Universitätsspital Basel

Department of Cardiac Surgery

Fluid Dynamics Simulations to Understand BAV Aortopathy Mechanisms and Risks

Bicuspid Aortic Valve, Numerical Interpretation of the Aortic Root Hemodynamics

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Disclosures

- None

Key points

- Introduction
- Anatomical background, definition of the Aortic root 3-D geometry
- Material and methods
- Results
  - impact of the BAV morphology on the local aortic root hemodynamics
  - impact of aortic valve pathology on the local hemodynamic profile in the ascending aorta, aortic arch and thoracic aorta
- Conclusion

Introduction

- **Bicuspid aortic valve (BAV)** occurs in about 0.5% to 1.5% of population

- BAV is associated to the elevated morbidity and mortality related to the
  - **aortic valve dysfunction** and
  - **arteriopathy (aneurysm formation and/or dissection**)

Introduction

- Evidence in recent literature regarding the impact of the **BAV morphology** on the local **aortic root hemodynamics** being responsible for development of the BAV dysfunction is restricted

- The predictive factors associated with **acute aortic syndrome** are well defined, however, the exact mechanism resulting in wall disruption is not known

Introduction

- Elevated pressure, low shear stress and turbulent flow pattern have been associated with **type A and B aortic dissection**

- Low shear stress and high pressure are predictive factors for vascular wall degeneration and sclerosis

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Introduction

- Aim was to evaluate the impact of aortic valve pathology (**BAV with insufficiency or stenosis**) on the local hemodynamic profile in the ascending aorta, aortic arch and thoracic aorta

- For this purpose, based on experimental data obtained fluid dynamic model of **BAV** with aortic valve **insufficency** and **stenosis** were developed

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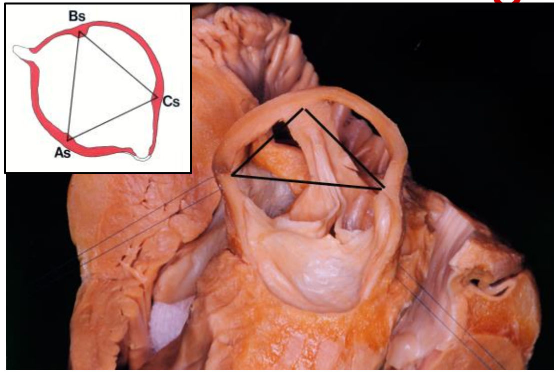
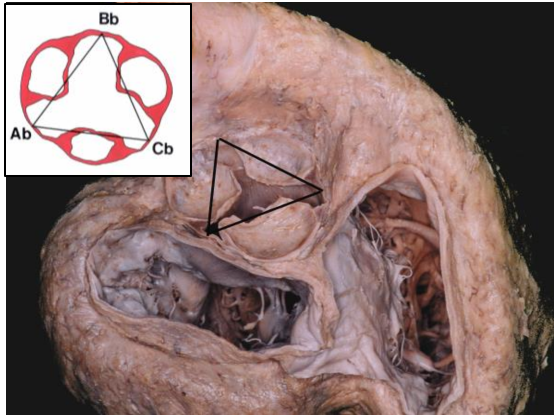
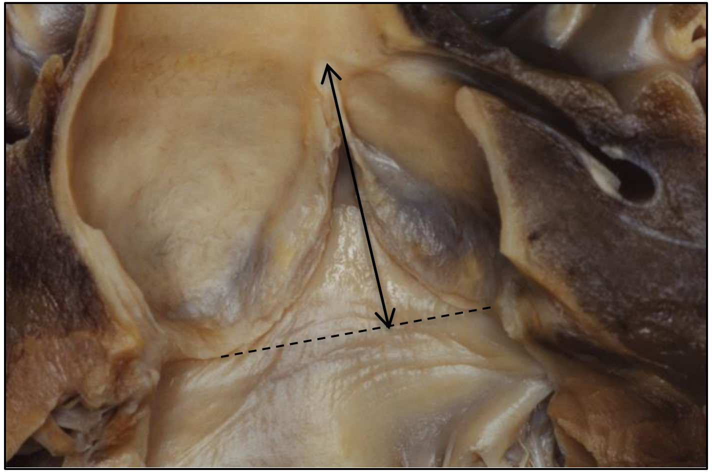
Anatomical background: Aortic Root 3-D Geometry





