Introduction to aortic root geometry

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From structure to function

“nothing in nature is without reason; understand the reason and you don’t need experience”

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

The function explains the structure
Geometry
“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)

“perche il buso della arteria aorto e trianghulare”
The three anatomic variations as designed by Leonardo

Quadricuspid  Tricuspid  Bicuspid
“the more obtuse angle is stronger than the right angle of the square”
“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”

"i panniculi delli 4 usscioli son piu deboli che li 3 usscioli perché colli loro anghioli son piu remoti dalla basa del triangolo loro che quel de 3 usscioli"
Effects of annular dilatation on leaflets (cross-sectional view)

(a) The Normal Aorta
(b) The Dilated Anulus
Effects of annular dilatation on leaflets (side view)
The NET RESULT

Stress on leaflet in isolated annular ectasia

$= 1.64 \times (\text{Stress on leaflet in normal condition})$

$\text{STRESS} = +64\%$
Anatomy:

.....not only leaflets (the aortic root)
Geometry as proportion of the various root components
Normal anatomy (nonpressurized)

Aortic annulus
Sinotubular junction
Valsalva sinuses
Aortic annulus

AORTIC ANNULUS
> SINOTUBULAR JUNCTION
with a 1 to 1.15 ratio

The sinotubular junction is larger than the annulus with a diameter ratio of 1.3 in a normal adult human heart.
Normal anatomy (nonpressurized)
Surgical anatomy of the aortic root: Implication for valve-sparing reimplantation and aortic valve annuloplasty

Laurent de Kerchove, MD, PhD, Ramadan Jashari, MD, Munir Boodhwani, MD, MMSc, Khanh Tran Duy, Ir, PhD, Benoit Lengelé, MD, PhD, Pierre Gianello, MD, PhD, Zahra Mozala Nezhad, MD, Parla Astarci, MD, PhD, Philippe Noirhomme, MD, and Gebrine El Khoury, MD

Surgical Anatomy of the Aortic Annulus: Landmarks for External Annuloplasty in Aortic Valve Repair

Nizar Khelil, MD, Ghassan Sleilaty, MD, Michele Palladino, MD, Mahmoud Fouda, MD, Remi Escande, MD, Mathieu Debauchez, MD, Isabelle Di Centa, MD, and Emmanuel Lansac, MD, PhD

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Difficulty for a complete root dissection causes a difference in the measurements of the root externally or internally.
INTERNAL MEASUREMENTS

Mean Annulus Diameter 25 mm
Mean Cusps Height 20-21 mm
Mean Interleaflet Length 20-21 mm

NO SIGNIFICANT DIFFERENCES among
the three cusps or
the three interleaflet triangles
Spatial relationship of the commissural posts in respect to the sinuses

Radius of curvature passing along the commissures
Radius of curvature passing along the sinus edges
Geometry as relationship leaflets/root component

Coaptation
“.. 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”
Aortic cusps coaptation

Level of coaptation inside the root or “Effective height”

Amount of leaflet coaptation or “Coaptation height”
Aortic cusps coaptation

Depends on the ratio between

• Annulus diameter
• Leaflet size
• Ratio STJ size/leaflet free margin
1. Annulus diameter and coaptation

![Graph showing the relationship between $d_{AA}$ and $h_E$](image)

Aortic root numeric model: Annulus diameter prediction of effective height and coaptation in post-aortic valve repair

Marom, Schaefers et al. JTCVS 2013
2. Leaflet size and coaptation

Aortic root numeric model: Correlation between intraoperative effective height and diastolic coaptation

Marom, Schaefers et al. JTCVS 2013
STJ size and coaptation

Sinotubular Junction Size Affects Aortic Root Geometry and Aortic Valve Function in the Aortic Valve Reimplantation Procedure: An In Vitro Study

Maselli, De Paulis et al. 2010

Decrease in the level and height of coaptation
Aortic root

• The aortic root is a dynamic unit that changes during the cardiac cycle
Functional geometry
The total length of the free margin
- equal to the circumference
- → to the intercommissural distance

Complete opening in systole
Wrinkle-free leaflet closure
Cusp free margin and circumference between commissures ARE EQUAL

Symmetric cusp configuration

Asymmetric cusp configuration
Folding and unfolding of the free edge of the leaflets is necessary for opening and closure of the normal tri leaflet (left) as well as for the bicuspid aortic valve (right).

Functional geometry

The progressive increase in aortic diameter maintain the leaflets flat through the whole sequence of leaflet opening.
Mechanism of opening: sequence of leaflet opening

- Stellate orifice
- Small triangle
- Triangle
- Circular orifice
Root deformation during the cardiac cycle: Isovolemic contraction

- Expansion at the commissures
  "Pull-and-release" mechanism

Increase in ventricular pressure through the interleaflet triangle causes an increase of diameter at the commissures before ejection
Root deformation during the cardiac cycle: **Ejection**

- Contraction at the annulus
- Expansion at the commissures

Root is more cylindrical to favor ejection

On the outside

Sinuses expansion to maintain the leaflet distended and flat

On the inside
From triangle to circular orifice

Due to an increase in blood velocity
Root deformation during the cardiac cycle:

**Diastole**

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

Recoil to restore the static equilibrium
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.

“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 perché nelle sue invenzioni nulla manca e nullo e superfluo”