The anatomical Roadmap of the Aortic Valve:

What we have learned over the years from anatomic and imaging studies about the aortic valve anatomy and function

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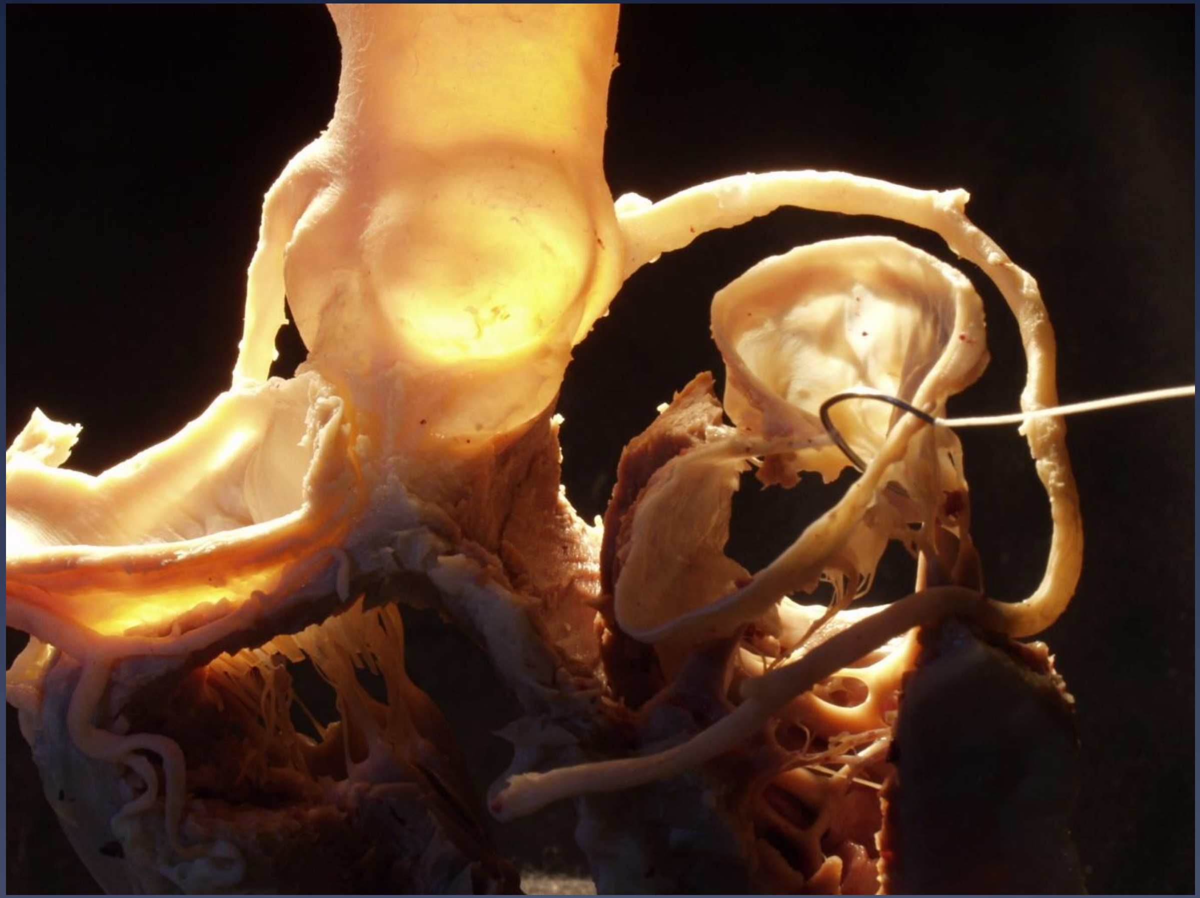
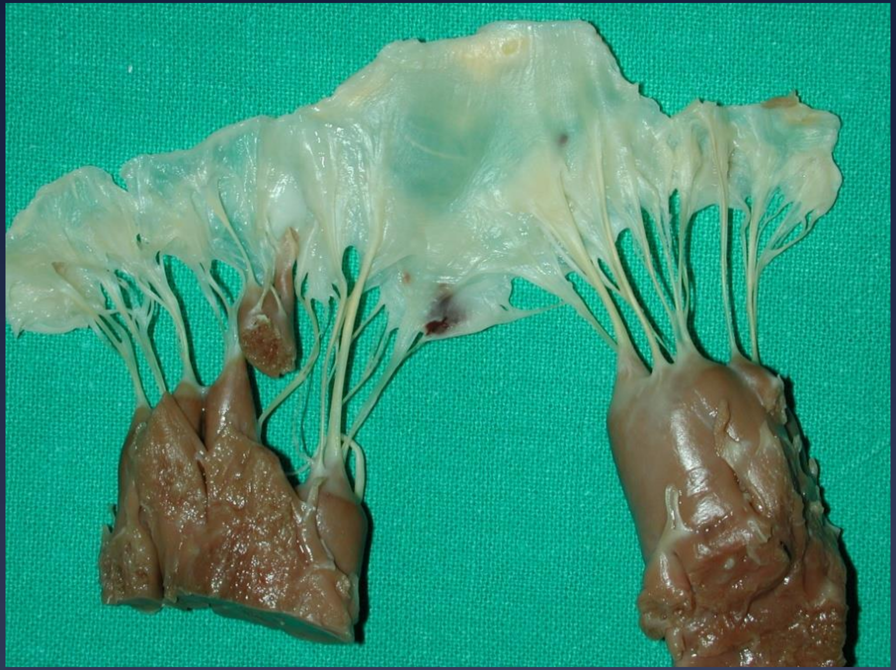
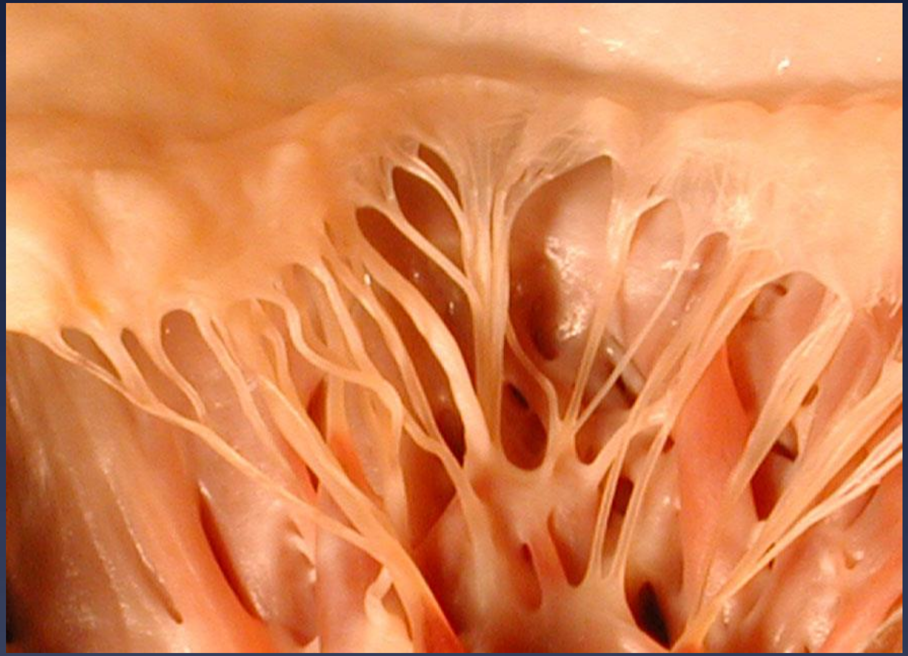
Aortic and Mitral Valve