Key landmarks for description of the aortic root 3D Geometry;

- three commissures
- their projections at the aortic root base
- height of intervalvular triangle



1) Berdajs D et al **Geometricla models of the aortic and pulmonary roots: suggestion for the Ross procedure** Eur J Cardiothorac Surg. 2007
2) Berdajs D et al **The anatomy of the aortic root** Cardiovasc Surg. 2002.

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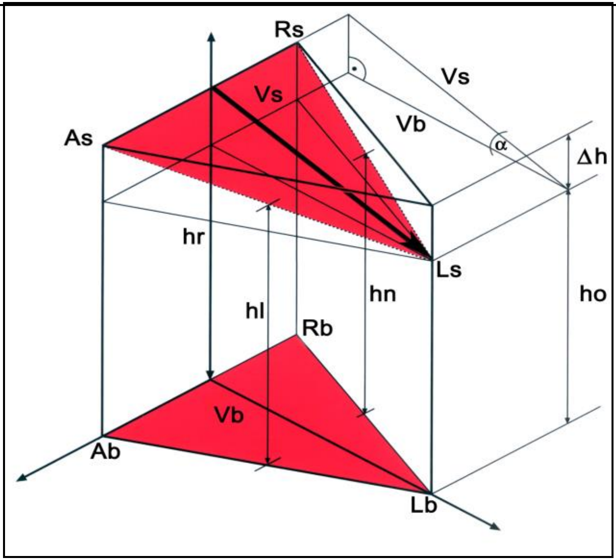
Anatomical background: Aortic Root 3-D Geometry

Connecting the determined 6 landmarks results a three sided prism

The three sided prism describes the aortic root natural asymmetry.
This asymmetry may be defined with one single parameter; by **Aortic Root Vector.**



1) Berdajs D et all**. Geometricla models of the aortic and pulmonary roots: suggestion for the Ross procedure** Eur J Cardiothorac Surg. 2007 Jan;31(1):31-5
2) Berdajs D et all. **The anatomy of the aortic root** Cardiovasc Surg. 2002 Aug;10(4):320-7.

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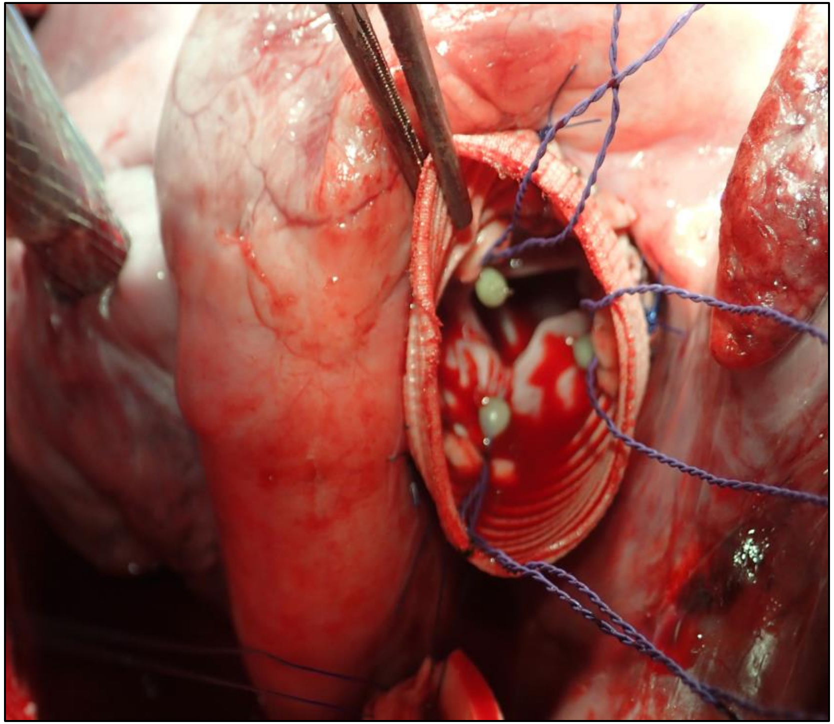
Methods

