# Cardiovascular Disease Modelling

## Towards Improved Diagnostic Correlations

**Faculty of Engineering**

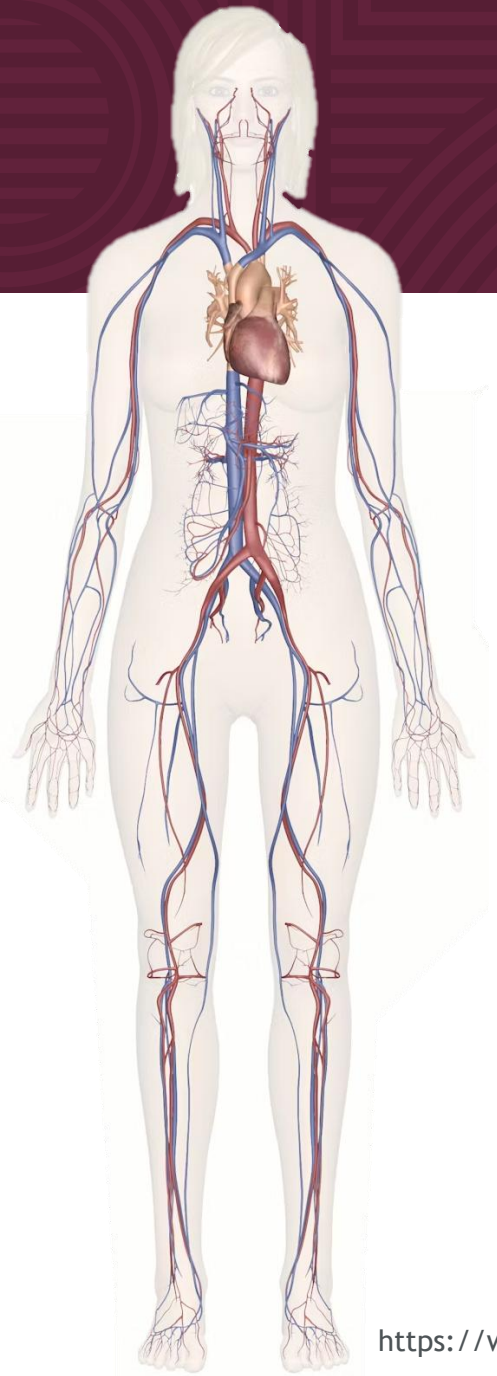
Industry Showcase 2026

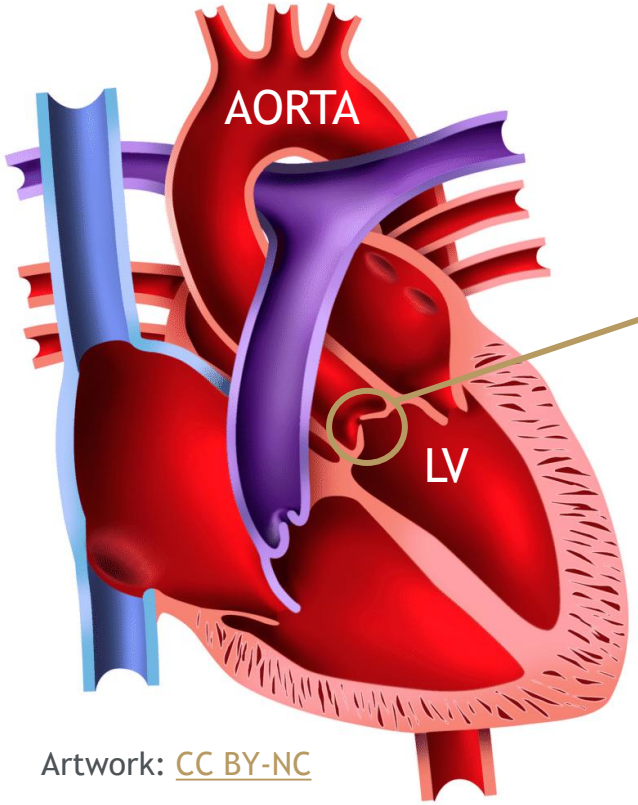
Dr Lindi Kock

Department of Mechanical and Mechatronic Engineering

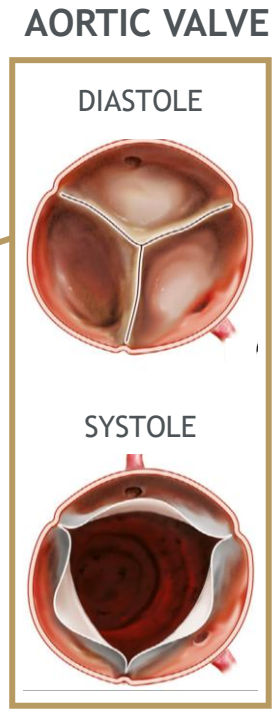
Photo by Stefan Els

# The Cardiovascular System







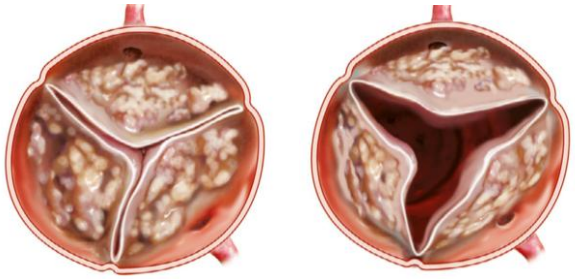



- Opens/closes ~100,000 times per day
- Two types of valve diseases
  1. aortic stenosis (AS)
  2. aortic regurgitation (AR)

