FLUID-STRUCTURE INTERACTION SIMULATIONS ON TRANSCATHETER AORTIC VALVE IMPLANTATION: DIFFERENT IMPLANTATION SCENARIOS

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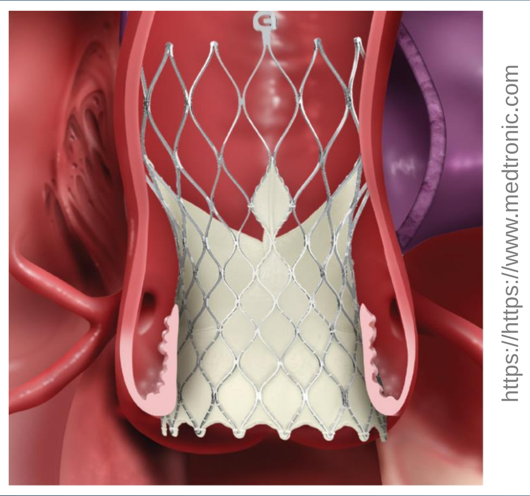
INTRODUCTION

Transcatheter aortic valve implantation (**TAVI**) is a minimally invasive procedure that is being increasingly adopted in the treatment of valvular diseases. In fact, it constitutes a solution for patients with significant contraindications for standard surgery [1]. The procedure consists of the insertion of a stented valve in the aortic root using a catheter. The heart valve (from biological tissue) is mounted within a stent made by a Nitinol super-elastic alloy.



One of the main complications after TAVI is the presence of paravalvular leak (**PVL**) [2], which is led by a malapposition of the stented valve in the aortic root.

This work focuses on a fully parametric modeling of different CoreValve Evolut R valves, which are virtually implanted in parametric stenotic patient models by means of fluid-structure interaction (**FSI**) simulation.

AIM: to compare different implantation scenarios with different device sizes and orientation by means of FSI simulations.

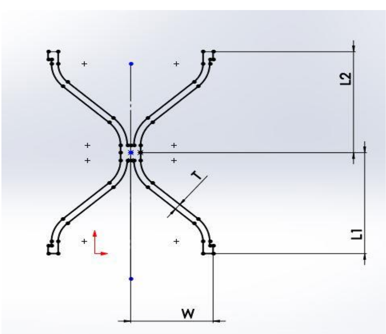
HYPOTHESIS: the valve size and orientation of the implantation strongly affect the numerical results in terms of structure kinematics and PVL estimation.

MATERIALS AND METHODS

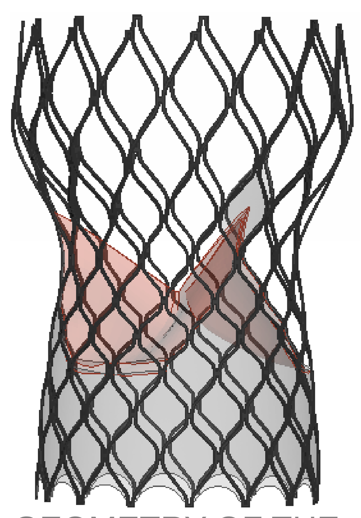
PARAMETRIC DEVICE MODEL

Device's geometries (29 mm and 34 mm of diameter) have been retrieved using illustrations in the literature and realized within SolidWorks 2018.

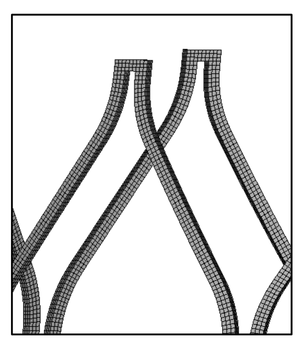
Thereafter FE model has been realized by means of ANSA pre-processor v19.1.1.