- Under experimental conditions ***Type I BAV*** with valve insufficiency (n=10 animals) and valve stenosis (n=10 animals) was created

- The 4D aortic root deformation was registered by implantation of 6 micro-sonometric (n=6) high-resolution (200 Hz) crystals in each aortic root modality



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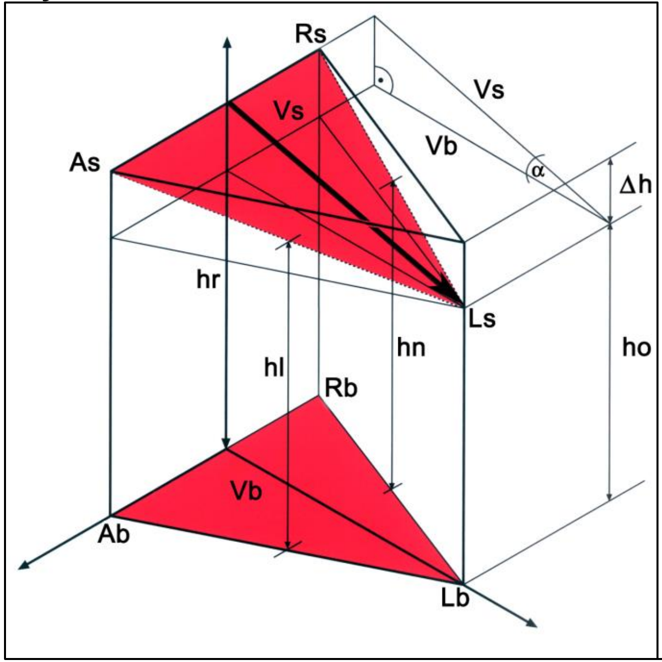
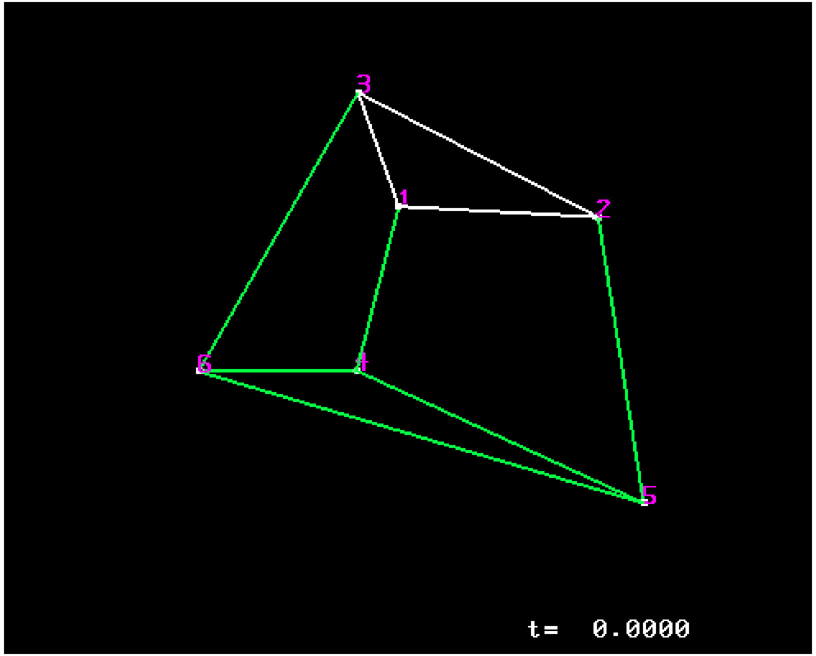
Methods

Cardiac cycle dependent 4D deformation of individual aortic root was defined by time and pressure related synchronization of the measured distances between micro-sonometric crystals.