https://www.innerbody.com/image/cardov.html

# Aortic Stenosis

## Calcific Aortic Stenosis — CAS



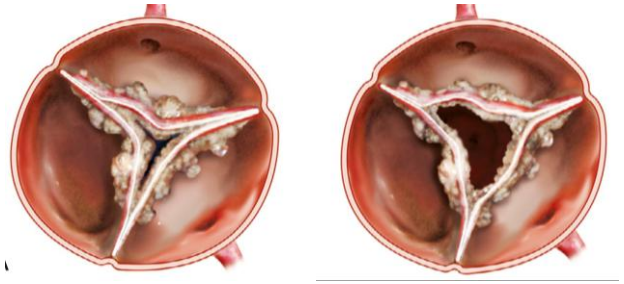
Mechanism:

- Degeneration
- Progressive calcification & fibrosis

Epidemiology:

- Most common in western countries (>65 yrs.)
- 12.6M cases globally in 2017

## Rheumatic Aortic Stenosis — RAS



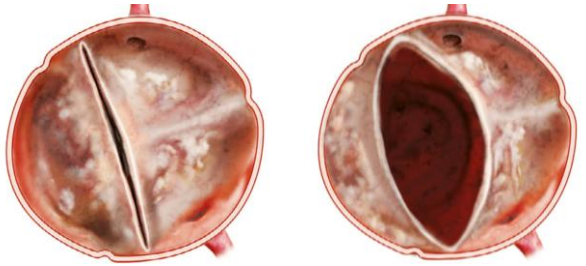
Mechanism:

- Infection – rheumatic heart disease (RHD)
- Commissural fusion

Epidemiology:

- Dominant in low-income countries
- 40M+ RHD cases globally

## Bicuspid Aortic Valve — BAV



Mechanism:

- Congenital malformation
- Two leaflets instead of three

★ *Current research*

Epidemiology:

- ~2% of population
- Most common congenital heart defect
- Higher risk of early CAS

# Clinical Evaluation

- Diagnosis of AS:
  ➔ peak velocity + valve area (AVA)
  + mean pressure gradient (ΔP)