PARAMETRIC GEOMETRY OF THE UNIT OF THE STENT

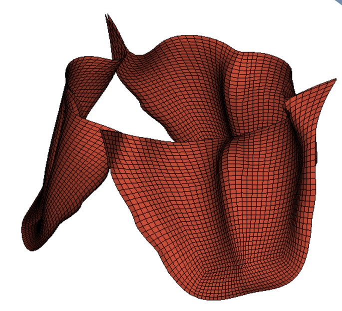


GEOMETRY OF THE DEVICE



STENT 129,130 HEXAHEDRAL SOLID ELEMENTS

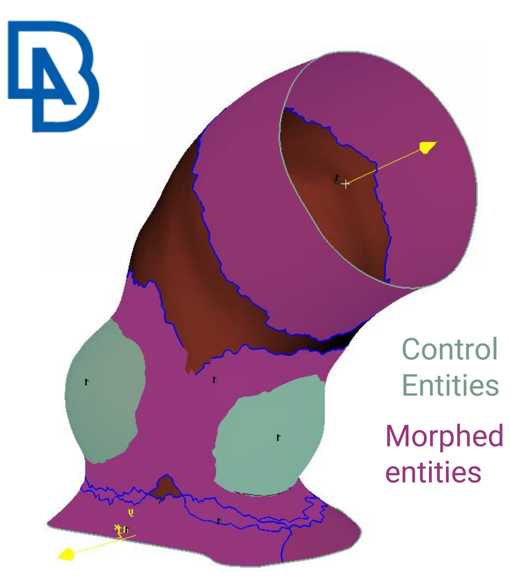
SKIRT 32,883 TRIANGULAR MEMBRANE ELEMENTS



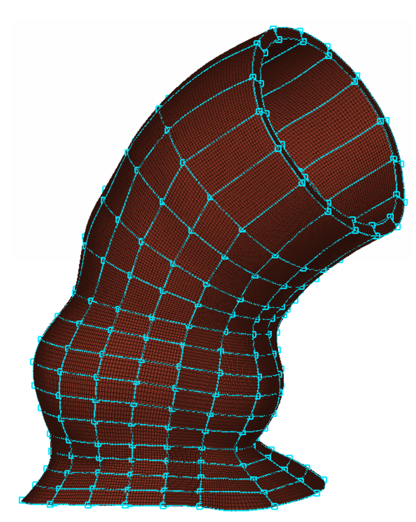
LEAFLETS 3,561 QUADRILATERAL SHELL ELEMENTS

PARAMETRIC PATIENT MODEL

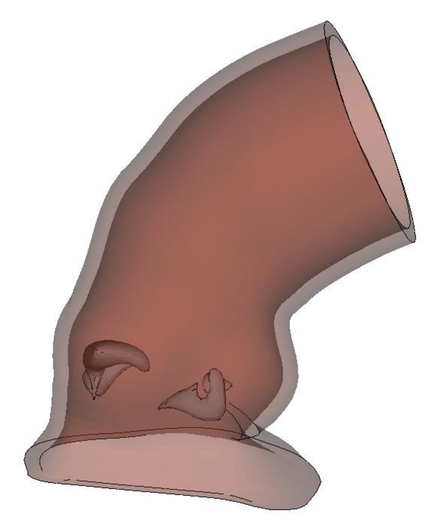
The parametric patient geometry (aorta, native valve and calcifications) has been defined by means of Morphing tool within ANSA pre-processor v19.1.1. A patient with 26 mm of annulus diameter was created and selected for this study.



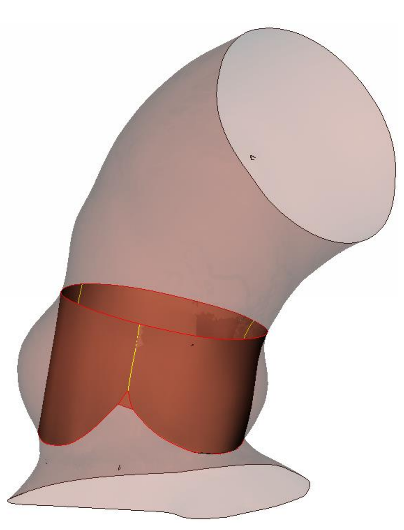
PARAMETRIC GEMEOTRY OF A STENOTIC PATIENT



