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

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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 insufficiency and stenosis were developed.
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

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**.

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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.
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.
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 Profile in BAV with valve insufficiency:

Moderate to low tangential pressure (40-65 mmHg) was present at:
- leaflets,
- coaptations,
- intervalvular triangles,
- three commissures

Almost during the whole period of cardiac cycle

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

Shear stress Profile in BAV with valve insufficiency:

Low shear stress (0-0.5 Pa) was found at all components of the aortic root over whole cardiac cycle
Results: BAV with aortic valve stenosis

**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)
Results: BAV with aortic valve insufficiency (BAV)

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

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
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.
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.