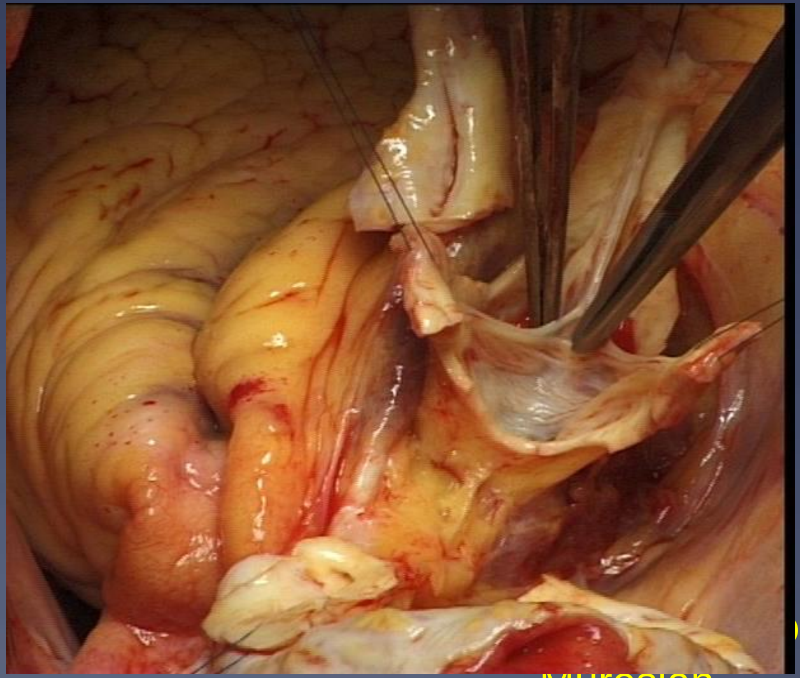


Two valves, next to each other within the heart, but so different in the way they have been treated: repair for one and replacement for the other.

Why ??





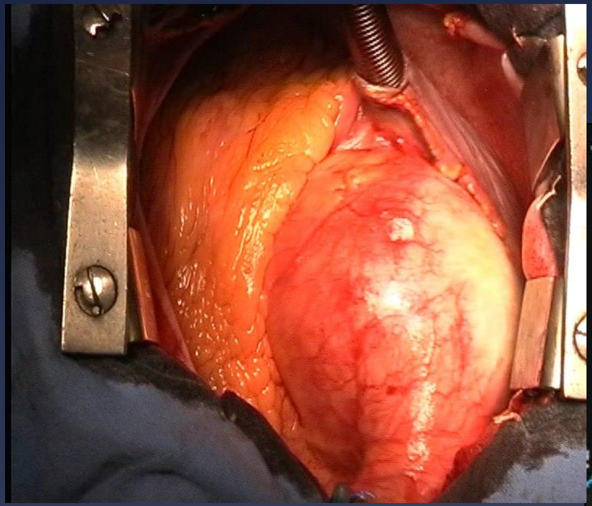


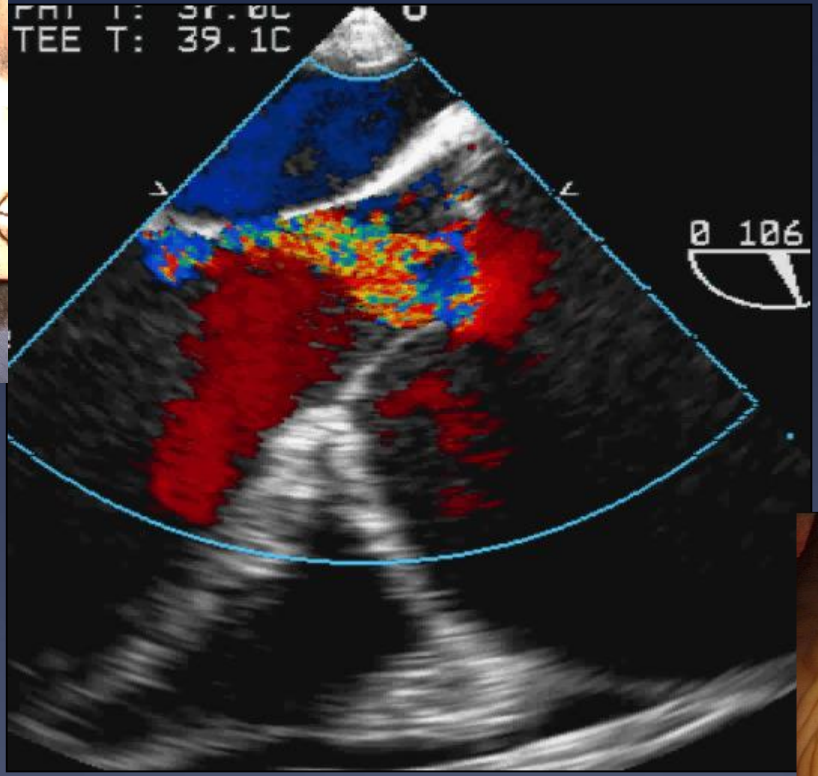
- 3 levels of «work» to repair the mitral valve:papillary muscle and chrdae,leaflet tissue and valve annulus(fuctional unit).while the aortic valve has been looked to as only leaflets

