A NUMERICAL FLUID-STRUCTURE INTERACTION METHODOLOGY TO MODEL THE THORACIC ENDOVASCULAR AORTIC REPAIR PROCEDURE

Anna **Ramella**[1], **Elena Redaelli**[1,4], **Francesco Migliavacca**[1], **Michele Conti**[2], **Santi Trimarchi**[3], **Giulia Luraghi**[1],

(1) LaBS, Dept. of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Milan, Italy. – (2) Department of Civil Engineering and Architecture, University of Pavia, Italy. –
(3) Department of Clinical and Community Sciences, University of Milan, Milan, Italy. – (4) I3A, Escuela de Ingenieria y Arquitectura, Universidad de Zaragoza, Spain.

INTRODUCTION

The **Thoracic Endovascular Aortic Repair** (TEVAR) is a minimally invasive technique to treat the thoracic aorta pathologies, such as aneurysms and dissections.

A **stent-graft** is crimped inside a catheter, inserted into the pathological region and released to restore the correct lumen.

Common long-term complications and consequences are: *Endoleaks, Device Migration, Bird Beak* and *Compliance Mismatch.*

AIM

To develop a **numerical workflow** to virtually implant a stent-graft in an idealized aorta and to reproduce the pre- and post-TEVAR hemodynamics.

Structural analysis
- Finite Element Analysis (**FEA**) → Device deployment into the vessel

Fluid-dynamic analysis
- Computational Fluid Dynamic (**CFD**)
- Fluid-Structure Interaction (**FSI**)

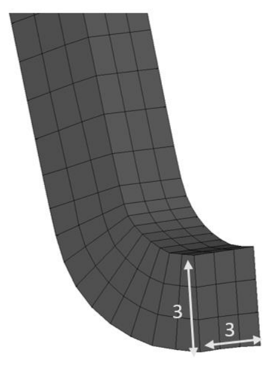
→ Pre-TEVAR and Post-TEVAR hemodynamics

METHODS

STRUCTURAL ANALYSIS

Medtronic Valiant **stent-graft** model

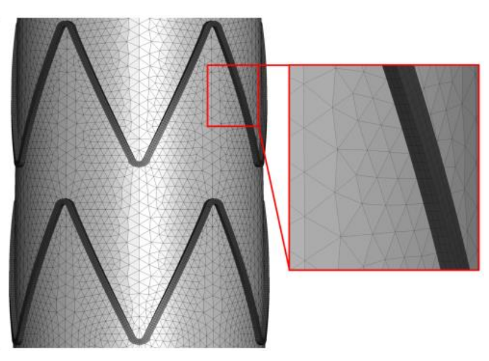
STENT



Mesh: hexahedral elements

Material: Nitinol

GRAFT



Mesh: triangular shell elements – node-to-node connection with the stent

Material: PET

IDEALIZED AORTA

Mesh: quadrangular shell elements

Material: Isotropic Hyperelastic Mooney-Rivlin constitutive model

Crimping, morphing and deployment of the stent-graft into the aorta

- Explicit LS-Dyna solver
- Timestep 0.001ms
- Penalty contacts in the deployment phase