measured

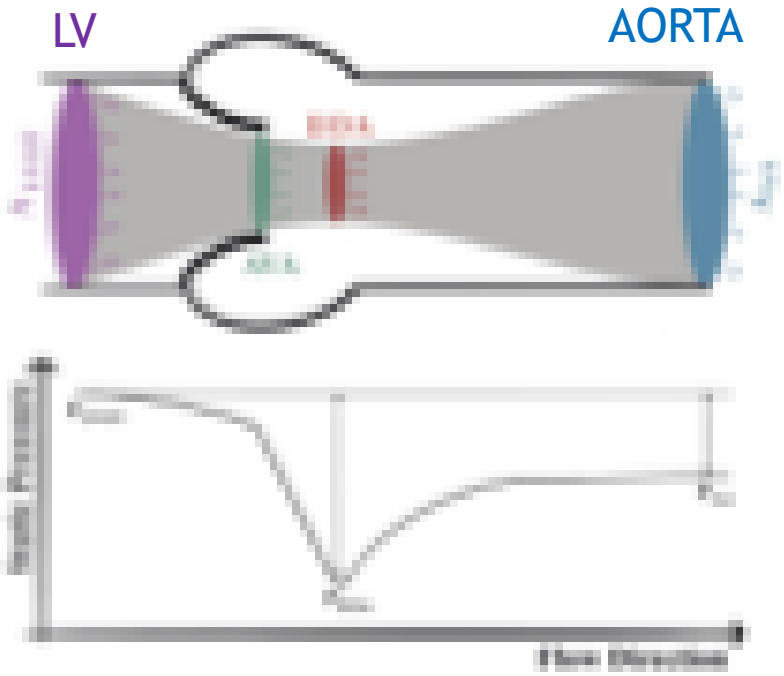
- Simplified Bernoulli equation ➔ ΔP

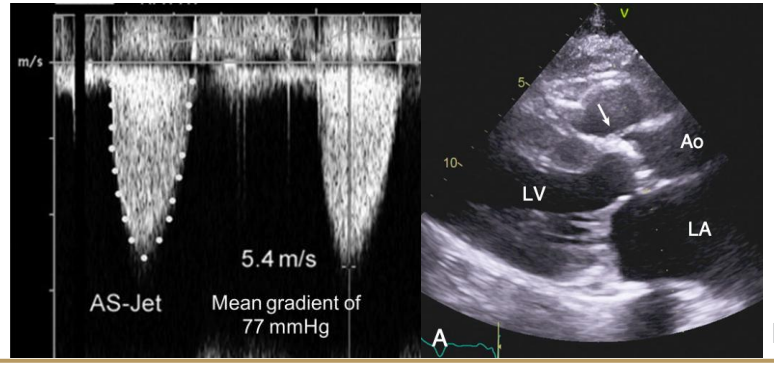
$$\Delta P = 4 \times V_{EOA}^{2}$$

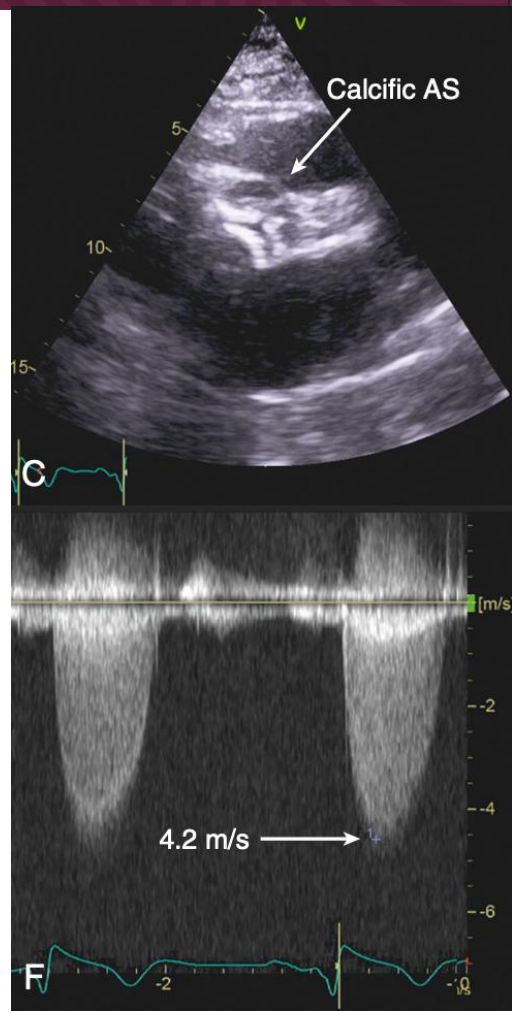
V = peak EOA velocity (m/s) | ΔP in mmHg