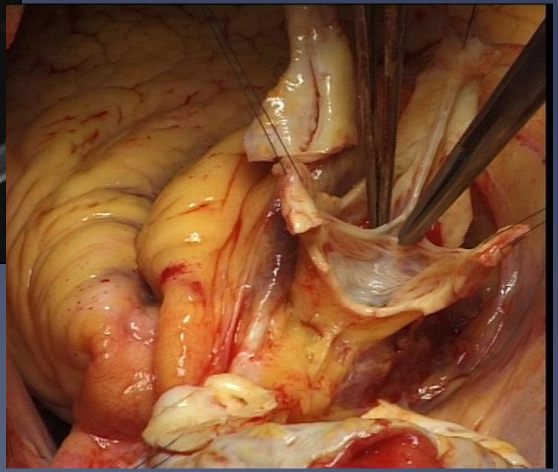
r.
Muresian

the Journey starts…

1st important observation: root/ascending aorta aneurysm may induce AR despite normal AV leaflets



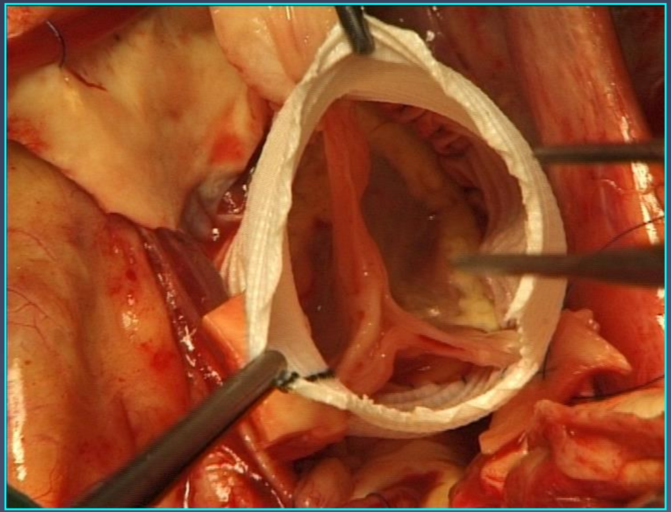


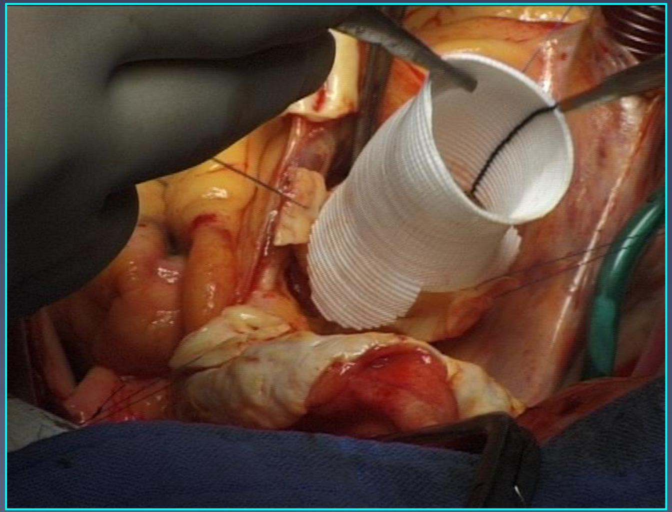


Sir M Yacoub (1993): remodeling of the aortic annulus

JTCVS 1993; 10 cases 1982-1990

*« Isolated aortic valve regurgitation that results from disease that **primarly** affects the aortic wall can be repaired by remodeling of the **aortic anulus** to restore its normal geometry…*
*increases in the **surface area** of the leaflet that are caused by **root dilatation** are often present and can be accomodated in the repair procedure »*