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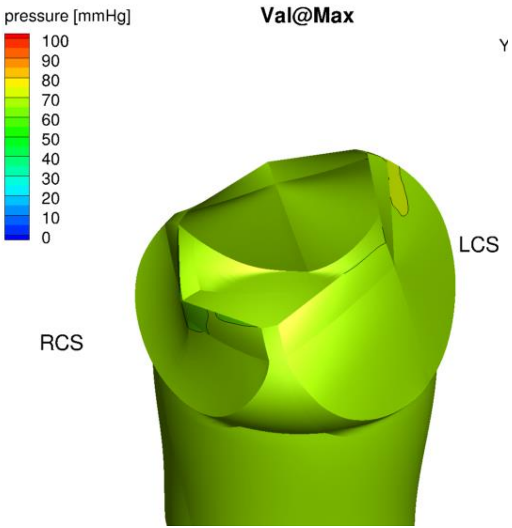
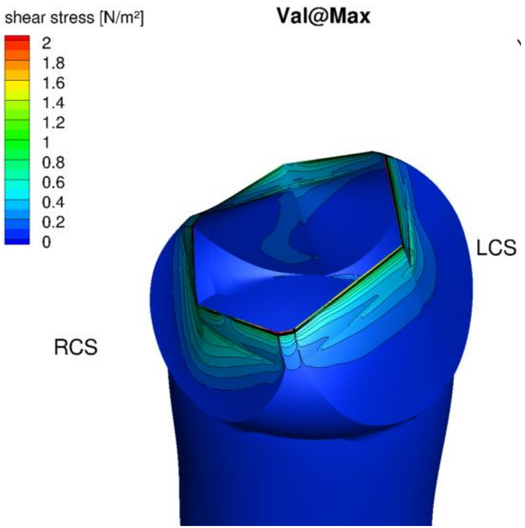
Methods

- **Computed fluid dynamic models** (CFD), based on experimental data, for the bicuspid aortic valve with insufficiency and stenosis were established in order to evaluate
  - **local pressure and shear stress profile** at the surface of the individual aortic root elements

- 4-D pressure and flow related computed fluid dynamic simulation of thoracic aorta in BAV with aortic valve stenosis and insufficiency was performed in order to simulate
  - **pressure, velocity and shear stress profiles** from the aortic root up to the descending thoracic aorta.

Results: BAV with aortic valve insufficiency





Pressure/Shear stress Profile of BAV with insufficiency at peak ejection

Pressure Profile in BAV with valve insufficiency:

Moderate to low tangential pressure **(40-65mmHg)** was present at:

- **leaflets,**
- **coaptations,**
- **intervalvular triangles,**
- **three commissures**

Almost during the whole period of cardiac cycle

At peak ejection moderately elevated pressure **(50-80mmHg)** was registered at mentioned elements

Shear stress Profile in BAV with valve insufficiency:

Low shear stress **(0-0.5Pa)** was found at all components of the aortic root over ***whole cardiac cycle***

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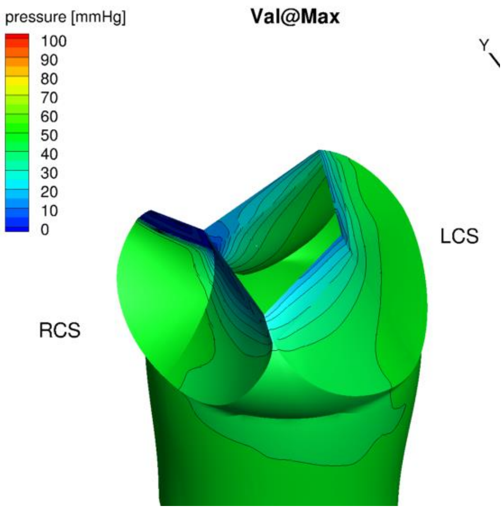
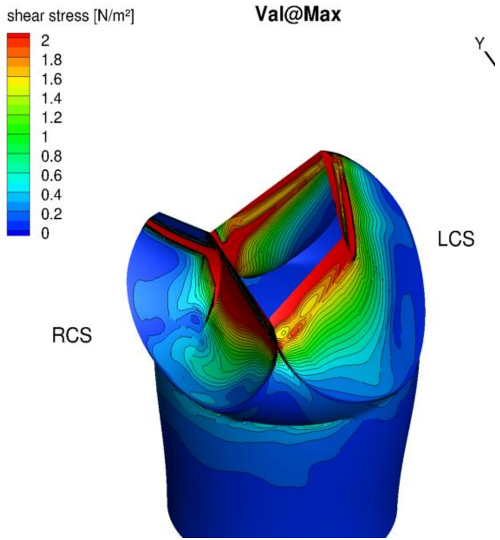
Results: BAV with aortic valve stenosis