  - Assumes steady, inviscid, isentropic flow
  - Morphology-insensitive

- Different morphologies ➔ different flow characteristics



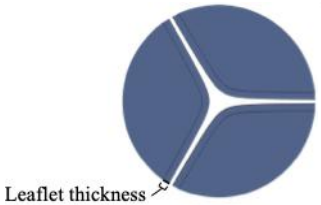



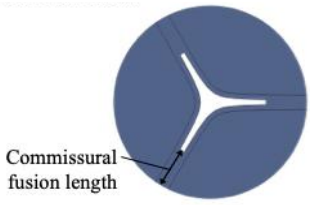
# Modelling Approaches

## Valve models

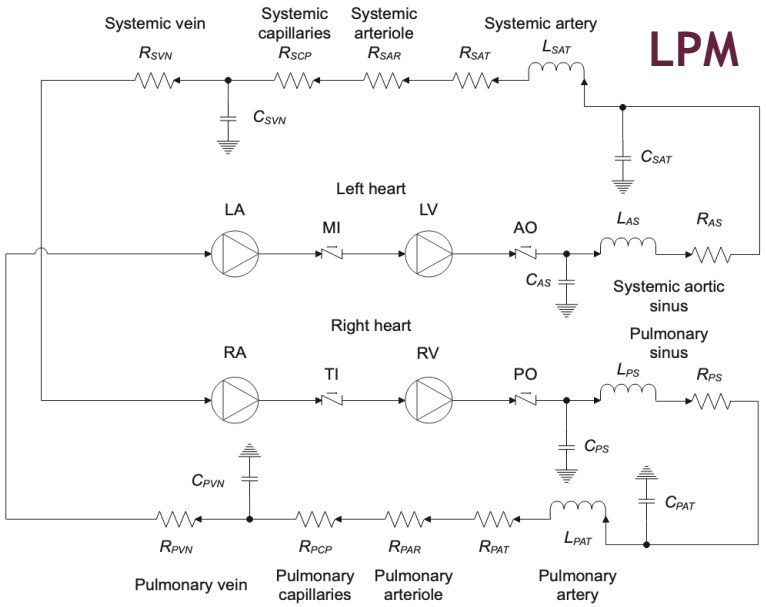
Calcific

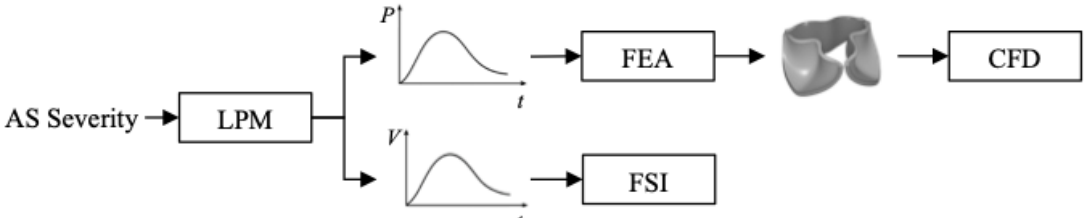



Rheumatic

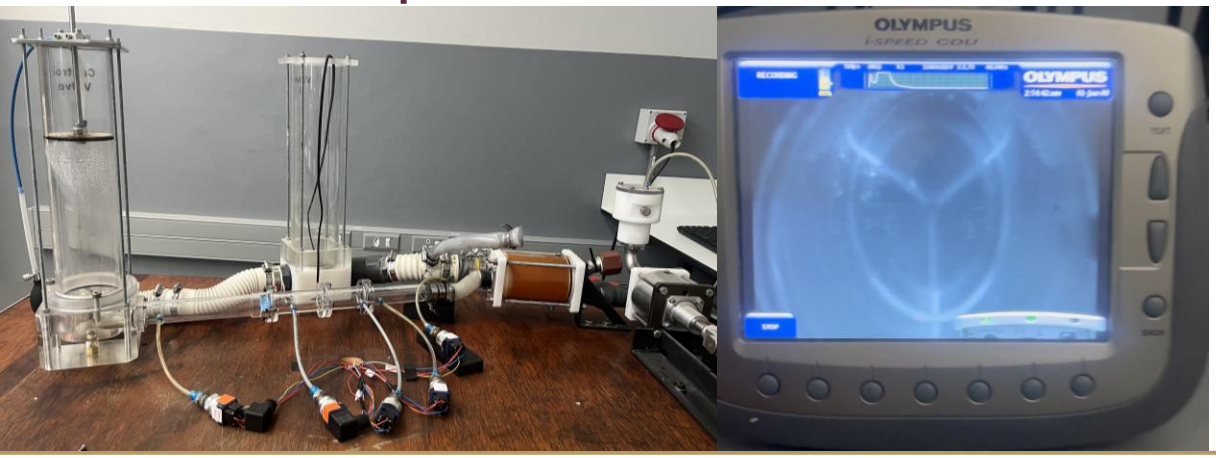


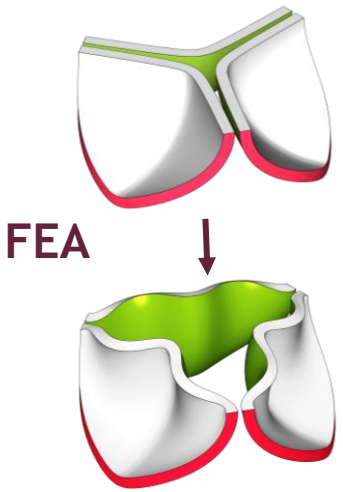

## LPM

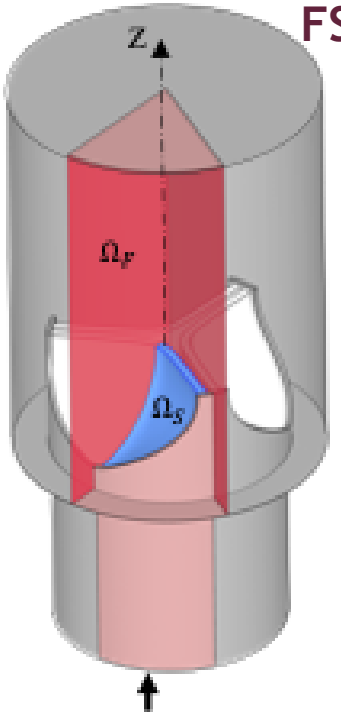


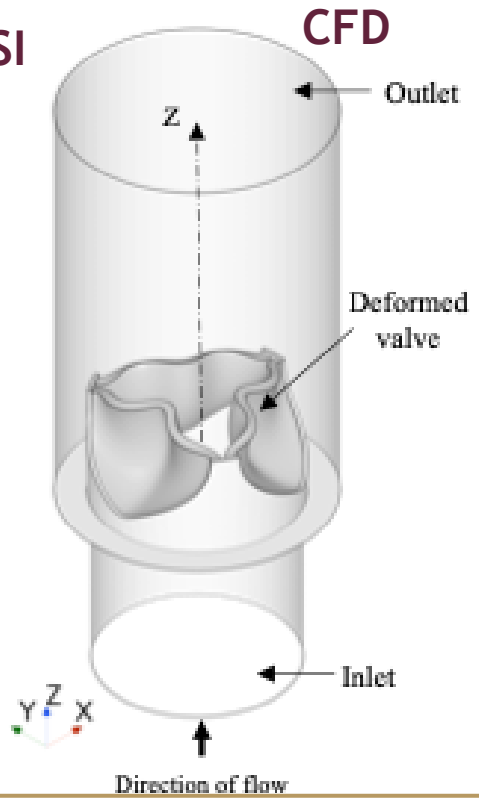




