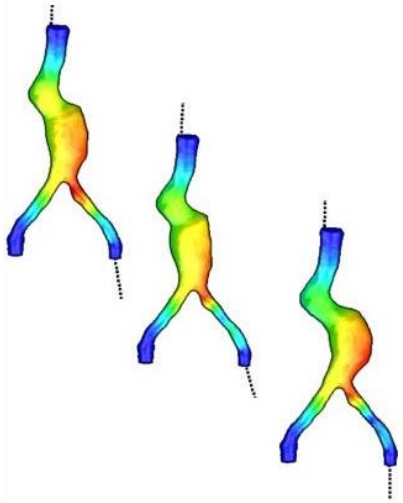
- 3 Shape modifiers
- 3 categories of source points (SP)
- 3 categories of domains (D)

The combination of the shape modifiers enabled us to explore a broad spectrum of possible aortic configuration



Materials and Methods – ROM Build-up

Learning data



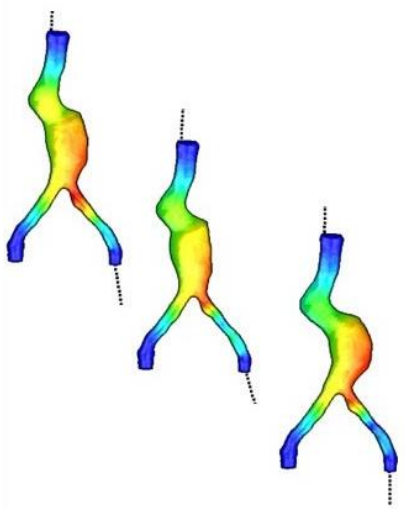
300 scenarios combining seven parameters