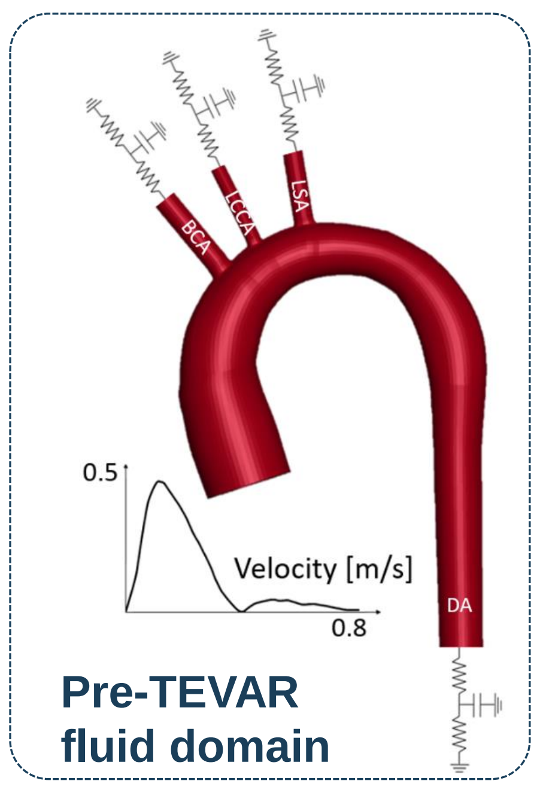
FLUID-DYNAMIC ANALYSIS

Preliminary **CFD simulations** are performed to test the boundary conditions, boundary layers and fluid mesh.

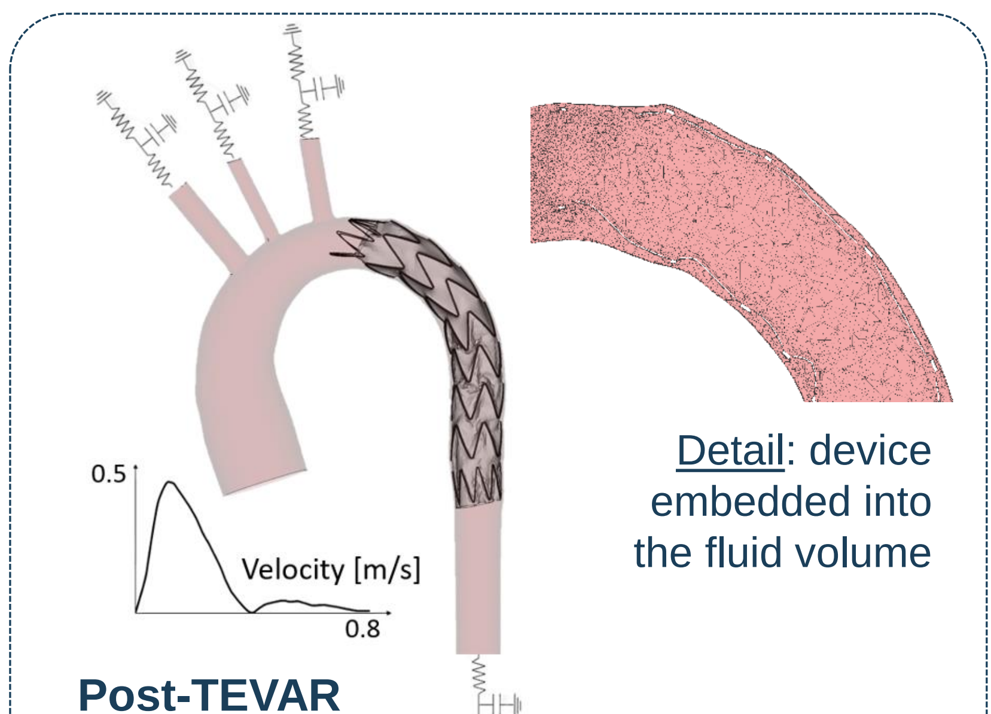
Two-way, strongly coupled and **boundary fitted FSI simulations** are carried out using:

- implicit ICFD solver of LS-Dyna for the <u>fluid domain</u>
- implicit FEA solver of LS-Dyna for the <u>structural domain</u>

Blood is modeled as a Newtonian and incompressible fluid.