## Cardiac Pulse Duplicator



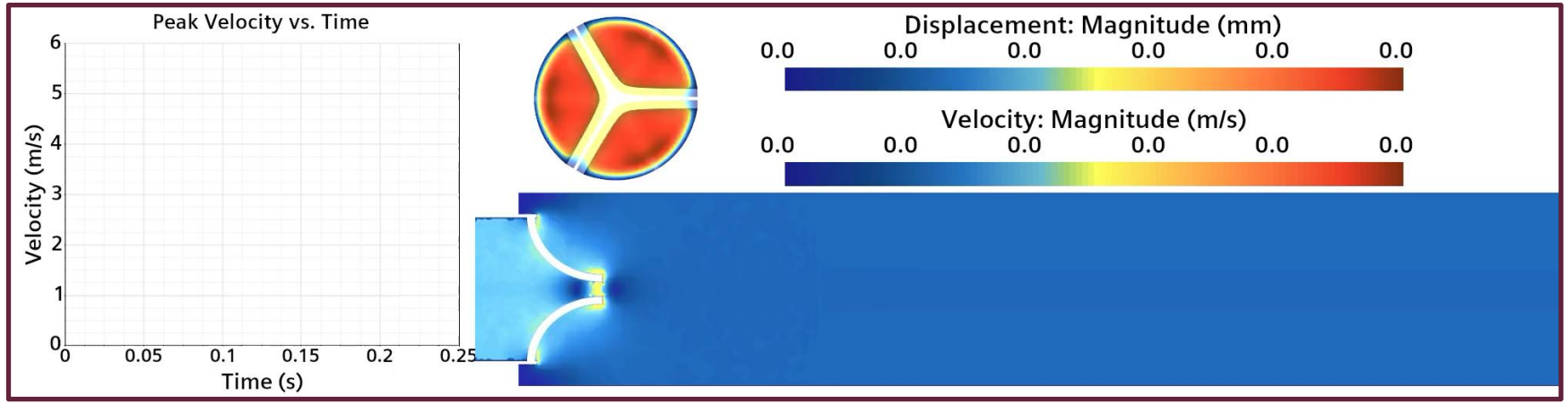



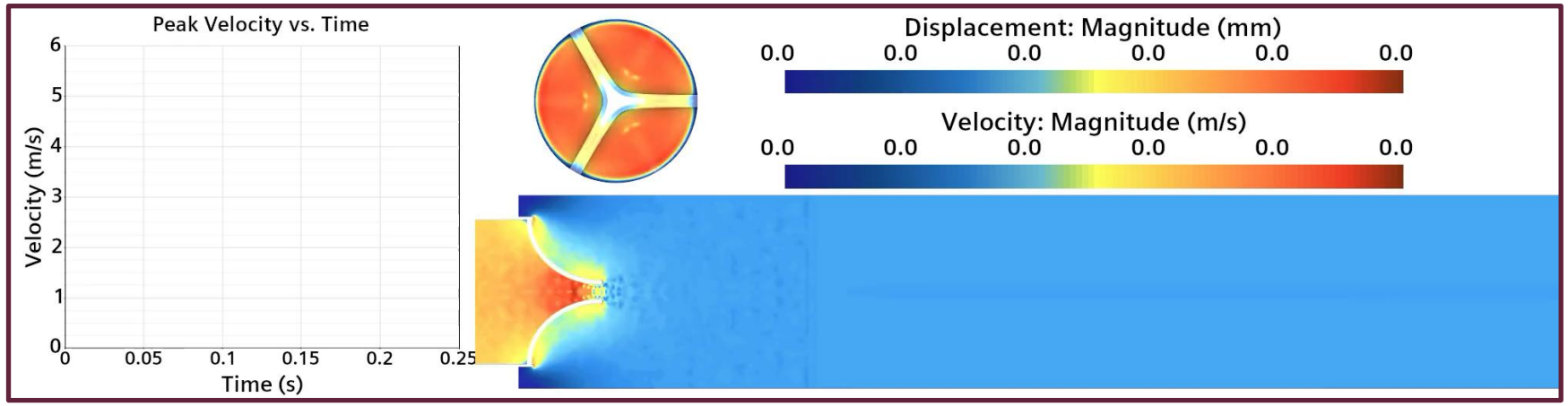
# Impact of Valve on Haemodynamics

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT

**Calcific Aortic Stenosis** **CAS**



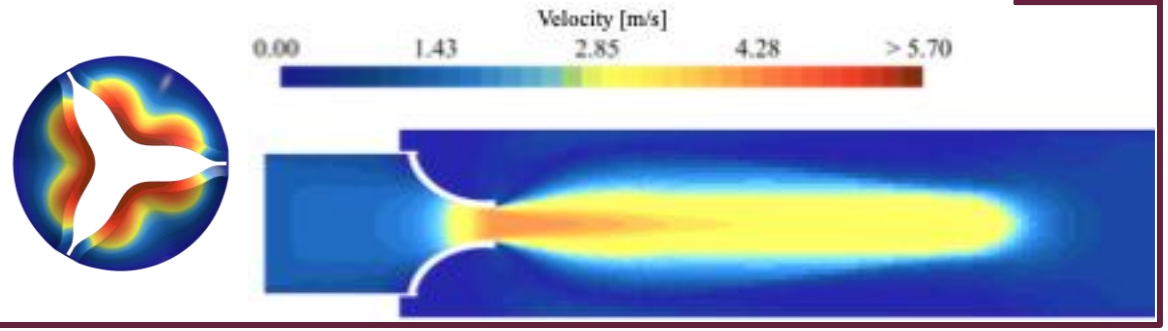

**Rheumatic Aortic Stenosis** **RAS**



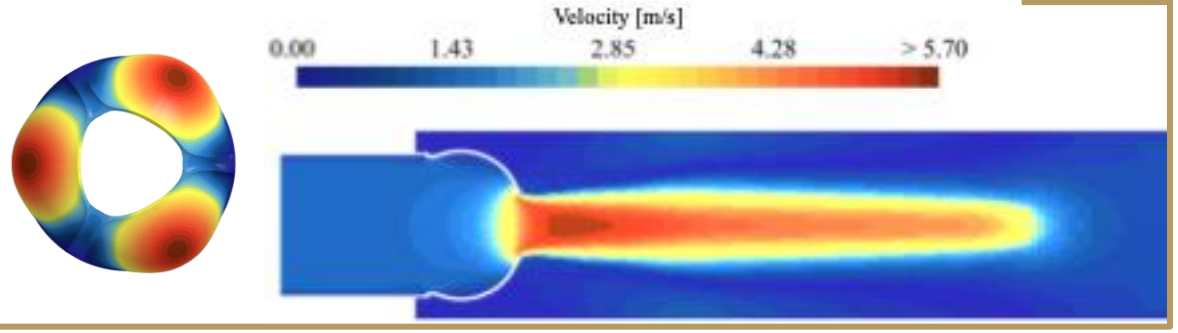
# Impact of Valve on Haemodynamics

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT

## Calcific Aortic Stenosis — CAS




## Rheumatic Aortic Stenosis — RAS




**21%**

Higher peak velocity in RAS at same severity (CFD & FSI)