200 scenarios for the ROM build-up

100 scenarios for ROM verification

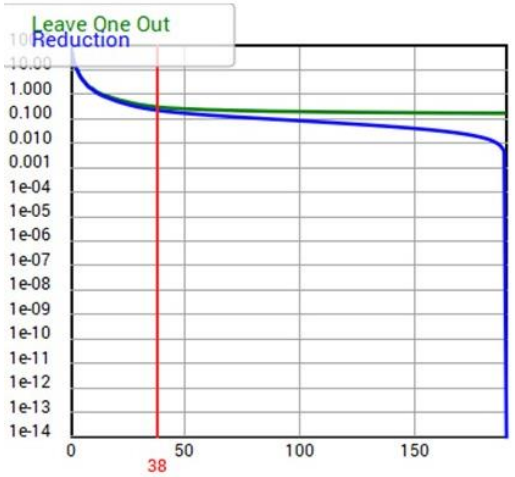
Materials and Methods – ROM Build-up

Learning data

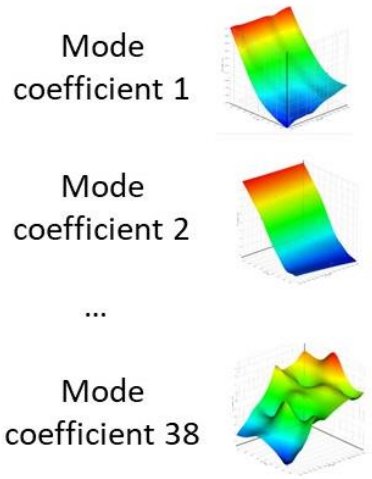


300 scenarios combining seven parameters

ROM Build-up

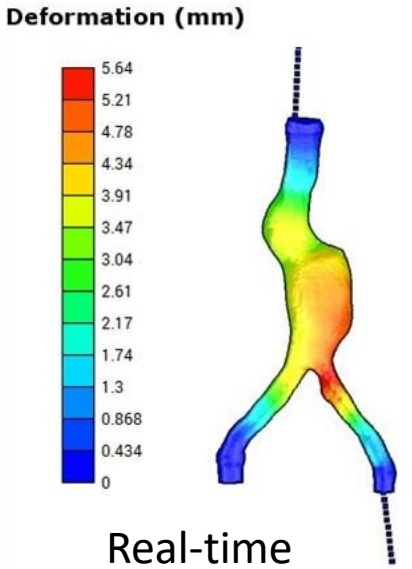


Singular Value Decomposition



Genetic Aggregation Response Surface

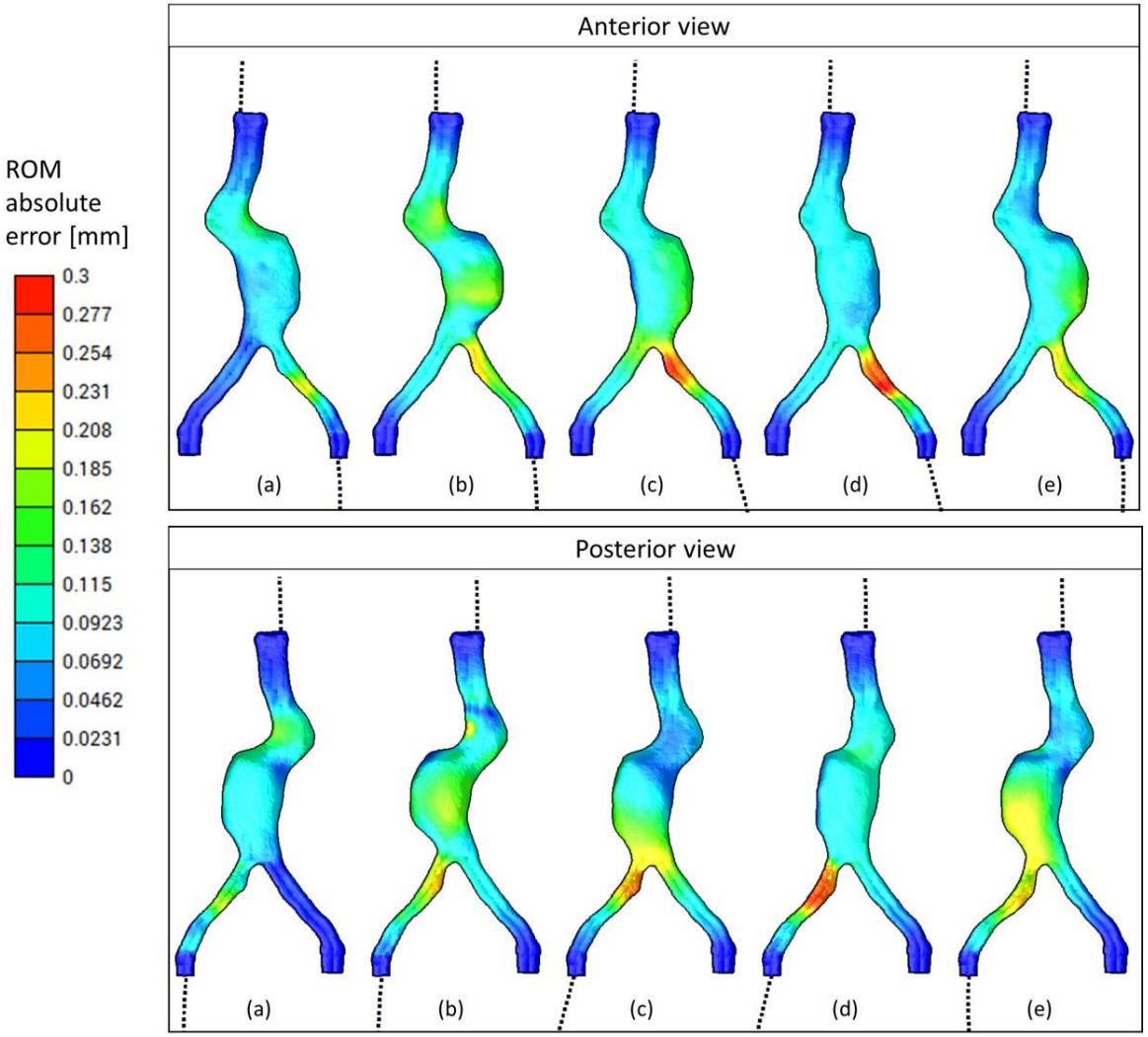
ROM exploitation



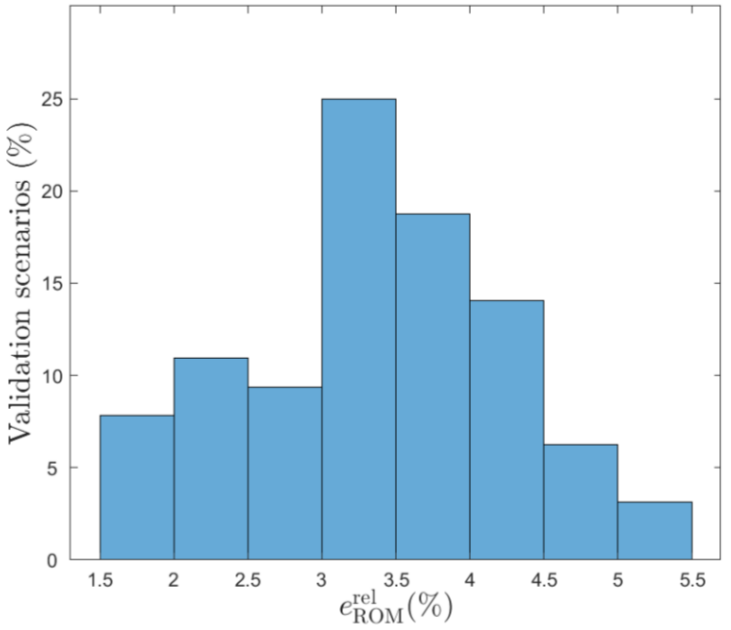
Real-time displacement

Results – ROM Accuracy

ROM absolute error = $|FE_{sol} - ROM_{pred}|$