Pre-TEVAR fluid domain



<u>Detail</u>: device embedded into the fluid volume

Post-TEVAR fluid domain

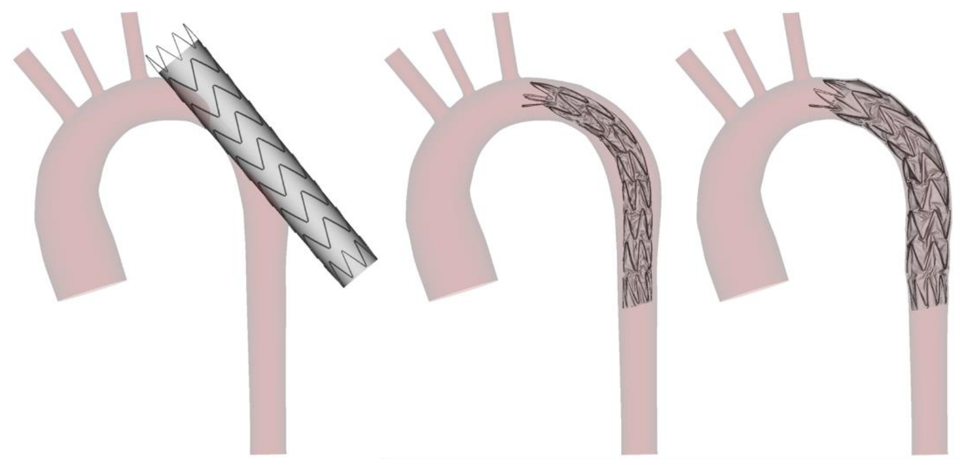
Inlet: physiological velocity waveform *[1]*
Outlets:.3-elements Windkessel circuits *[2]*

In the post-TEVAR, the materials, geometries, contacts and stress/strain distribution are imported from the structural FEA results.

RESULTS

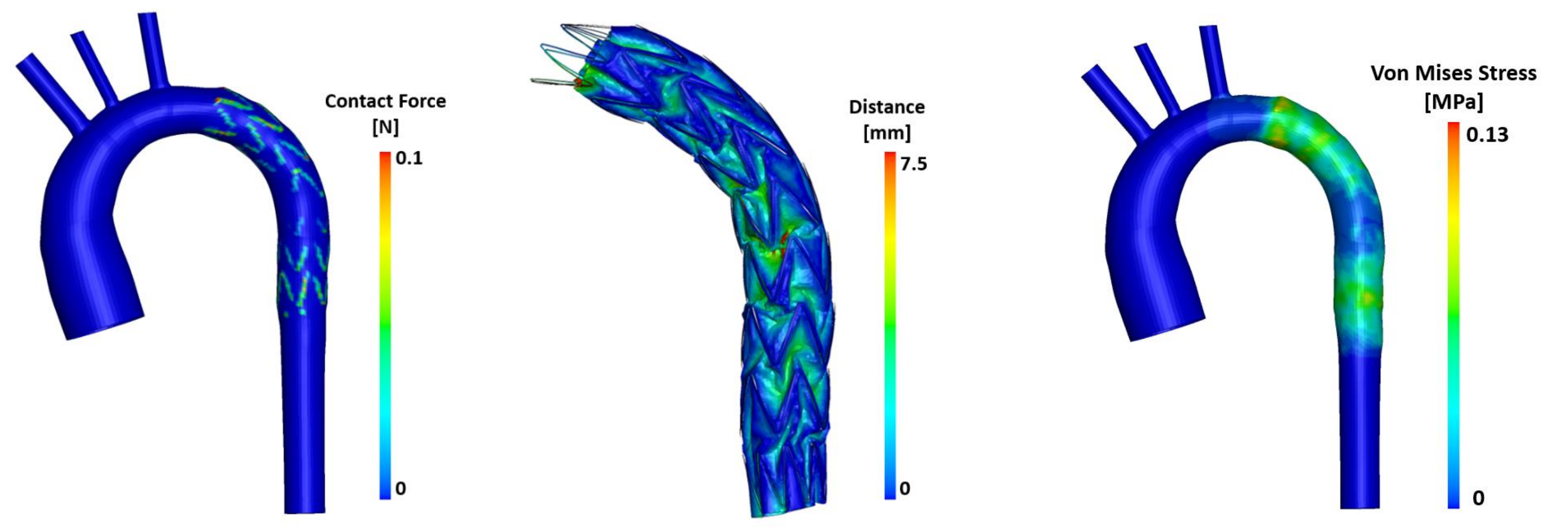
STRUCTURAL ANALYSIS

Crimping, morphing and deployment **simulation**.



