UNIVERSITA' degli STUDI di ROMA
TOR VERGATA

Role of Computational Simulations in Heart Valve Dynamics & Design of Valvular Prostheses

Maria Antico
Supervisor Prof. Roberto Verzicco
Engineering Sciences

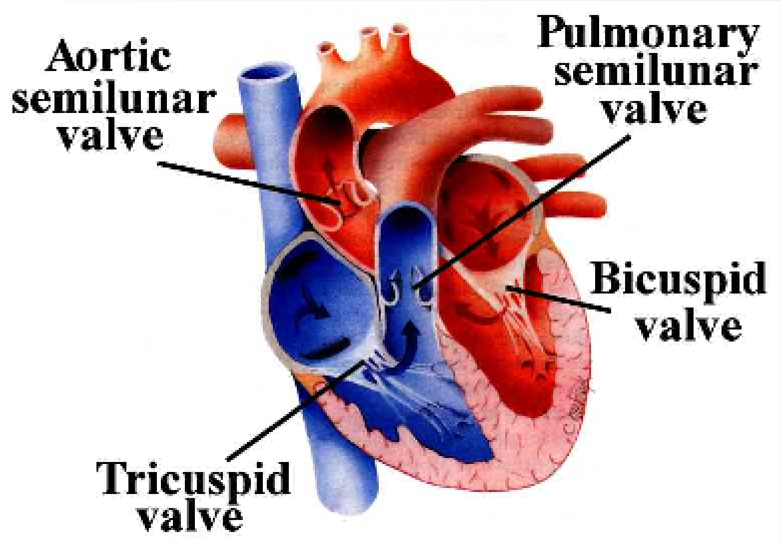
The importance of Computational Simulations

Computational Simulations are increasingly playing a major role in our ability to analyze:

- Normal Human Physiological function
- Etiology of Diseased States
- Design and Evaluation of artificial implants

DIFFERENT STUDIED CASES

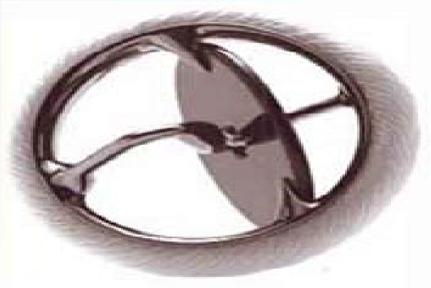
NATIVE VALVES



PROSTHETIC VALVES

BIOPROSTHETIC

MECHANICAL



DYNAMIC SIMULATION

The Dynamic Simulation for Heart Valves can be divided into two categories:

FINITE-ELEMENT (FE) STRUCTURAL ANALYSIS

Structural Analysis on Valvular Apparatus

FLUID-STRUCTURE INTERACTION (FSI) ANALYSIS

Structural Analysis on Valvular Apparatus and Fluid Dynamic Analysis of blood flow past the valve

AIM OF FINITE-ELEMENT STRUCTURAL ANALYSIS

NATIVE VALVES

To have a basis for comparison

Understand diseases of non-healthy valves

BIOPROSTHETIC VALVES

To detect regions of **higher stress distribution**, that are strongly related to **leaflet calcification** (main problem for BHV)

Optimize the design and valve repair strategies

MECHANICAL VALVES

Not commonly performed

Application

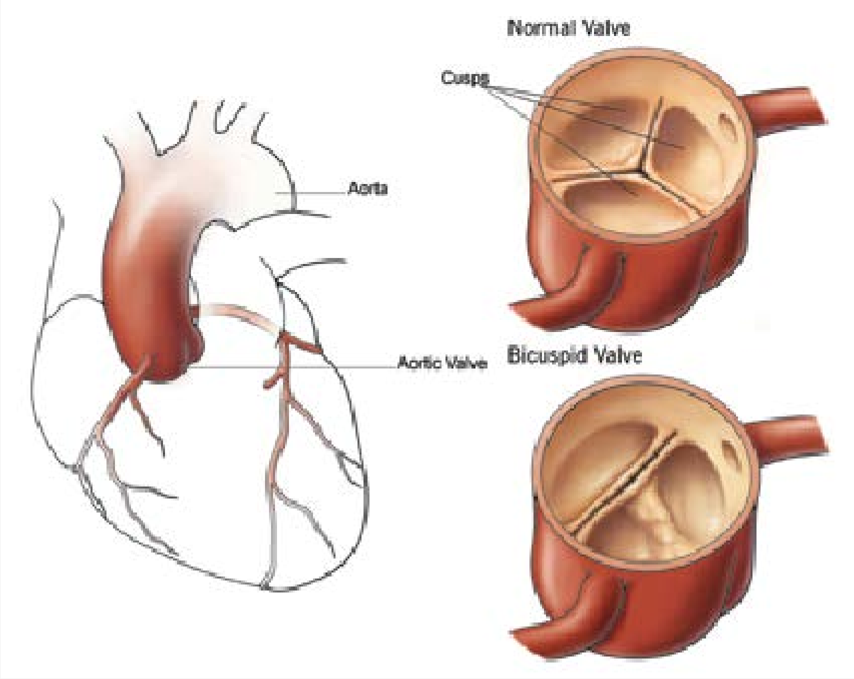
CONGENITAL BICUSPID AORTIC VALVE (CBAV)