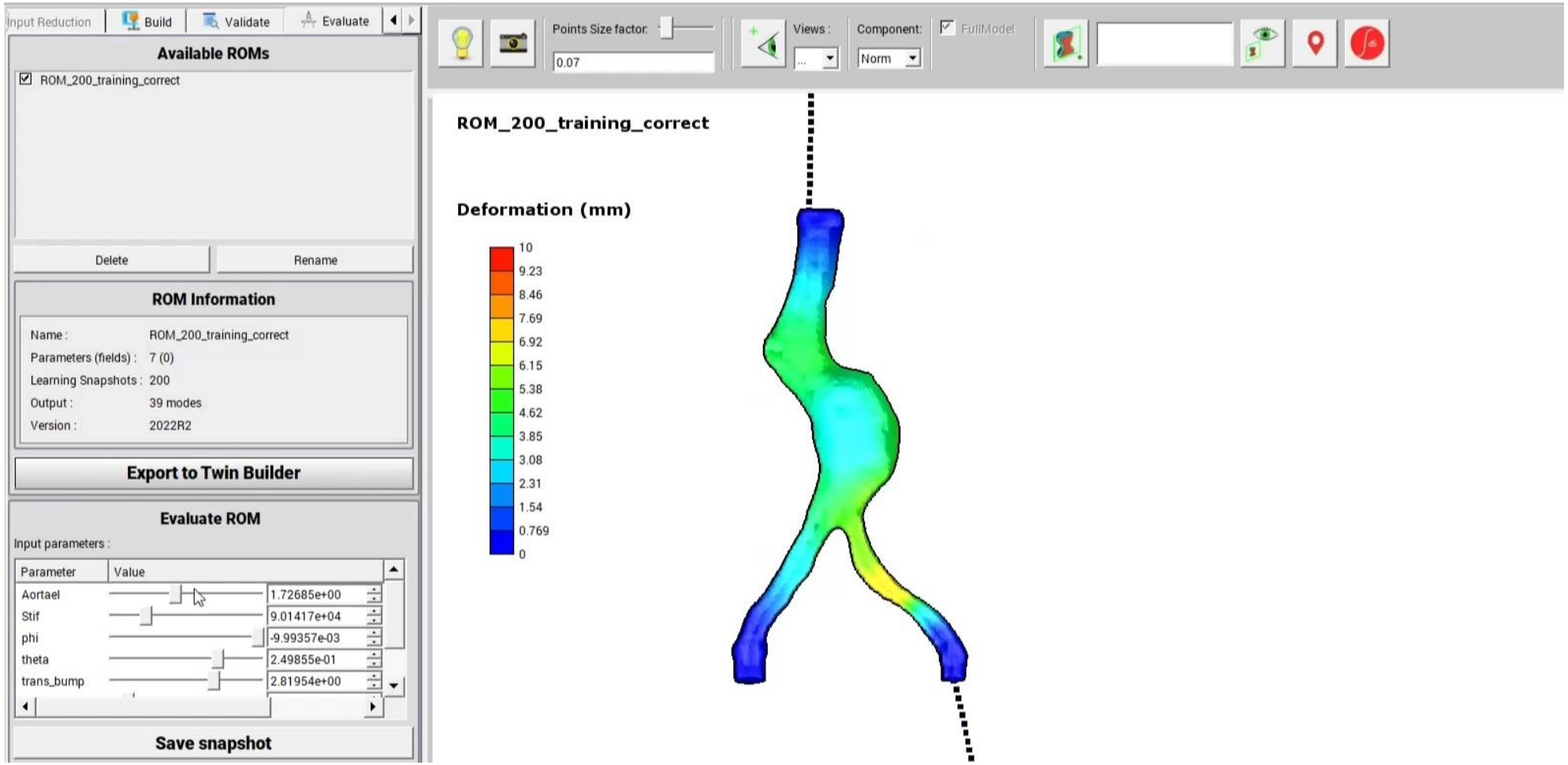


$e_{ROM}^{rel} = |FE_{sol} - ROM_{pred}| / |ROM_{pred}| * 100\%$

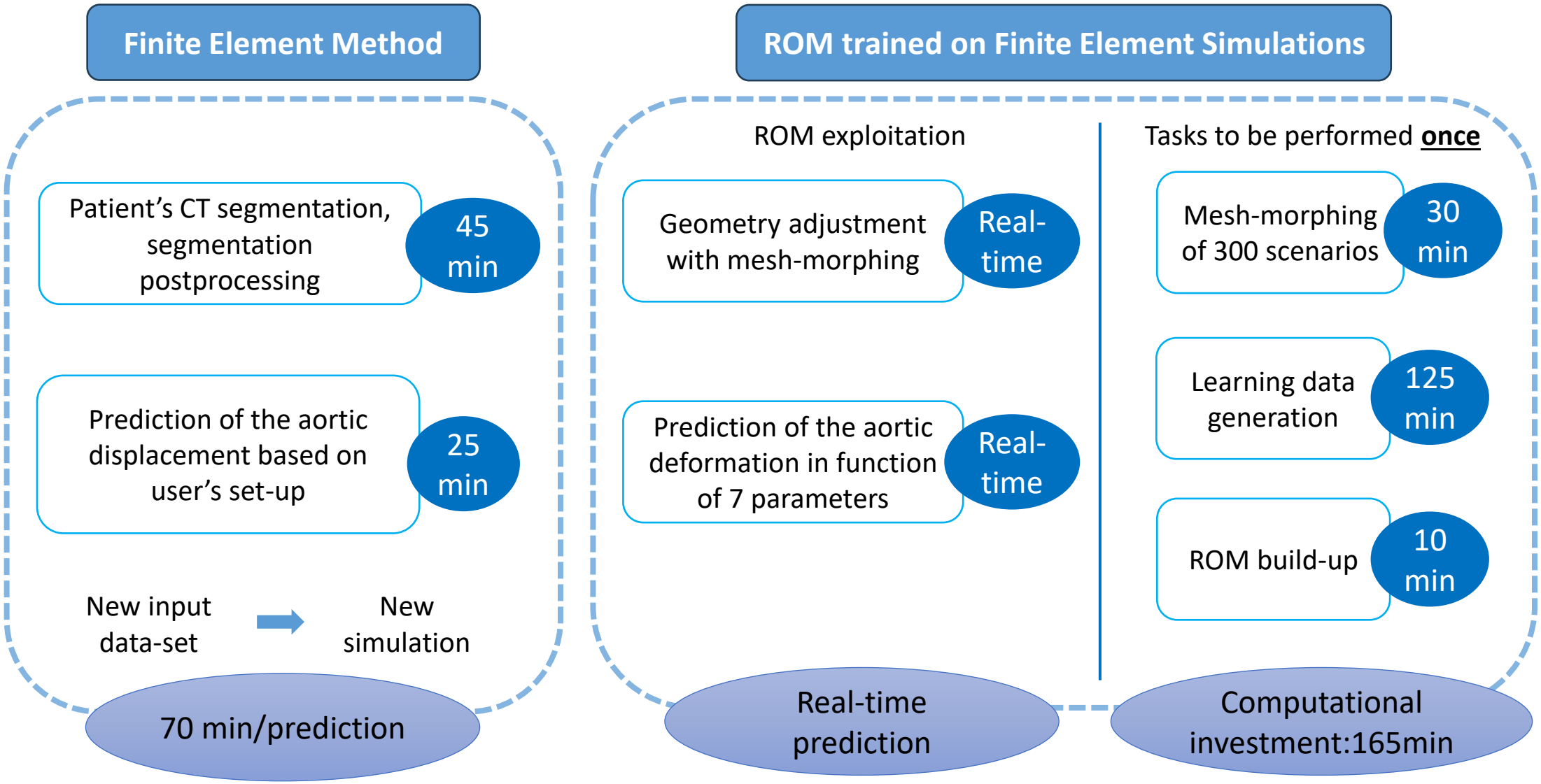


The ROM is able to predict the guidewire-induced aortic displacement with **sufficient accuracy**

Results – ROM Exploitation: example



Results – Timeframe comparison between FE and ROM



Conclusions

A comprehensive framework which fuses the **ROM approach** and the **RBF mesh morphing** for the **prediction of the guidewire-induced deformations** was presented

Research Highlights

- ✓ ROM build-up within **3 hours and 15 minutes** starting from CT images.
- ✓ Exploration of a wide spectrum of scenarios, varying seven **mechanical, morphological and clinical parameters**.
- ✓ Fast ROM execution compatible with **pre- and intra-operative** timeframe.

Limitations & Future Directions

- ➢ Inclusion of more **learning scenarios**
- ➢ Application of the workflow to more **challenging anatomies**
- ➢ Adoption of more **realistic boundary conditions** and **material model** for aortic tissue

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Thank you for your attention!

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