Pressure

Shear stress





Pressure/Shear stress Profile of BAV with stenosis at peak ejection

Pressure Profile in BAV with valve stenosis:

Low tangential pressure **(0-30mmHg)** was present at

- **leaflets,**
- **cooaptations,**
- **intervalvular triangles,**
- **three commissures**

Almost during the whole period of cardiac cycle

At peak ejection moderately elevated pressure was registered **(50-80mmHg)**

Shear stress Profile in BAV with valve stenosis:

Low shear stress was present **(0-0.5Pa)** at mentioned components almost during the whole period of cardiac cycle

At peak ejection :

Low shear stress **(0-0.5Pa),** was registered

- at inferior 1/3 of the leaflets and triangles

High shear stress was registered

- superior 2/3 of leaflets
- commissures and cooaptations **(0.8-1.5Pa),**
- leaflets fusions sites **(>2Pa)**

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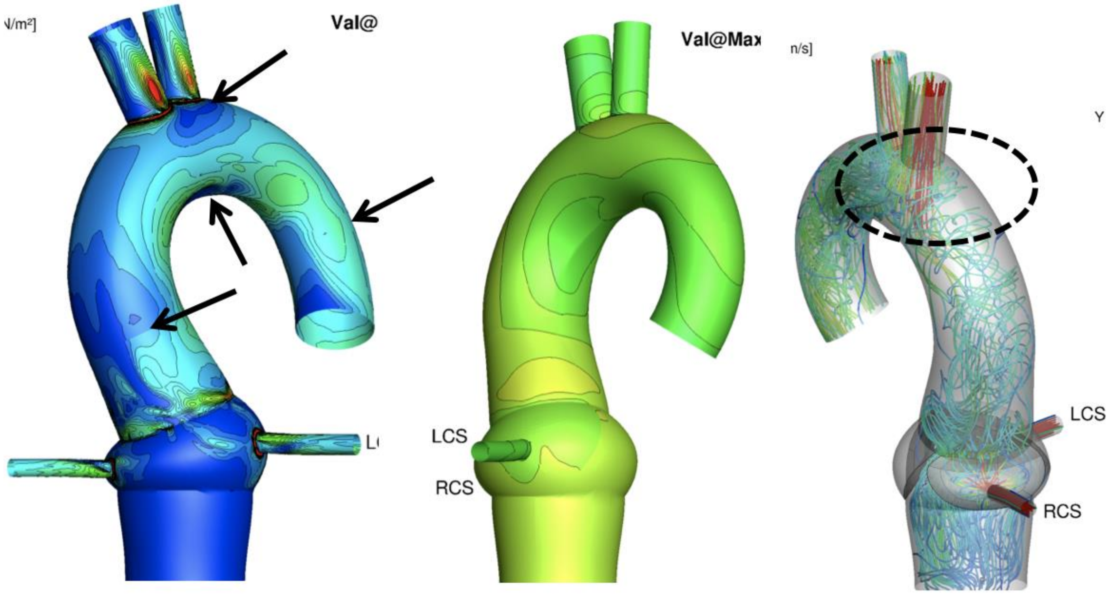
Results: BAV with aortic valve insufficiency (BAV)