Starting point — Maximum crimping — Final instant

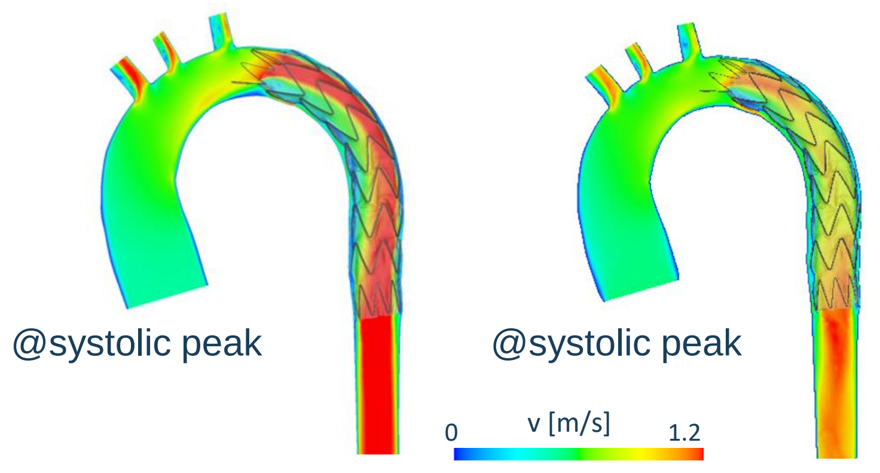
Simulation results show that the device is more in contact with the vessel in the proximal and distal regions.



