A FLUID-STRUCTURE INTERACTION PATIENT-SPECIFIC COMPUTATIONAL METHODOLOGY TO STUDY AORTIC ROOTS WITH NATIVE CALCIFIED VALVES

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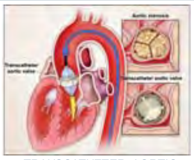
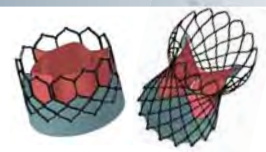
INTRODUCTION

The representation of the real patient's condition with truthful anatomy, materials and working conditions is the first step to be achieved to model minimally invasive treatment for high-risk patients with aortic diseases like the transcatheter aortic valve implantations (TAVI). This work focuses on the pre-implantation step of a wider clinical study on TAVI.

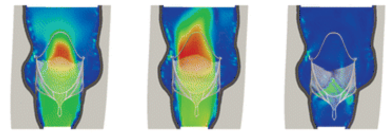


TRANSCATHETER AORTIC VALVE REPLACEMENT [1]

The Fluid-Structure interaction (FSI) modelling is the best numerical approach for reproducing both the valves mechanics and the hemodynamics [2]. A recent scientific publication on percutaneous valves involving FSI [3] demonstrates the potentiality of the numerical method for being used in patient-specific cases.



CAD MODELS OF BALLON-EXPANDABLE AND SELF-EXPANDABLE DEVICES FOR TAVI PROCEDURE



FEASIBILITY STUDY ON FSI ANALYSIS TO MODEL TAVI PROCEDURE [3]

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

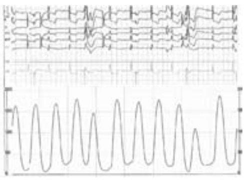
MATERIALS AND METHODS

1 - PATIENT-SPECIFIC DATA ACQUISITION

Patient-specific data are collected from routinely acquired exams, including computed tomography (CT), Doppler and pressure curves measurements. The patient, suffering from aortic stenosis, is part of our database, which currently includes 8 patients treated at Humanitas Hospital before TAVI.

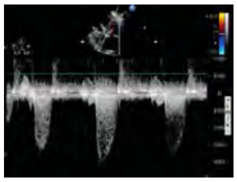
CT

Geometry reconstruction:
- Aorta and valve leaflets
- Calcium sites



PRESSURE

Boundary Conditions:
- Ventricular pressure
- Aortic pressure

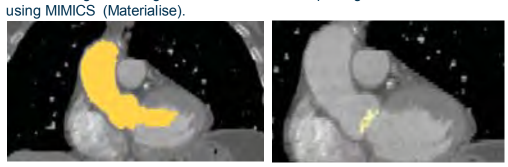


DOPPLER

Comparison with numerical results:
- Flow rate
- Maximum velocity

2 - GEOMETRY RECONSTRUCTION

The CT images are segmented to create a complete geometrical model of the aortic root with the calcified valve using MIMICS (Materialise).



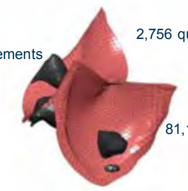
LEAFLETS RECONSTRUCTION by identified reference points [4] in HYPERMESH (Altair).

AORTIC LUMEN

CALCIFICATION and AORTIC WALL

3 - NUMERICAL MODEL

AORTA
26,730 hexahedral solid elements
$E = 2\ MPa$
$\upsilon = 0.45$
$\rho = 1100\ kg/m^3$



VALVE
2,756 quadrangular shell elements
$E = 8\ MPa$
$\upsilon = 0.45$
$\rho = 1100\ kg/m^3$

CALCIFICATION
81,139 tetrahedral solid elements
$E = 10\ MPa$
$\upsilon = 0.3$
$\rho = 2000\ kg/m^3$

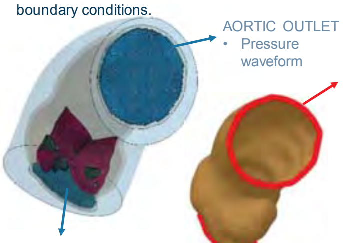
BLOOD
212,547 eulerian 8-node elements
$\rho = 1060\ kg/m^3$
$\mu = 3\ cP$

CONTACT
- Tied contact aorta – leaflets
- Tied contact leaflets – calcium deposits
- Automatic contact aorta – calcium deposits
- Self contact leaflet - leaflet

FLUID-STRUCTURE INTERACTION
- Aorta and calcified valve with blood

4 - FSI SIMULATION

The FSI simulation is performed using the non-boundary fitted method implemented in LS-DYNA 971 (Ansys, Inc.). The structures, valve leaflets and aorta, are totally immersed in the fluid grid and the interaction is given by a transfer of forces. Ventricular and aortic pressure waveforms, derived from the patient's data, are used as boundary conditions.