AORTA 124,392 HEXAHEDRAL SOLID ELEMENTS OBTAINED WITH HEXA BLOCKS APPROACH



CALCIFICATION 10,952 TETRAHEDRAL SOLID ELEMENTS



VALVE 3,150 QUADRILATERAL SHELL ELEMENTS

MATERIAL MODELS

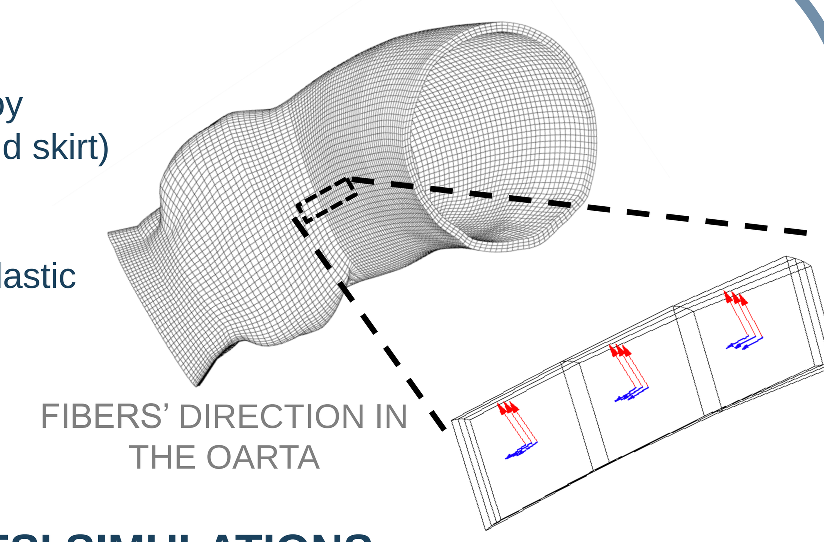
STENT
shape memory alloy

PERICARDIUM (leaflets and skirt)
linear elastic

AORTA
anisotropic hyperelastic

VALVE
linear elastic

CALCIFICATION
elasto-plastic



FIBERS' DIRECTION IN THE OARTA

FSI SIMULATIONS

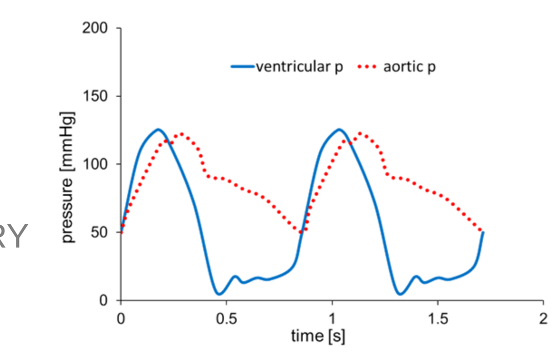
LS-DYNA

The FSI simulations were performed using a non-boundary fitted method [3] implemented in LS-DYNA 971 Release 10.1. All the structures were immersed in a fluid domain and the blood was modeled as a Newtonian fluid.

STEPS

- the valve, was crimped down in a catheter of 9 mm diameter,
- the crimped valve was positioned coaxially to the aorta and released by unsheathing the rigid catheter.
- Once the valve was implanted, idealized pressure curves were applied to the fluid domain to reproduce two cardiac cycles.