FLUID-DYNAMIC ANALYSIS

POST-TEVAR CFD VS. FSI COMPARISON

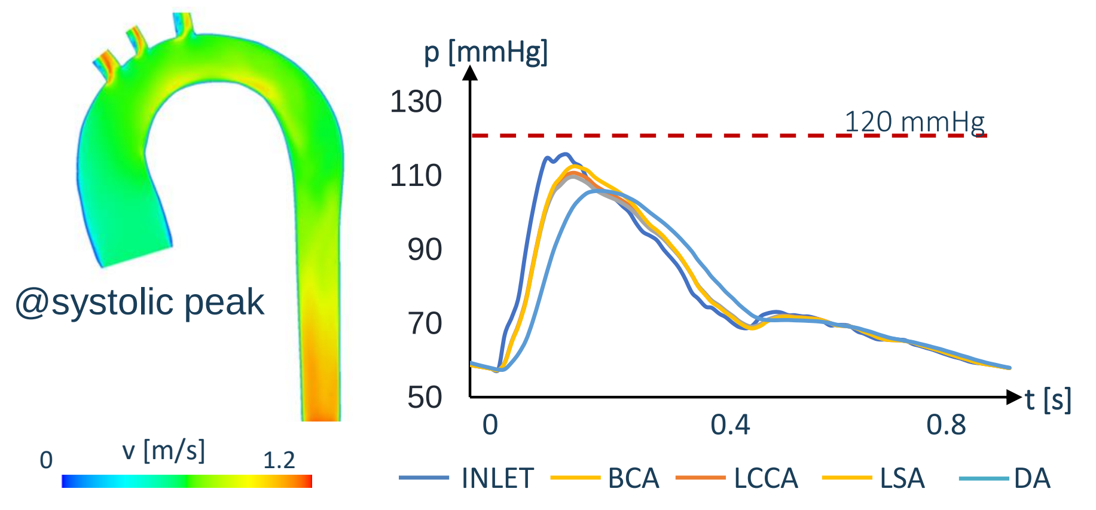
CFD — **FSI**



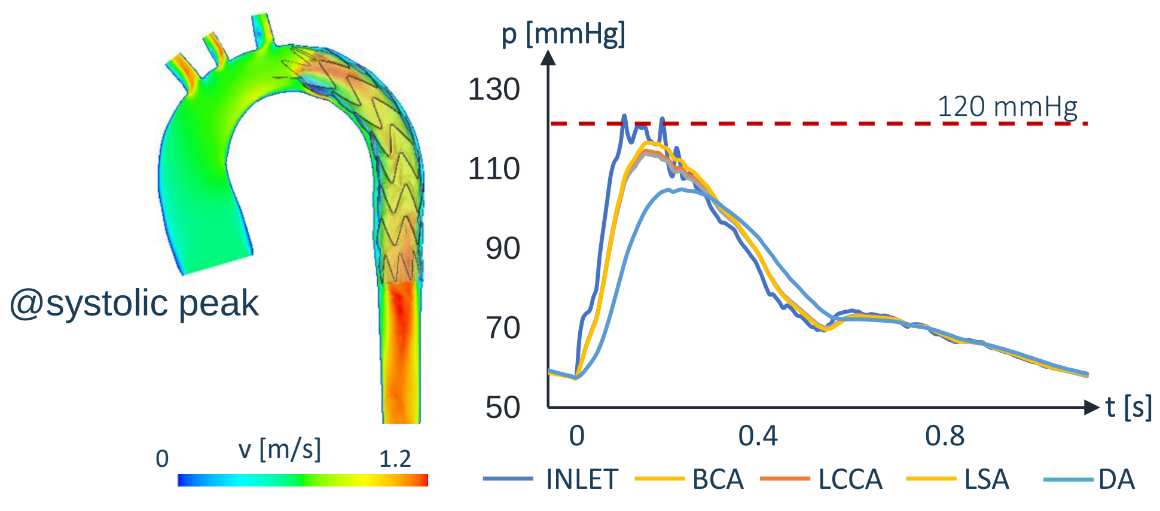
The **FSI analysis is necessary** to account for the material deformability.

FSI PRE-TEVAR VS. FSI-POST TEVAR COMPARISON

PRE-TEVAR



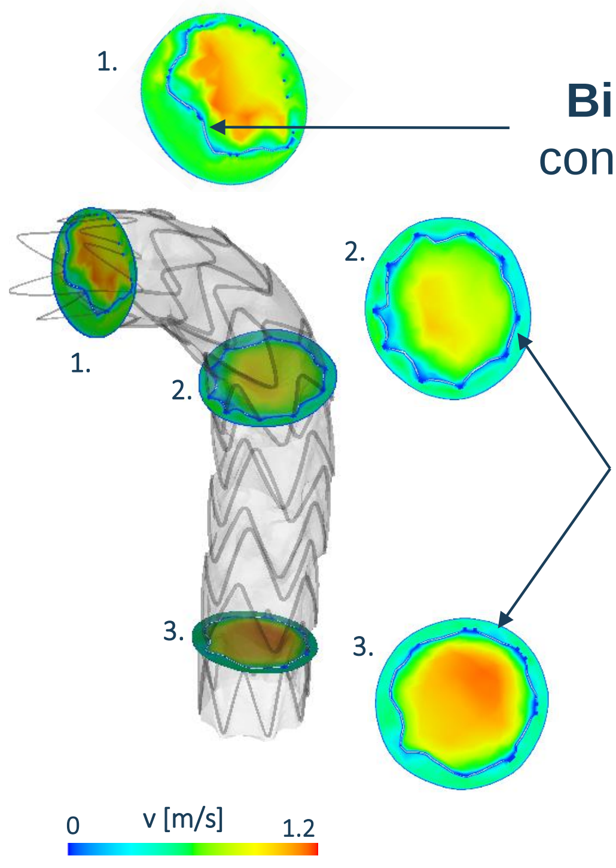
POST-TEVAR



<u>*In the post-TEVAR*</u>:
- Higher velocity in systole
- Higher systolic pressure @INLET, @BCA, @LCCA, @LSA

The device increase the downstream resistance.