STATISTICAL DATA

- It is prevalent in 1-2% of the population
- The 30-50% will face clinical complications (stenosis, regurgitation)

ANALYSIS DESCRIPTION

- Non- linear anisotropic material description
- Performed with the leaflet in fully closed position (Pressure on the aortic side $\sim 80\ mm\ Hg$)



FINITE-ELEMENT (FE) STRUCTURAL ANALYSIS

Application

COMPARISON BETWEEN NORMAL TRICUSPID AORTIC VALVE (TAV) AND CONGENITAL BICUSPID AORTIC VALVE (CBAV)

$$\tau_{eq} = \frac{1}{\sqrt{3}} \sqrt{\tau_{11}^2 + \tau_{22}^2 + \tau_{33}^2 - \tau_{11}\tau_{22} - \tau_{22}\tau_{33} - \tau_{11}\tau_{33} + 3(\tau_{12}^2 + \tau_{23}^2 + \tau_{13}^2)}$$

CRITICAL RESULTS:

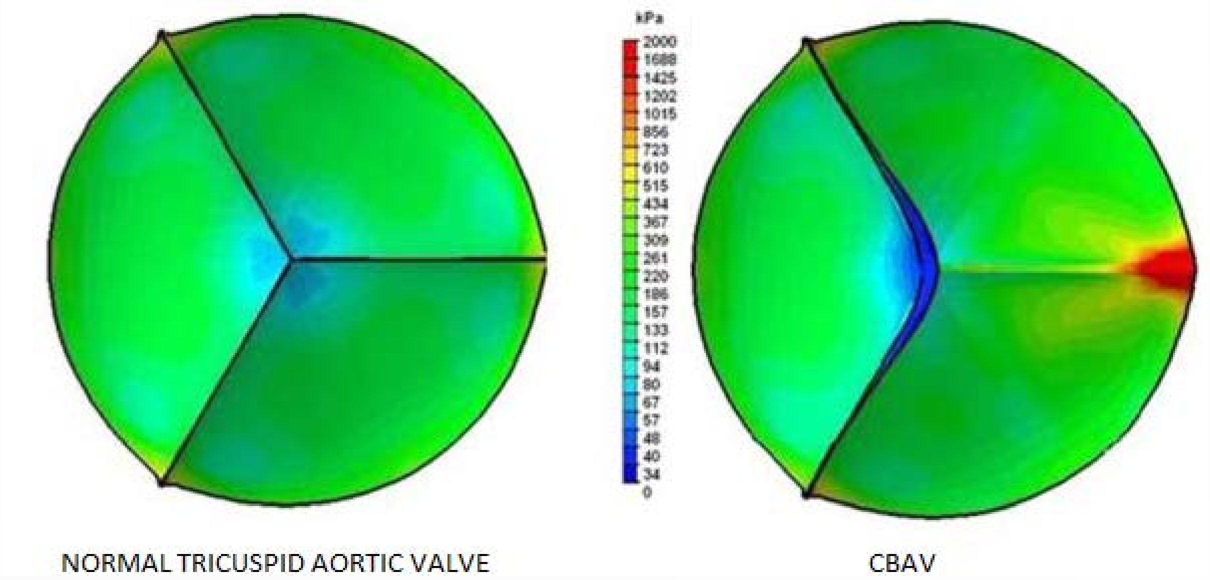
- At the extreme right edge:

(TAV) ⟶ $\tau_{eq} \sim 300$ Kpa

(CBAV) ⟶ $\tau_{eq} \sim 1400$ KPa

- At the center:

inefficient leaflet closure ⟶ INCOMPETENCY RISK



VON MISES STRESS DISTRIBUTION

AIM OF FLUID-STRUCTURE INTERACTION ANALYSIS

NATIVE & BIOPROSTHETIC VALVES

To perform a more detailed analysis, considering fluid-induced stresses contribution