**62%**

Higher mean gradients in RAS at same severity (FSI)

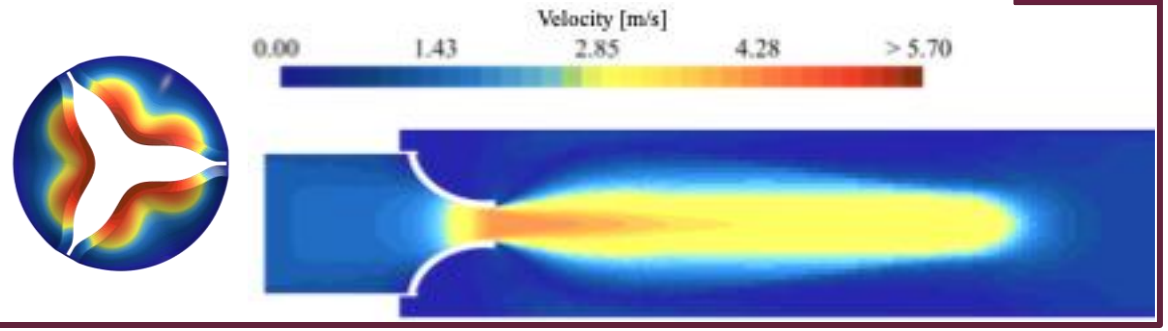
**35%**

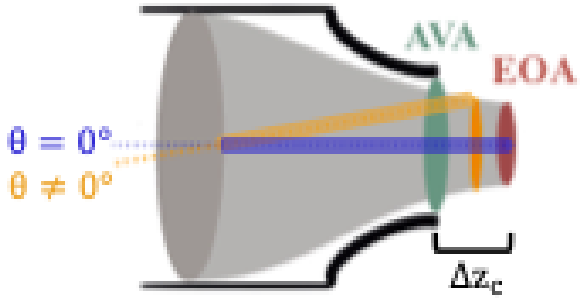
Higher lost work in RAS at same severity (CFD & FSI)

# Impact of Valve on Haemodynamics: Clinical Implication

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT

## Calcific Aortic Stenosis — CAS

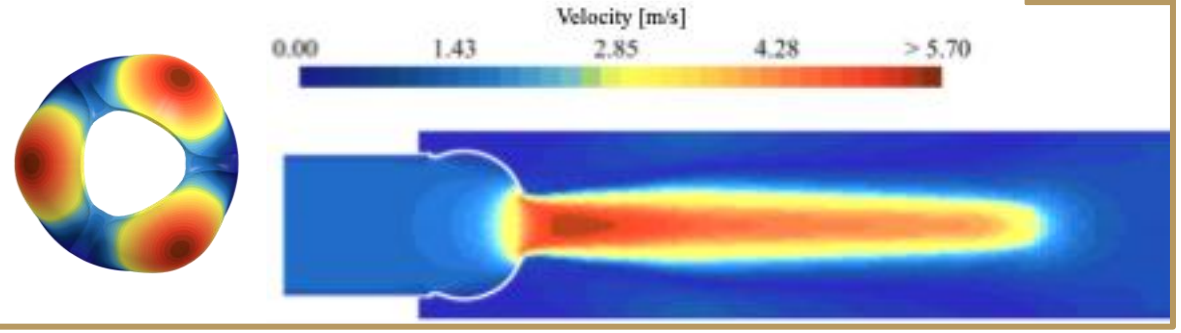



**27%**

Simplified Bernoulli overestimates mean gradients in CAS

## Rheumatic Aortic Stenosis — RAS




**21%**

Higher peak velocity in RAS at same severity (CFD & FSI)