Shear stress Pressure Flow profile

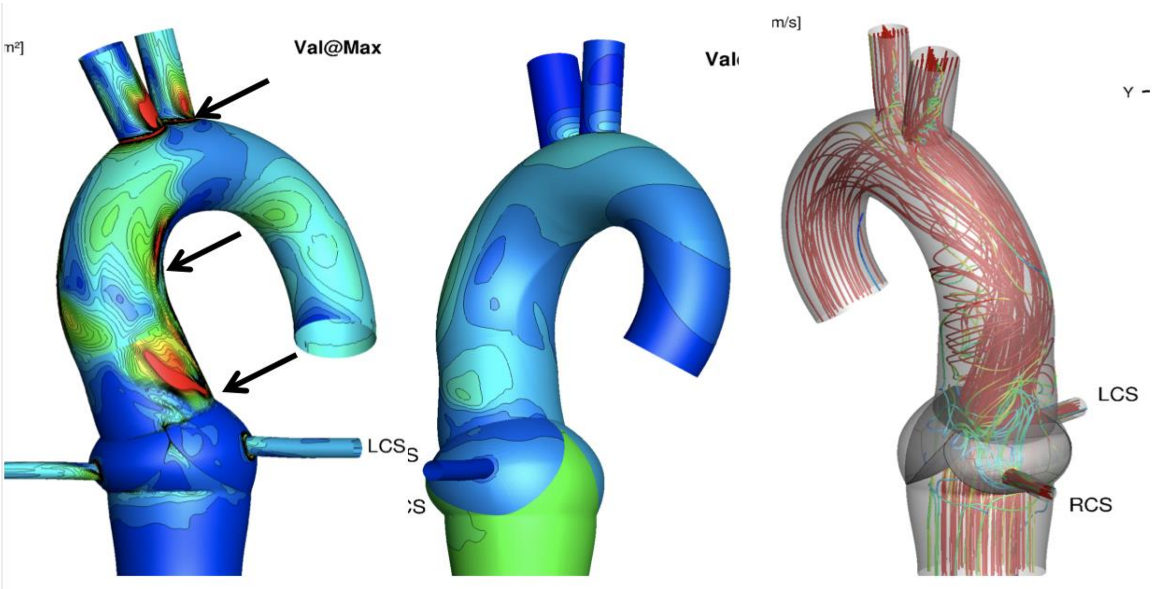


In aortic valve insufficiency, low shear stresses, with large blood flow velocity oscillations, were found

- at the **ascending aorta**,
- at the **lesser curvature of the aortic** arch,
- in **front of cervical vessels** and
- at **aortic isthm**

Results: BAV with aortic valve stenosis

Shear stress Pressure Flow profile



In aortic valve stenosis
high shear stress with elevated pressure were found

- at the **sinotubular junction**,
- at the **ascending aorta**
- at the **ostium of both cervical arteries**