FLUID DOMAIN AND PRESSURE BOUNDARY CONSITIONS



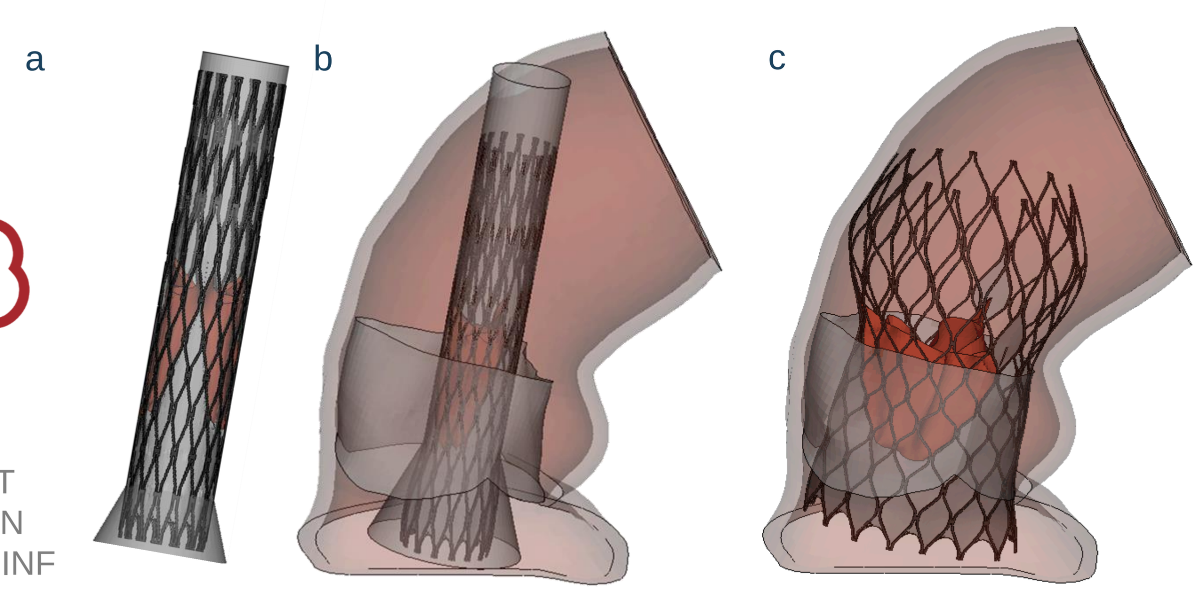
IMPLANTATION SCENARIOS

Two different valve sizes in two different orientations:

- CoreValve R29 - reference and 60 degrees rotated
- CoreValve R34 - reference and 60 degrees rotated

RESULTS

The four implantation scenarios was successfully modeled (in the figure only one implantation is shown). All the results were analyzed with META post-processor v19.1.1



a) CRIMPING OF THE VALVE IN THE CATHETER
b) POSITION INTO THE PATIENT
c) EXPANSION OF THE VALVE IN THE PATIENT BY UNSHEATHINF THE CATHTER

