Anatomy of the Aortic Valve and Root - A (Pediatric) Cardiac Surgeon‘s View

Markus K Heinemann
Klinik für Herz-, Thorax- und Gefäßchirurgie
Universitätsmedizin Mainz
Conflicts of Interest (?)

- I am a surgeon for congenital heart disease by training.
- „Pediatric“ cardiac surgeons tend to be peculiar.
- Their views may be somewhat idiosyncratic.
- Fortunately, I have also done research and published on aortic dissection.
- So it might be worth staying in the room after all.
- Don‘t say you haven‘t been warned!
- CoI: EACTS pays for the hotel and the petrol. Thank you!
What exactly is the „aortic root“?

- Wikipedia (what else?):

  - The **aortic root** is the portion of the aorta beginning at the aortic **annulus** and extending to the **sinotubular junction**.
  
  - It is sometimes regarded as a separate entity from the rest of the ascending aorta.
  
  - Between each commissure of the **aortic valve** and opposite the **cusps** of the aortic valve, three small dilatations are called the **aortic sinuses**.
  
  - The **sinotubular junction** is the point in the ascending aorta where the aortic sinuses end and the aorta becomes a tubular structure.
The aortic valve:

Notes on the valves of the heart and the flow of blood within it - and a drawing of a mould for the making of a glass model of the pulmonary or aortic valves. (ca.1512–13).

Credit: Royal Collection Trust
© Her Majesty Queen Elizabeth II
What shall we focus on, then?

- Aorto-ventricular junction
  (back to the roots of the root)
- Anulus
  (the enigma)
- Cusps
  (aka „Leaflets“)
- Sinus
  (yes, that’s the plural)
- Coronaries
  (lest we forget)
- Ascending Aorta
  (where the root ends)
Aorto-ventricular junction

- Variable degree of muscle ingrowth
- Transitional zone: muscle >>> vessel
- Important for annuloplasty / „David“ dissection
- Whoops! There’s a hole in the RIGHT ventricle…


Anulus

- Latin: aNulus, pl.: aNuli = small ring
- Why we should have an aNNulus, but simply an aNus nobody knows.
- A: complex, 3-dimensional, crown-shaped structure (surgical)
- B: diameter at base of aortic root („unanatomical“, reference measure)

from: Pershad A, Stone D, Morris MF, Fang K, Gellert G
Aortic annulus measurement and relevance to successful TAVR
Anulus – some harsh words

- „Descriptions of the aortic root over the years have been BEDEVILED by accounts of a valve aNulus.“

- „There are at least 2 RINGS within the root…“

- „…we describe…the current problems which have arisen due to INDISCRIMINATE descriptions of a NONEXISTENT aNulus.“

Anular Enlargement

- Classic Surgery (AVR)
- To prevent patient-prosthesis mismatch
- Simple and efficient

The incision is directed toward the mid-mitral line (an imaginary line that divides the anterior leaflet into two equal halves), down to the level where the roof of the left atrium is attached to the fibrous curtain. A teardrop-shaped pericardial patch is sutured to this extended aortotomy with a continuous 4-0 polypropylene suture.

Anuloplasty

- If you tighten your belt…
- …you lift up your trousers
- Anuloplasty increases coaptation height

Anuloplasty

- Decreasing anulus diameter increases coaptation height and area
- Measuring effective coaptation height helps to judge valve performance after reconstruction

Cusps (mathematical)

- Cusp geometric height (gH) higher than presumed ?!
- Non-fused cusps in bicusps larger than in tricusps
- In case of retraction forget repair


Cusps

- **EMBRYOLOGY**
  - Fusion of outflow tract cushions
  - Appearance of intercalated cushions
  - Excavation of their distal margins
  - Ingrowth of non-myocardial tissue for sinus

Spicer DE, Bridgeman JM, Brown NA, Mohun TJ, Anderson RH. The anatomy and development of the cardiac valves. Cardiol Young 2014; 24: 1008–22

Cusps (anatomical) I

- Ultrastructure of Cusps
- 3 layers
  - Lamina FIBROSA (widest, aortic surface)
  - Lamina SPONGIOSA (= „media“)
  - Lamina RADIALIS (thinnest, ventricular surface)
  - Extracellular honeycomb collagen fibers
  - Interstitial cells („myofibroblasts“)

El-Hamamsy I, Chester AH, Yacoub MH
Cellular regulation of the structure and function of aortic valves
J Adv Res 2010;1:5-12
Cusps (anatomical) II

- Contractile abilities in **circumferential** direction
- Basal region well prepared for enhanced shear stress (**hinge mechanism**)


- Regulation of biomechanics via **endothelial pathways**

Cusps – embryology II

- Usually 3 = tricuspid, „normal“
- Sometimes 2 („bicuspid“) 1% of population (?)
- Rarely 1 (unicuspid)
- Very rarely 4 (quadricuspid)

