AORTIC VALVE AND AORTIC ROOT ANATOMY

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“nessuno effetto in natura e sanza ragione; intendi la ragione e non ti bisogna sperienza“

“nothing in nature is without reason; understand the reason and you don’t need experience”
The three anatomic variations
“perche il buso della arteria aorto e trianghulare”

“why the orifice of the aortic artery is triangular”

Royal Library, Windsor 19117v. Leonardo’s sketch of a tricuspid valve inserted in a circle in its open and closed configuration. (The Royal Collection © 2004, Her Majesty Queen Elisabeth II)
Anatomy

...not only leaflets (the aortic root)
Anatomical design

Two fixed rings: The skeleton of the root

- Sinutubular junction
- Crown-like semilunar attachments
- Anatomic ventriculo-aortic junction
- Virtual basal ring
Aortic root

The aortic root is a dynamic unit that allows easy opening and closing and shares stress for the valve leaflets.
Normal anatomy (nonpressurized)

ST junction
Valsalva sinuses
Aortic annulus

AORTIC ANNULUS > ST JUNCTION with a 1 to 1.15 ratio

Echocardiographic anatomy

The sinotubular junction is larger than the annulus with a diameter ratio of 1.3 in a normal adult human heart.

### Echocardiographic anatomy

<table>
<thead>
<tr>
<th>Valve Size</th>
<th>Average Leaflet Length</th>
<th>Average Sinus Height</th>
<th>Average Coaptation Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 (n=4)</td>
<td>21.3 mm (20.6-21.8)</td>
<td>21.4 mm (20.9-22.0)</td>
<td>11.2 mm (10.8-12.6)</td>
</tr>
<tr>
<td>22 (n=2)</td>
<td>22.2 mm (21.8-22.5)</td>
<td>22.3 mm (22.1-22.6)</td>
<td>11.7 mm (11.4-12.0)</td>
</tr>
<tr>
<td>23 (n=6)</td>
<td>23.4 mm (22.6-24.0)</td>
<td>23.2 mm (22.7-23.8)</td>
<td>12.3 mm (11.6-12.8)</td>
</tr>
<tr>
<td>25 (n=2)</td>
<td>25.3 mm (25.2-25.5)</td>
<td>25.1 mm (25.0-25.3)</td>
<td>12.9 mm (12.7-13.1)</td>
</tr>
</tbody>
</table>

V. Vijay et al. EACTS/ESTS Joint Meeting 2000
Geometry

From structure to function…
“per la qual cosa langolo più ottuso e più forte chellangolo retto del □to”

“the more obtuse angle is stronger than the right angle of the square”
“i pannicul delli 4 usscoli son piu deboli che li 3 usscioli perche colli loro angholi son piu remoti dalla basa del triangolo loro che quel de 3 usscioli”

“the membranes of four valve-cusps are weaker than those of three valve-cusps because their central angles are more remote from the bases of their triangles than those of the three valve-cusps”
Functional geometry

...the function indicates the structure
The total length of the free margin:

- equal to the circumference
- > to the intercommissural distance

⇒ Complete opening in systole
⇒ Wrinkle-free leaflet closure
Folding and unfolding of the free edge of the leaflets is necessary for opening and closure of the aortic valve.

The progressive increase in aortic diameter maintain the leaflets flat through the whole sequence of leaflet opening.
Histology
Composition of aortic root

✓ Annulus
  collagen only at the nadir of leaflets attachment

✓ Sinuses
  elastic tissue

✓ ST junction
  elastic component but important collagen support

✓ Interleaflet triangles
  divide the sinuses and are exposed to ventricular pressure
“lla sagace natura provide dj durissima resisstentia nella infima baseza del cerchio dellinpeto”

“the wisdom of nature provides a very hard resistance at the lowest base of the circle of impetus”
"...delle gia chiuse porte lequali si seran no colle fronte come le altre porte ma cosua lati con gran cotatto e potente"

".. from the previously closed (aortic) valve-cusps which are not closed with their margin like the other doors but with their sides with great and powerful contact"
"il sangue che col suo inpeto percote esso vsscjolo non potedo sfondarlo seguita il suo moto allo insu e allargha edjstende le grinze"

The blood which with his impetus percusses this valve-cusp, not being able to rupture it, continues its upward motion, enlarges and distends the folds of the cusp"
Physiology
Root deformation during the cardiac cycle: Isovolemic contraction