VASCULAR DAMAGE

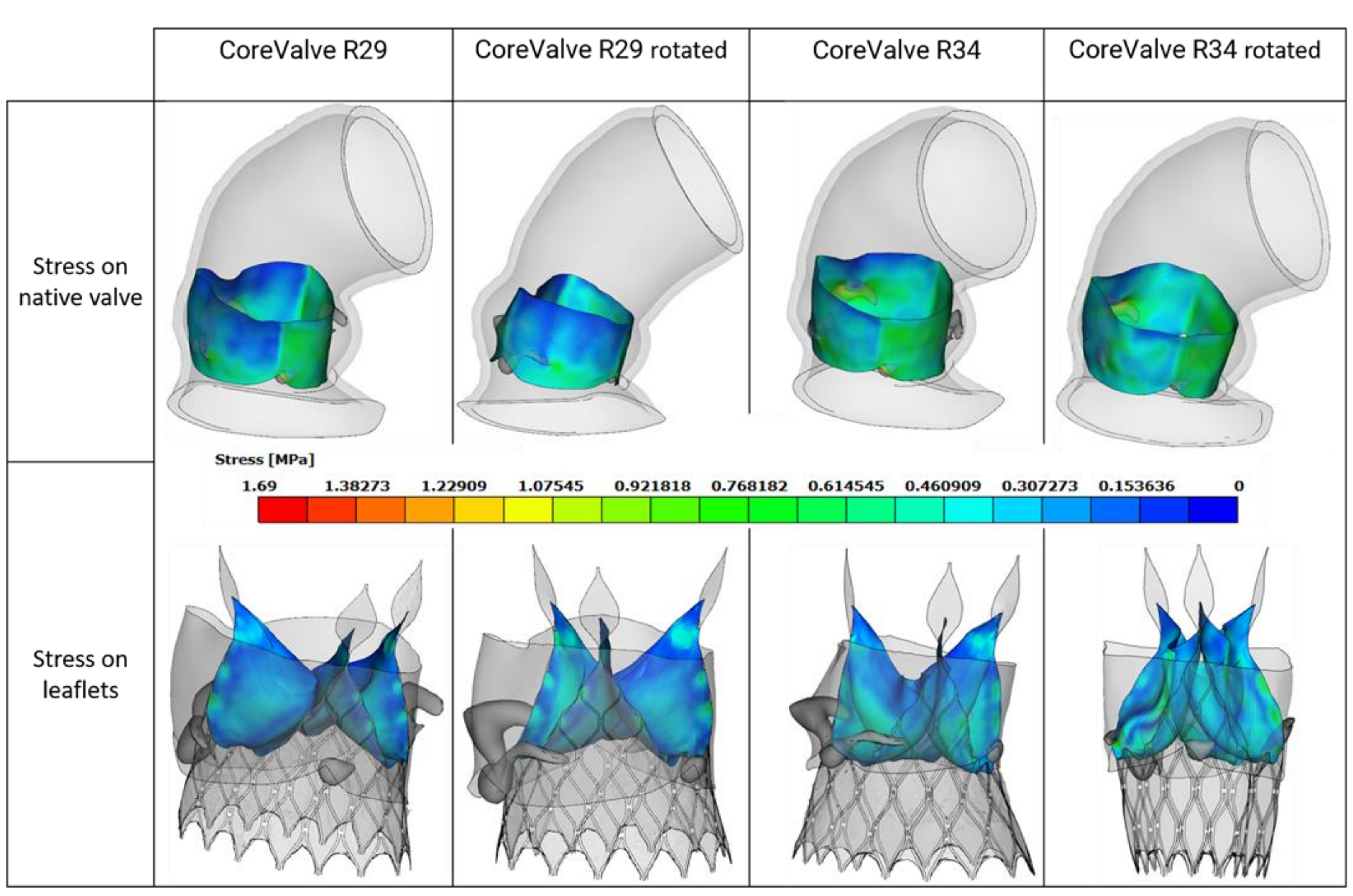
Higher stresses are reached with device CoreValve R34 in the rotated configuration during the whole cardiac cycle.

