IMPACT OF AORTIC TISSUE ANISOTROPY AND VALVE CALCIFICATION ON PATIENT-SPECIFIC TRANSCATHETER AORTIC VALVE IMPLANTATION SIMULATIONS

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INTRODUCTION

Transcatheter aortic valve Implantation (TAVI) is a minimally invasive treatment for high-risk or inoperable patients with aortic stenosis, such as old aged people: the increasing life expectancy is going to make this pathology more widespread and so the use of TAVI [1].
The stresses produced on the tissue of the left ventricular outflow tract (LVOT) during the deployment of the transaortic valve are a critical aspect of this treatment.

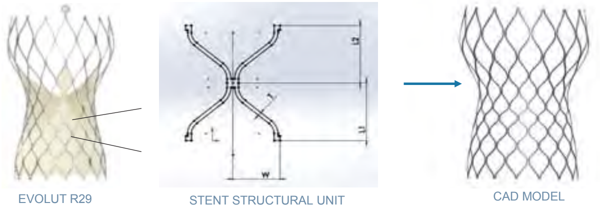
The forces exert by the valve on the arterial wall may be sufficient to prevent the migration of the valve without altering the normal functioning of the heart [2]. In addition, the correct positioning of the valve is key for a successful intervention.
This work focuses on a fully parametric modeling of different CoreValve Evolut R valves and the computational structural simulation of the implantation in the aortic root.

AIM: development of a patient-specific structural model to evaluate the influence of the natural mechanics of the native aortic root and native valve on TAVI.

MATERIALS AND METHODS

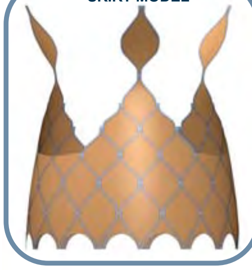
CAD MODEL

STENT MODEL



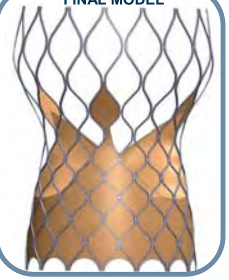
PARAMETRIZABLE VARIABLES:
- L1: length of lower part
- L2: length of upper part
- T: circumferential thickness
- W: width
- Radial thickness

SKIRT MODEL

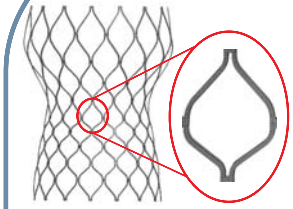


LEAFLETS MODEL

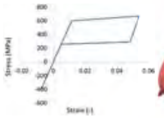
FINAL MODEL



NUMERICAL MODEL



STENT (Nitinol)
48,240 hexahedral solid elements



VALVE
1,859 quadrangular shell elements
$E = 3\ MPa$
$\upsilon = 0.3$
$\rho = 1{,}100\ kg/m^3$

CALCIUM
38,429 tetrahedral solid elements

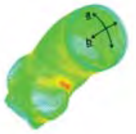
a. ELASTIC
$E = 10\ MPa$
$\upsilon = 0.4$
$\rho = 2000\ kg/m^3$

b. PLASTIC
$E = 10\ MPa$
$\upsilon = 0.4$
$\sigma_y = 0.1\ MPa$
$Et = 1\ MPa$
$\rho = 2000\ kg/m^3$

AORTA
35,640 hexahedral solid elements

c. ELASTIC
$E = 2\ MPa$
$\upsilon = 0.3$
$\rho = 1{,}100\ kg/m^3$

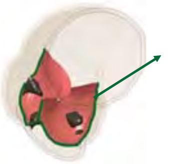
d. ANISOTROPIC HYPERLASTIC



FE SIMULATION

The structural simulation is performed using the explicit solver LS-DYNA 971 (LSTC). The valve leaflets, calcium and aorta, are subjected to the forces due to the release of the stent in the aortic root. The morphology and the material parameters of these structural elements are depend on the clinical situation of the patient .