- Expansion at the commissures
  “Pull-and-release” mechanism
Root deformation during the cardiac cycle: **Ejection**

- Contraction at the annulus
- Expansion at the commissures

*Root is more cylindrical to favor ejection*
Root deformation during the cardiac cycle: Diastole

- Re-expansion at the annulus
- Contraction at the commissures

Recoil to restore the static equilibrium
Mechanism of opening: sequence of leaflet opening

1. Stellate orifice
2. Small triangle
3. Triangle
4. Circular orifice
The paradoxes of the aortic valve

- The valve opens before the presence of forward flow.
- Ejection continues even after the aortic pressure exceeds ventricular pressure.
- The aortic valve already starts closing during ejection.
Answer:

From stellate orifice to small triangle

Increase in ventricular pressure through the interleaflet triangle causes an increase of diameter at the commissures before the valve opens.
From small triangle to triangle

Sinuses expansion (increased 16%) to maintain the leaflet distended and flat
The paradoxes of the aortic valve

- The valve opens before the presence of forward flow
- Ejection continues even after the aortic pressure exceeds ventricular pressure
- The aortic valve already starts closing during ejection
Due to an increase in velocity the blood enter the aorta because of motion’s inertia more than pressure gradient”

“Noble phenomenon”
Mechanism of leaflets closure: the role of the sinuses
Old technique
“by hand”

New technique
“phase contrast MRI”

Royal Library, Windsor 19117v.
“apresi per il moto incidete e sserrasi col moto refresso”

“it is opened by the incident motion and closed by the reflected motion”

“…jnPari tempo qual sara la proporzione
delle varie largezze dessa canna”

“will be proportional to the different sizes of the pipe”

“…e poi si rivolta insu con moto refresso
e ritorna alla porta del suo primo introito”

“…and then curls up and goes back to the entrance door”

“limpeto che riman nel sangue serra lusciolo”

“the propulsion that remain in the blood closes the valve”
In the absence of Valsalva sinuses
In the presence of Valsalva sinuses
The paradoxes of the aortic valve

✓ The valve opens before the presence of forward flow

✓ Ejection continues even after the aortic pressure exceeds ventricular pressure

✓ The aortic valve already starts closing during ejection
Answer:

a-b = rapid valve opening; b-c = slow systolic closure; c-d = rapid valve closing; RVOT = rapid valve opening time; RVCT = rapid valve closing time; ET = ejection time; D1 = maximal leaflet displacement; SCD = slow closing displacement; D2 = leaflet displacement before rapid valve closing

-Schematic drawing of an M-mode tracing describing the measured aortic valve opening and closing features
Concept of the functional unit sinus-cusp

Shock absorbing
Stress sharing
Stress and aortic valve

At 100 mmHg the aortic valve withstand a pressure of:

✓ 1.3 Kg vertically

✓ 0.6 Kg horizontally (200 g for each commissure)

*Elasticity is an important variable specially at sinus level*
Stress contours in the aortic root when the flexible sinuses are present versus when the sinuses are absent

Five hundred frames/sec cinematography showing the leaflet surface during valve opening

Stiffening of the aortic wall at the level of the sinuses leads to loss:

- the physiologic pull-and-release function of the aortic root

- stress overload on the aortic leaflets (eventually cusp fibrosis and calcification, and in some cases hemodynamically significant aortic valve disease)
Cause of impairment of physiologic function

- **Degenerative (increased aortic stiffness)**
  - Age
  - Dilatation
  - Aortic wrapping (?)

- **Surgery (root replacement)**
  - Absence of sinuses
  - Non compliant sinuses
For a long-lasting aortic leaflet function

✓ Maintain or reconstruct the sinuses
  - Natural shape of the sinuses
  - Normal proportion of the components
  - Large leaflet coaptation

✓ Elasticity of the wall
“Anchorache lo ingegno umano faccia inuentioni varie rispondendo con uari strumenti a un medesimo fine mai esso trovera inuentione piu bella ne piu facile ne piu breue della Natura perchē nelle sue invenzioni nulla manca e nullo e superfluo”

“Though human ingenuity might make various inventions which by the help of various machines answering the same end will never device any invention more beautiful, nor more simple, nor more to the purpose than nature does; because in her invention nothing is wanting, and nothing is superfluous”
The Italian Navy cadet ship Amerigo Vespucci arrives in Auckland.  

Luna Rossa ITA sails out to meet her. On 20 October 2002