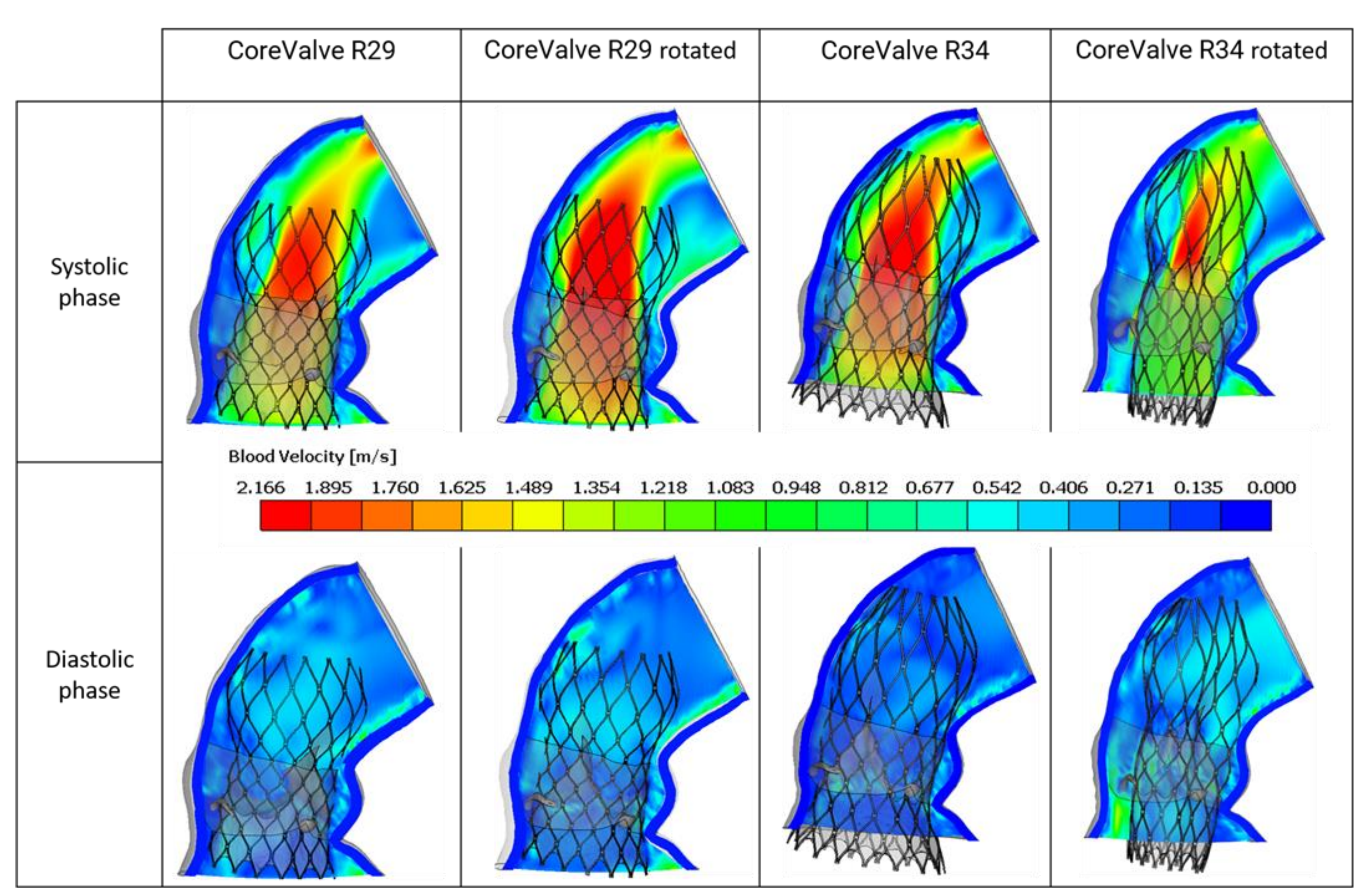
PERICARDIUM LEAFLETS DAMAGE

Highest stresses are detected during the diastole in the commissure region and in the central area of each leaflet. Due to the larger dimensions of the CoreValve R34, the stresses are higher and more uniformly distributed as compared to the case with the CoreValve R29.

HEMODYNAMICS

Blood reaches higher velocity in case of CoreValve R34 during both diastolic and systolic phases. In fact, for the CoreValve R34, the maximum velocity was equal to 2.93 m/s, whereas for the CoreValve R29, in both configurations, the maximum velocity did not exceed 2.51 m/s.





CONCLUSIONS

The developed FSI methodology, used to study the impact of different valve size and orientation on the procedure outcome *in silico*, proves to be a **valuable tool able to faithfully represent the actual problem faced and therefore to drive clinicians in the crucial pre-surgery phase**. In this particular "virtual" patient, the obtained results allow to conclude that, from a hemodynamic viewpoint, the 29 mm of diameter device, due to its dimensions with respect to aortic anatomy, is the best implantation option to ensure a PVL reduction. it is also proven that it is possible to significantly reduce the PVL by implanting the device with a rotation of 60 degrees with respect to the reference direction, which represents the best possible configuration.

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References:

[1] Smith et al., N Engl J Med., 2011.
[2] Genereux et al., J. Am. Coll. Cardiol., 2013.
[3] Luraghi et al., CVET, 2019.