MECHANICAL VALVES

Investigate on **fluid-induced stresses,** that are stricty related to propensity for **thrombosus deposition**
(main problem for MHV)

Optimize their design

FLUID-STRUCTURE INTERACTION (FSI) ANALYSIS

Application

PLATLETS SIMULATION

FLOW-INDUCED STRESSES → **PLATLETS ACTIVATION**

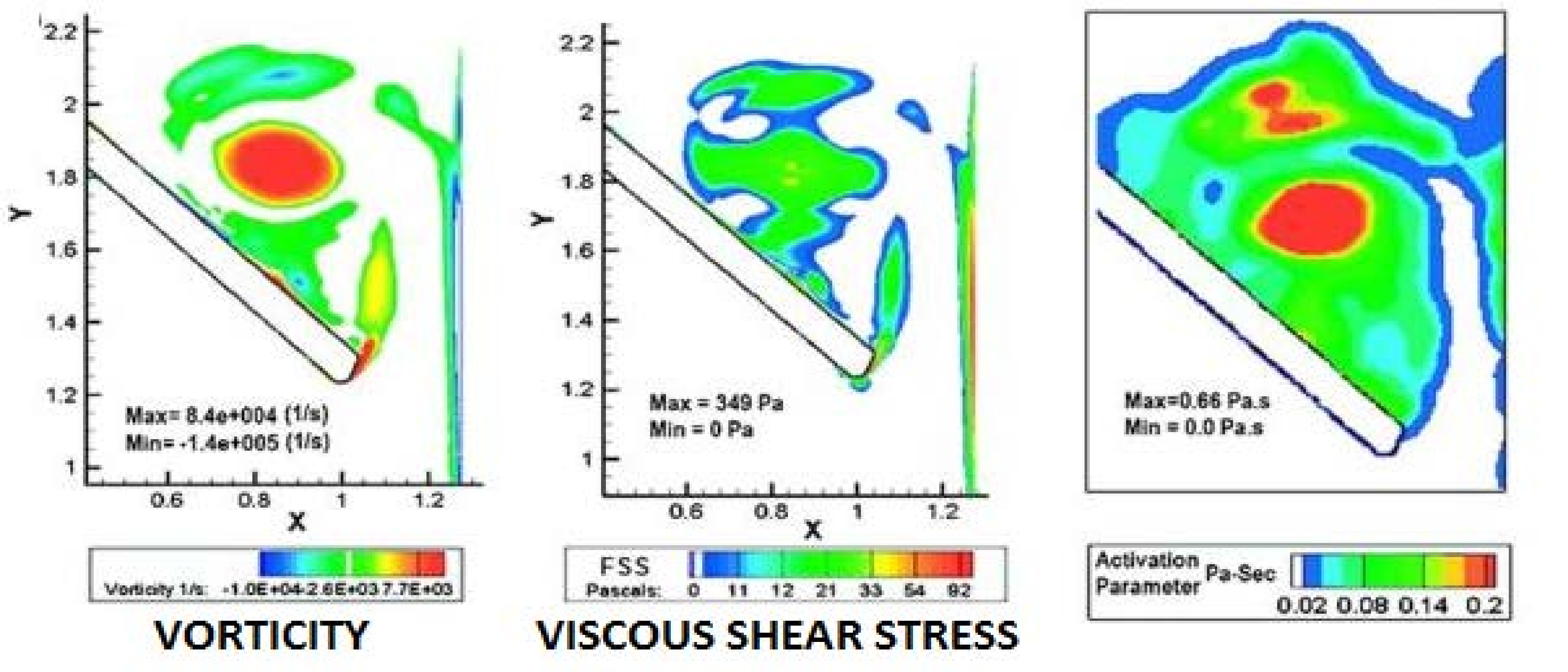
ANALYSIS DESCRIPTION

- Bileaflet Mechanical Valve in mitral position at instant of valve closure (angular velocity: $\omega = 349{,}07\ {}^{rad}/_{s}$)
- Particle Dynamic Analysis employed (point sphere radius: $r = 2\mu m$, blood density: $\rho = 1056\ {}^{kg}/_{m^3}$)
- Local mesh refinment incorporated in the flow solver through the gap width (regions of high velocity and vorticity gradients highly refined)