*Hurwitz LE, Roberts WC. Quadricuspid Semilunar Valve Am J Cardiol 1973; 31: 623-626*
Tricuspid aortic valve (+ VSD…)

- Small, high conoventricular VSDs
- Lack of support & Venturi effect >>> prolapse of right- (non-) coronary cusp
- Frater stitch through Noduli Arantii (1967)
- Trusler plasty (1973, 1992)
Bicuspid aortic valve

- Stenotic by definition (effective orifical area oval) - regurgitation may occur
- Pattern and degree of cusp fusion ?!
- Associations with Ascending Aortic Aneursym, Coarctation of the Aorta
- Isolated: „life expectancy“ 40 – 50 years, wide range (morphology)

**Sievers HH, Schmidtke C. (MP)**
A classification system for the bicuspid aortic valve from 304 surgical specimens.
J Thorac Cardiovasc Surg 2007; 133: 1226-1233
Bicuspid aortic valve

- Equal sized cusps
  - Regurgitation
  - Incomplete opening

- Unequal sized cusps
  - heavy calcification
  - stenosis

- 1/3 – 2/3 valve
  - calcification
  - regurgitation + stenosis

Bicuspid aortic valve and the Aorta

- "Weaker" wall of ascending aorta with thinner media
- Extracellular matrix protein changes (hen or egg problem)
- Metalloproteinase activity increase
- Collagen, laminin, fibronectin changes

- Dilatation, aneurysm formation >>> encourages AI
- Danger of aortic dissection
Unicuspid aortic valve

- 2 rudimentary commissures lower than coronary ostia
- Mostly regurgitant, also impeded orifice area by definition
- Pediatric / adolescent population – reconstruction preferable

Quadricuspid aortic valve

- Nice to look at (clover leaf)
- Instable - regurgitation
- Pediatric / adolescent population…
- … Common Arterial Trunk valve

…or Syrian hamsters

Sinus

- = bay, bulge
- Plural: Sinus (U-DECLINATION)
- the area behind the cusps
- providing room for the cusps
- reducing stress on cusps *
- sort of Hidden Valleys

Antonio Maria Valsalva (1666-1723)
- „anatomist and surgeon“


Sinus

Green – sinotubular junction
Blue – mid-sinus level (widest)
Red – basal cusp attachment
Red dot – „echo“ anulus

Sinus

- Largest diameter of root anyway
- **Pear / onion** in connective tissue disease (Marfan etc)
- Dilatation in **bicuspsids**
- Enlarged in **cyanotic CHD** with limited pulmonary blood flow (ToF!) – redirection towards one outlet already in fetal life

„*root aneurysm*“

Sinus


Kirklin JW, Barrat-Boyes BG (eds) Cardiac Surgery Churchill Livingstone, NYC, 1993
„Sinus Valsalva Aneurysm“
“There is no point in the body you cannot reach with a strong arm and a 9 G needle.”

Beware of interatrial transseptal puncture !!!

Anat Rec 2001;264:273-283
Coronary Arteries

- Part of the root
- Remember the Alamo (here: early TAVI experience)
- Always in the way
- Make the David / Yacoub procedures tedious / unpopular
- May have abnormal pattern
Coronary Arteries

- **EMBRYOLOGY**
  (Oh no – not you again…!)

- Observations by Raymond Vieussens
  (1635 – 1715)

- Ingrowth rather than Outgrowth

- Debated by RH Anderson (of course)

- **ALCAPA** - how can it happen?

_Bogers AJJC, Gittenberger-de Groot AC, Dubbeldam JA, Huysmans HA._ The inadequacy of existing theories on development of the proximal coronary arteries and their connexions with the arterial trunks. *Int J Cardiol* 1988;20:117-23

Ascending Aorta

- Starts at Sino-tubular junction
- Is the first really tubular part of the aorta
- Contains more elastic fibers than the rest…
- …and is therefore happy to dilate
- May be replaced „supracoronarily“ (if justified)
- …but is often inseparable from its root

Ascending Aorta

- Aortic Dissection Type A
- Ascending aortic aneurysm
- Dilatation in bicuspsids
- Extension of root pathology
- Children: supravalvular aortic stenosis (media)!
  (Williams-Beuren syndrome, aortoplasty Doty, Brom)

Ascending Aorta

More MATHS…:

- Tirone’s Rule for graft diameter in ascending aortic replacement
  - 1. Take circumference of sino-tubular junction
  - 2. subtract diameter at brachiocephalic trunk take-off
  - 3. multiply by zero
  - 4. and add 26.

- \((\text{CFstj} - \text{Dbrc}) \times 0 + 26 = \text{Dgraff}\)