**62%**

Higher mean gradients in RAS at same severity (FSI)

**3%**

Simplified Bernoulli overestimates mean gradients in RAS

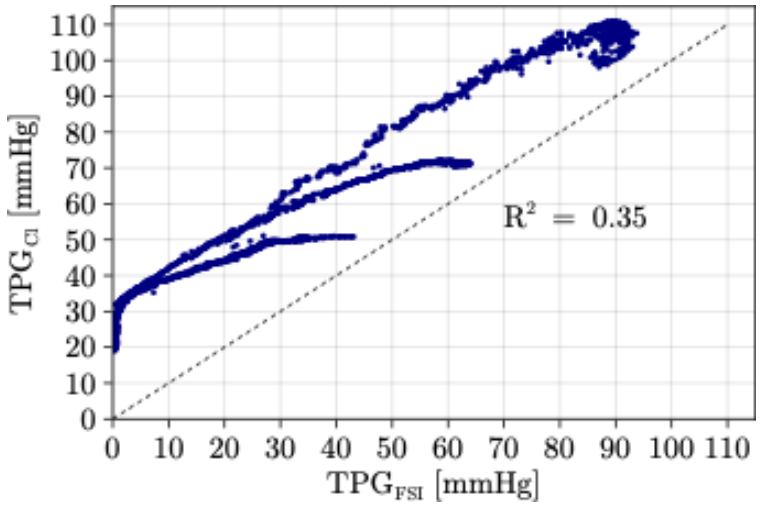
**35%**

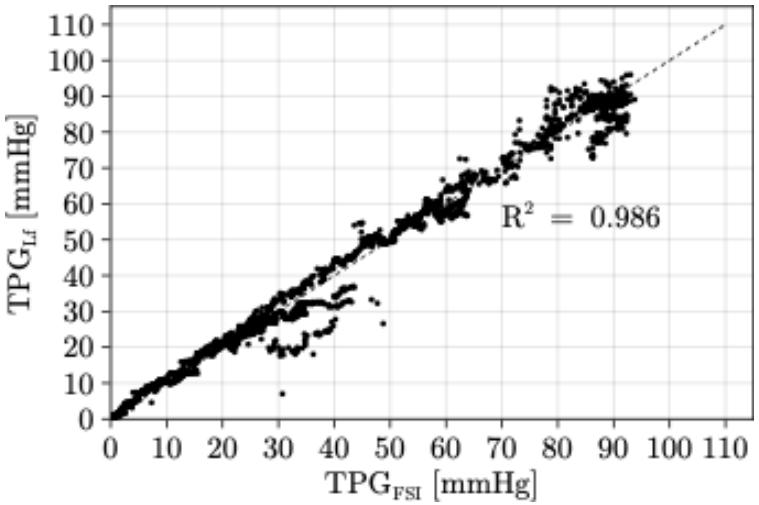
Higher lost work in RAS at same severity (CFD & FSI)

# FSI-informed Correlations

## Calcific Aortic Stenosis **CAS**

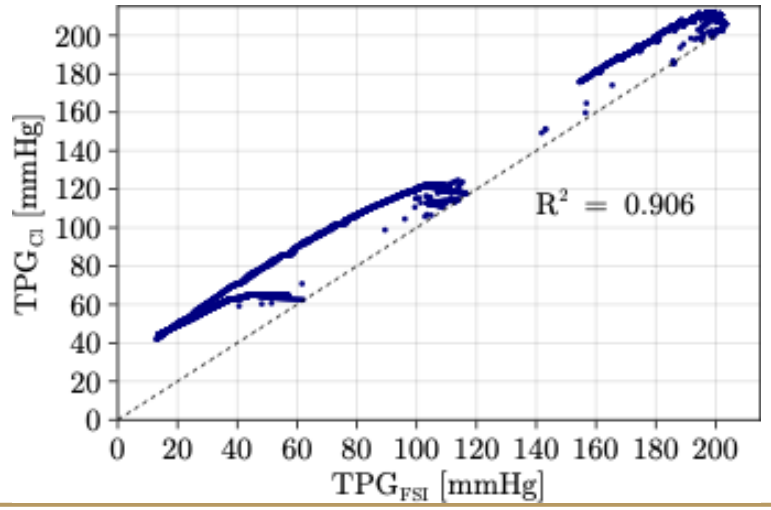
Mean TPG error = 5.1 mmHg
(vs 17.8 mmHg)