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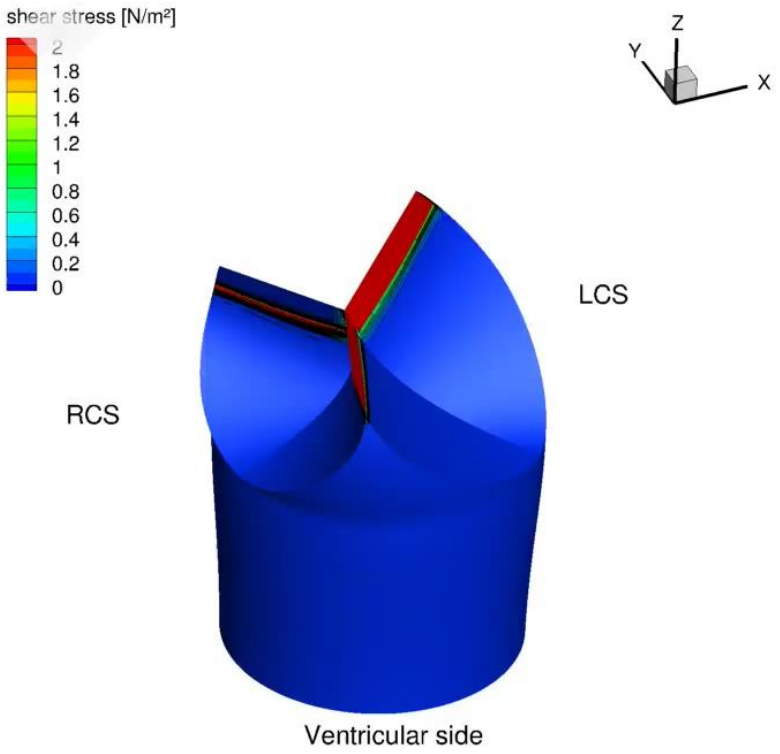
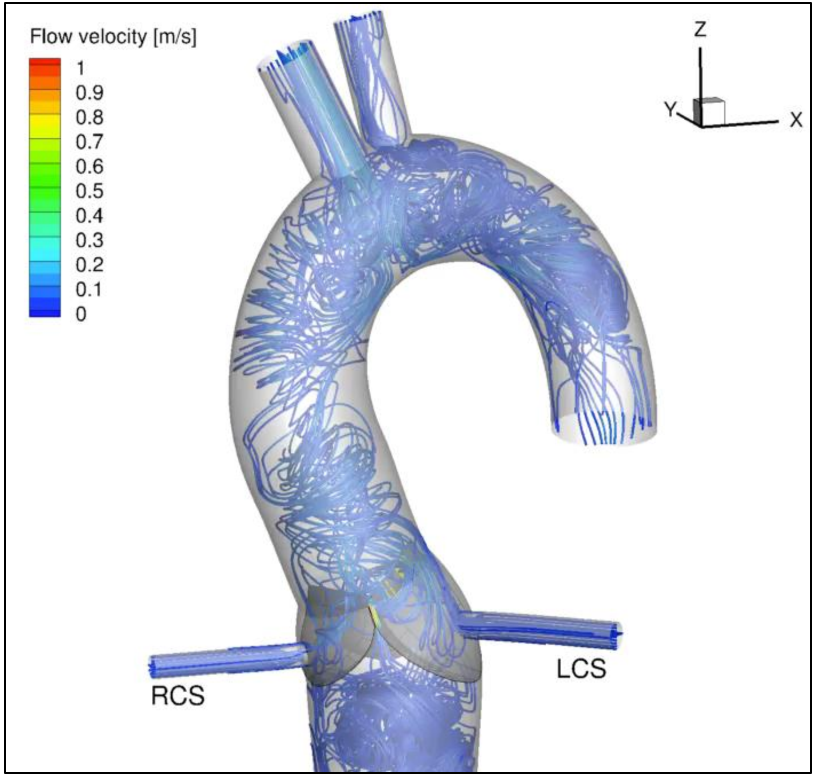
Conclusion



In **BAV with stenosis** during the ejection period of cardiac cycle the leaflets are exposed to moderately elevated pressure and high shear stress. This especially at the coaptation surface.

In contrast in BAV with insufficiency at ejection phase the moderately elevated pressure was combined with low shear stress.

Conclusion



In real-time pressure-flow numerical simulation of BAV with valve insufficiency the low shear stresses and turbulent/oscillation flow regions were documented at traditional levels of entry tears in **aortic dissection type A and B**.

In comparison, in *in vivo* simulation of BAV with valve stenosis, high shear stress with elevated pressure at the ascending aorta and aortic arch may be identified as contributing elements for vessel dilatation, aneurysm formation and direct intimal tear typically for type **A aortic dissection**.

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Conclusion

According to the present results one can conclude that bicuspid stenotic aortic valve is hemodynamically less favorable situation as compared to the BAV with insufficiency.

The elevated pressure conjoined with elevated shear stress in **stenotic BAV** may in long term **promote degenerative processes** of the leaflets and consequently **the failure of the valve** function.

Further **predictive models** for **type A and B aortic dissection** can be developed in the future.

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