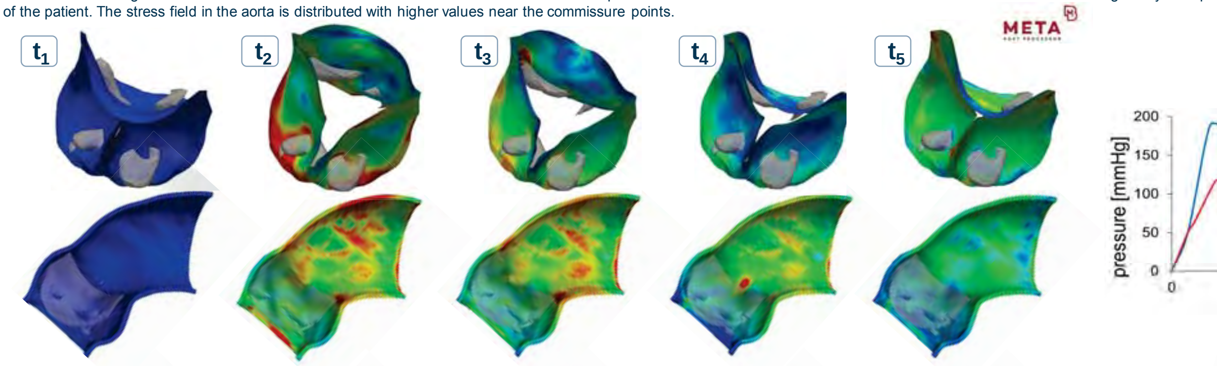


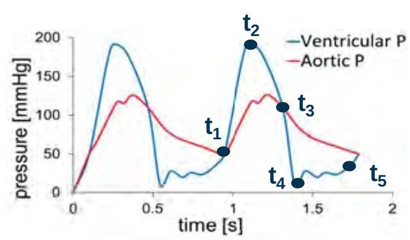
OUTPUT
Structure:
- Calcified valve kinematics
- Stress-strain fields on aorta and valve

Fluid:
- Velocity field
- Flow rate

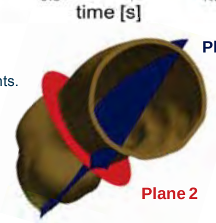
RESULTS

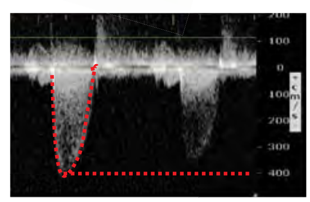
VALVE AND AORTA: The region of the native valve with maximum stress is located at the calcium deposits and the commissures. The aortic valve area between the leaflets during the systolic peak is 1.47 cm², congruent value with the aortic stenosis of the patient. The stress field in the aorta is distributed with higher values near the commissure points.





BLOOD: The FSI model predicts a blood flow rate of 4.1 l/min and a total regurgitant flow through the stenotic valve of 0.51 l/min, which is consistent with the Doppler peak velocity measurements. The maximum velocity in the FSI simulation is 4.2 m/s.





CONCLUSIONS

A complete FSI model representing the pre-implantation scenario of a patient suffering from aortic stenosis was implemented. The innovative aspects regarding the FSI methodology are the use of patient-specific anatomy and boundary conditions, and the inclusion of calcifications, which lead to macroscopic variations of potential clinical relevance [4]. In conclusion, **the development of realistic and accurate FSI patient-specific models can be used as a support for clinical decisions before valve implantation**.

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References:
[1] Smith CR et al. *N Eng J Med.* 2011; 364: 2187-2198.
[2] Luraghi G et al. *J Biomech.* 2017; 58: 45-51.
[3] Wu W et al. *Ann Biomed Eng.* 2016; 44(2): 590-603.
[4] Morganti et al. *J Biomech.* 2014; 47: 2547-2455.