AORTIC ROOT
- Fixed ends

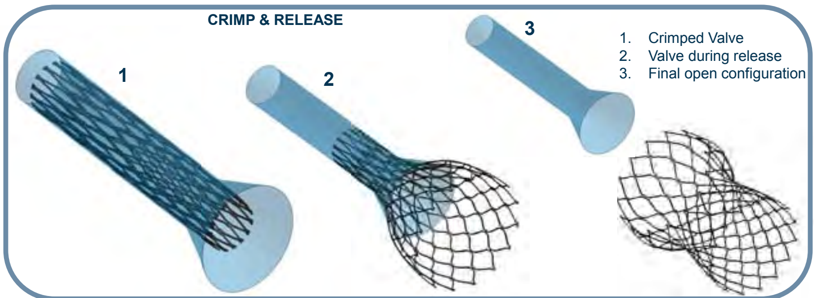


COMMISSURE EDGE
- Tied nodes

OUTPUT
- Calcified valve kinematics
- Stress-strain fields on stent, aorta and valve

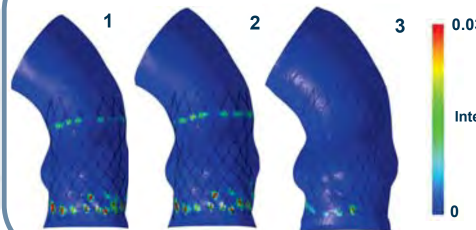
RESULTS

CRIMP & RELEASE



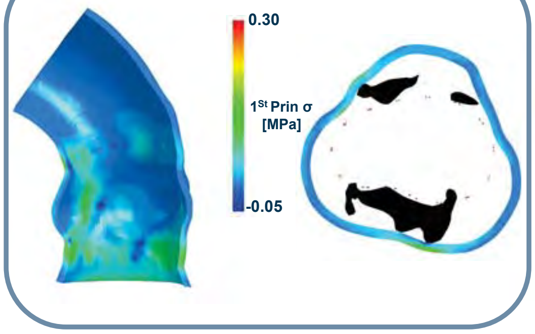
1. Crimped Valve
2. Valve during release
3. Final open configuration

RESULTANT INTERFACE FORCES

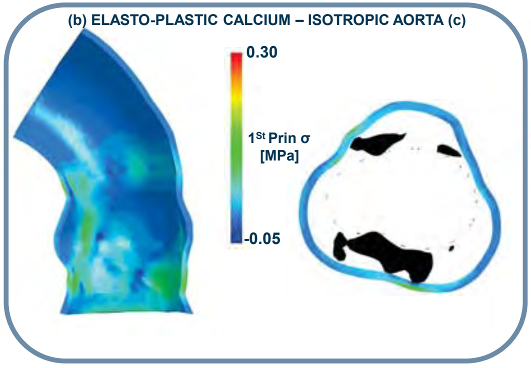


1. **(a) elastic calcium – isotropic aorta (c)**
2. **(b) elasto-plastic calcium – isotropic aorta (c)**
3. **(a) elastic calcium – anisotropic aorta (d)**

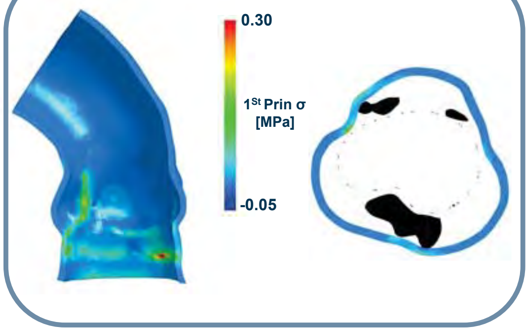
(a) ELASTIC CALCIUM – ISOTROPIC AORTA (c)



(b) ELASTO-PLASTIC CALCIUM – ISOTROPIC AORTA (c)



(a) ELASTIC CALCIUM – ANISOTROPIC AORTA (d)



CONCLUSIONS

Results show a significant **impact of the mechanical behavior of the aorta on the deployed geometry of the valve and on the stress field generated in the aorta after valve deployment**.
In this particular, larger and more localized stresses around the anulus of the native valve are obtained with the anisotropic aortic model. This stress concentration could be related to the generation of cardiac arrythmias after TAVI. In addition, the effect of aorta anisotropy on the deployed geometry of the valve may impact the sensitivity of valve performance to TAVI malapositioning.

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References: [1] O' Brien KD et al. *J Invest Med 2007;55:284-291* [2] S. Tzamtzis et al. Medical Engineering & Physics 2013;35:125–130