FLUID-STRUCTURE INTERACTION (FSI) ANALYSIS

Application

PLATLETS SIMULATION



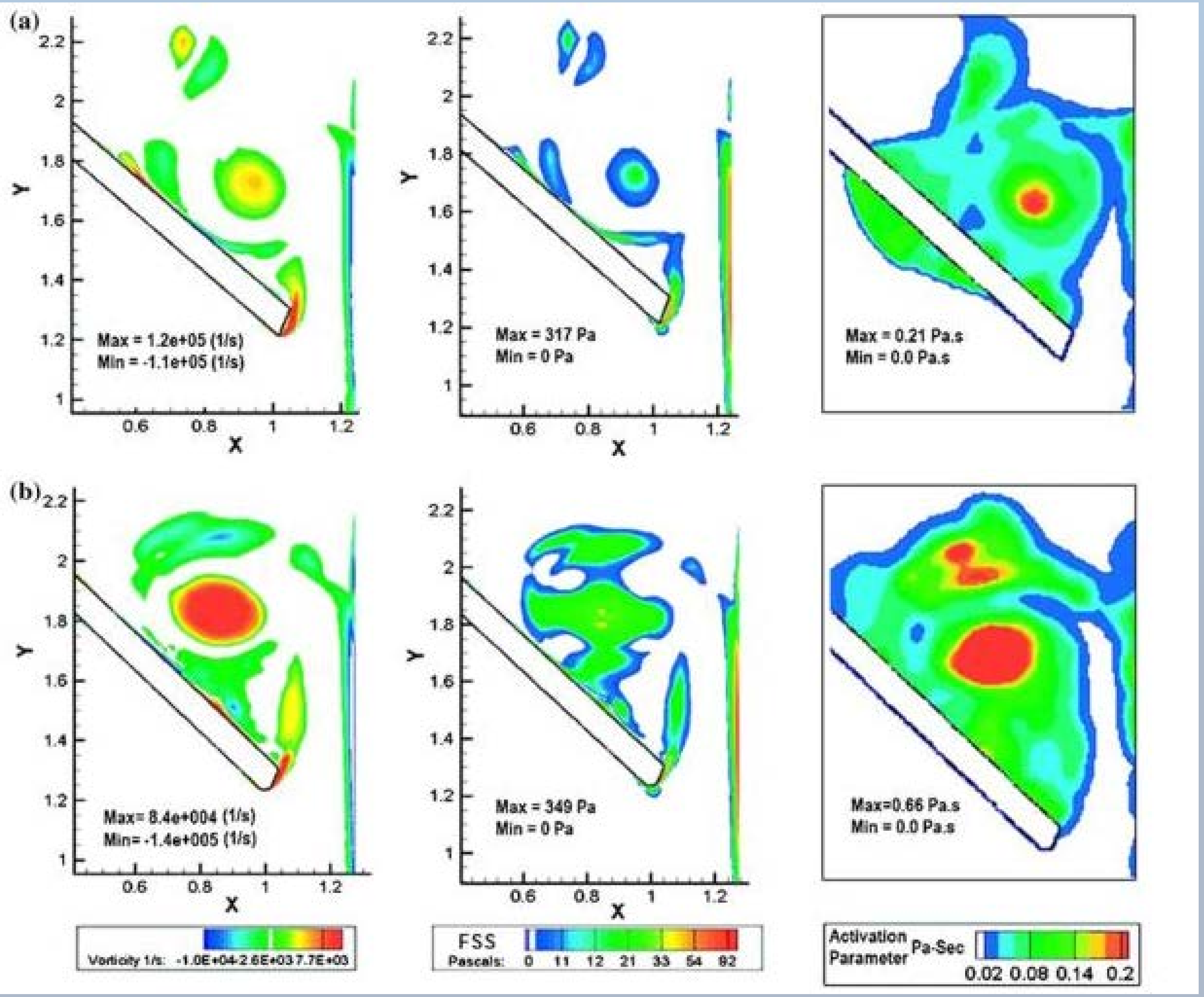
RESULT: Potential for thrombosus deposition on the leaflet structure during the closing phase of the valve

FLUID-STRUCTURE INTERACTION (FSI) ANALYSIS

Application

RESULTS COMPARED FOR TWO BILEAFLET VALVE WITH DIFFERENT TRANSVERSE ANGLE

On the top: bileaflet valve transverse angle of 55°
On the bottom: bileaflet transverse angle of about 64°



RESULT

Higher transverse angle

↓

Higher possibility for platlets activation

CONCLUSIONS

- Through *Computational Simulations* both Native and Artificial Valves can be accurately analysed.

- However, due to the wide disparity in length scales, *Multi-Scale Simulations* accounting for both temporal and spatial scale variations need to be developed in order to describe these events in a more realistic way.

Thank you for your attention!