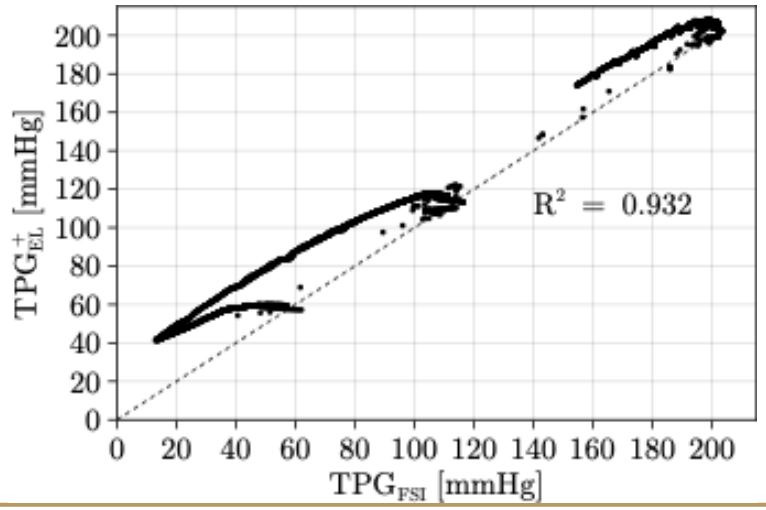



## Rheumatic Aortic Stenosis **RAS**

Mean TPG error = 5.2 mmHg
(vs 5.8 mmHg)

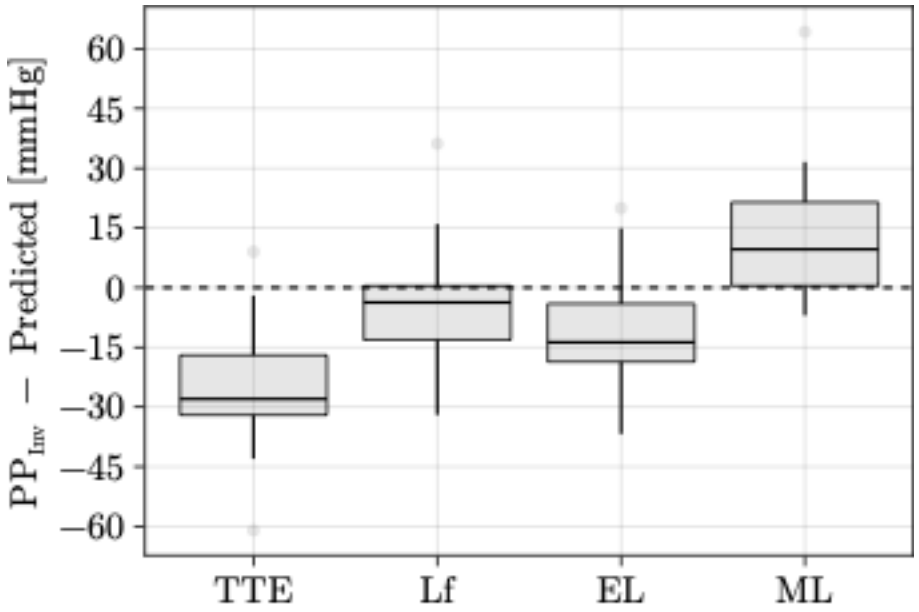


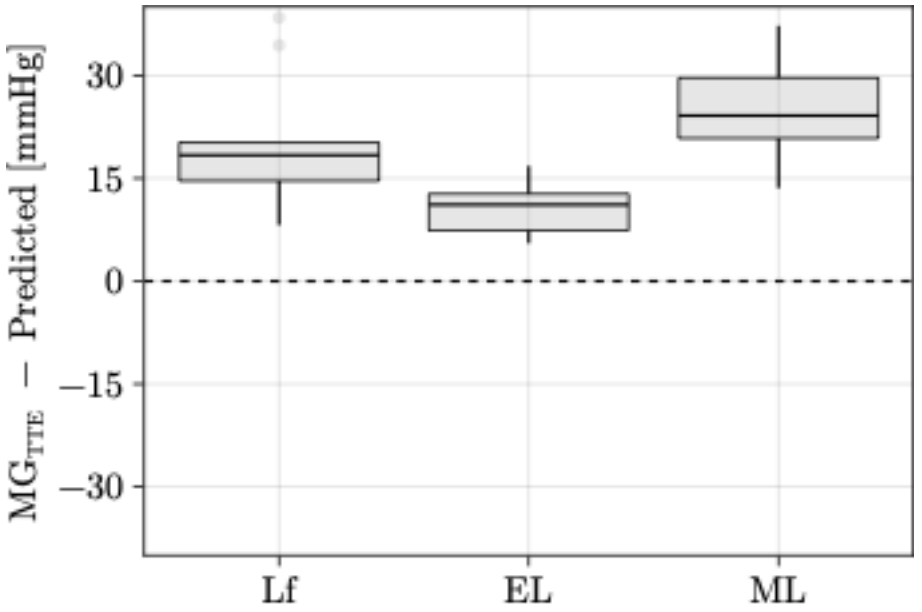



# FSI-informed Correlations: In vivo comparison

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT

Calcific Aortic Stenosis **CAS**



# What's Next?

- Further develop pressure gradient correlations
  - More simulation data
  - Larger patient cohort to test correlations
- Experimental validation of other FSI cases
- Model BAV and combined CAS and BAV cases (new projects started in 2026)
  - Develop correlations
- Consider effect of aortic root compliance on pressure (new project started in 2026)




Photo by Stefan Els