TEVAR COMPLICATIONS AND CONSEQUENCES



Bird beak configuration

Endoleak

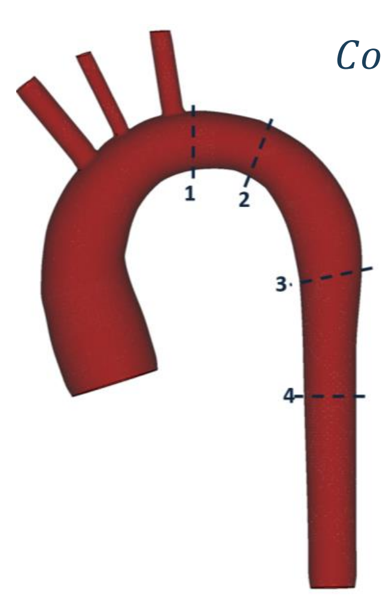
The **device migration** is studied by computing the displacement force (DF) acting on the device *[3]*.

$$DF\ [N] = \int p\, dA + \int \tau\, dA$$

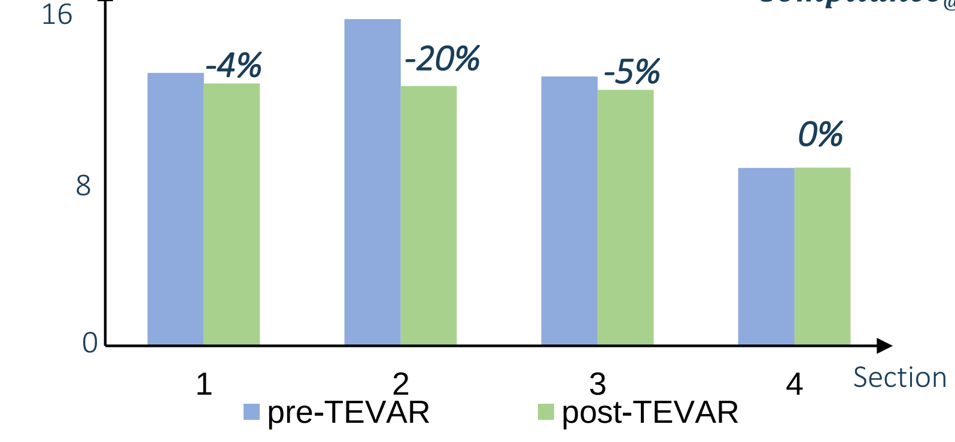
DF direction does not change during the cardiac cycle

The **compliance mismatch** verifies because of a difference in stiffness at the device-arterial wall interface. It is evaluated on 4 sections along the length of the device *[4]*.

$$Compliance\ [mmHg^{-1}] = \frac{1}{A_{sys}} \cdot \frac{A_{sys} - A_{dia}}{p_{sys} - p_{dia}}$$



$$err[\%] = \frac{Compliance_{@post} - Compliance_{@pre}}{Compliance_{@pre}} * 100$$



CONCLUSIONS

This numerical tool can be used both for procedural planning and stent-grafts design optimization to minimize complications. The Windkessel Boundary conditions make the procedure applicable to patient specific cases. Also, common TEVAR complications can be both qualitatively and quantitatively analyzed.
The real novelty – with respect to literature studies – are the complex FSI simulations which take into account for material non linearities and contacts; moreover, the device is embedded into the fluid volume thus allowing some local movements.

AKNOWLEDGEMENTS

This work received founding from the MIUR FISR-FISR2019_03221 CECOMES

References:
[1] Burk et al., J Cardioovasc Magn Reason, 14:1-11, 2012
[3] Marrocco-Trischitta et al., Eur J Vasc Endovasc Surg, 55(4):584-592, 2018
[2] Pirola et al, J Biomech, 60:15-21, 2017
[4] Morris et al., Eur J Vasc Endovasc Surg, 51(1):44-55, 2016

<u>Contact address:</u>
anna.ramella@polimi.it