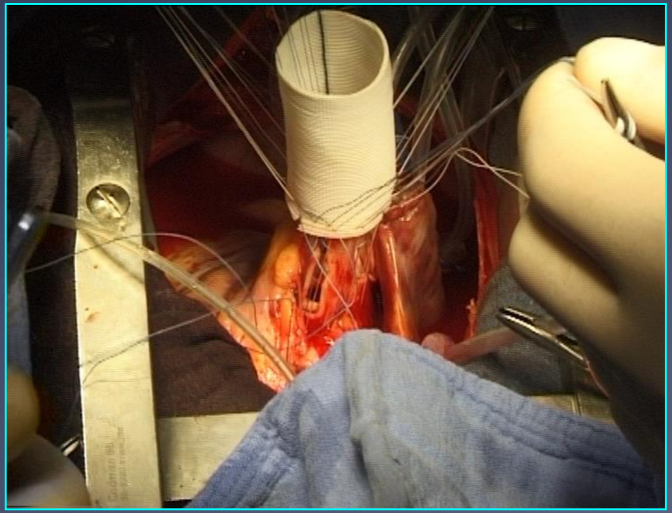


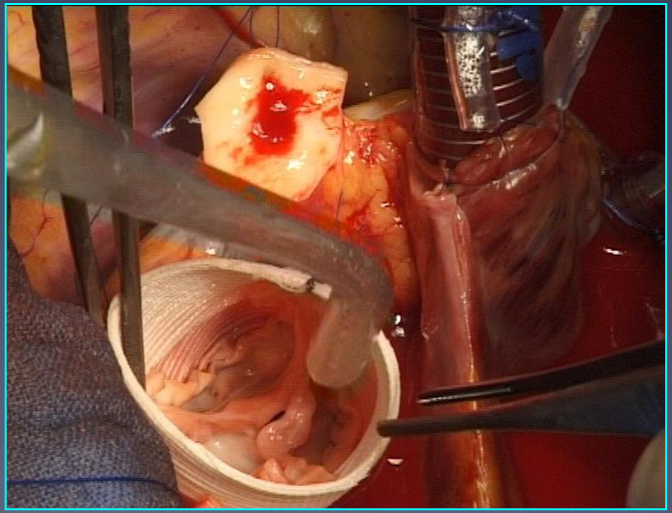


Dr. T David (1992): reimplantation of the aortic valve

JTCVS 1992 (10 patients 1988-1992);

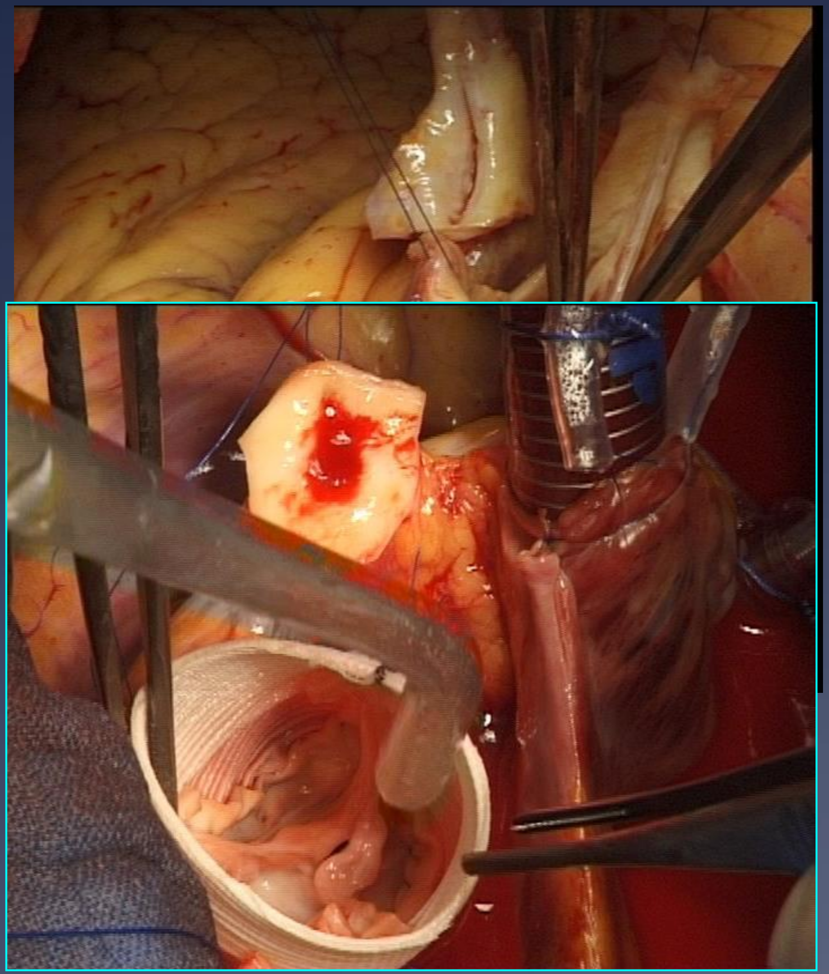
*"A number of patients who require an operation for complications of annuloaortic ectasia, such as aortic incompetence or aneurysm of the aortic root (or both), have **normal aortic valve leaflets**.*
*We have treated these patients by excising the aneurysmal portion of the ascending aorta and sinuses of Valsalva... The aortic valve is **reimplanted** inside a collagen-impregnated tubular Dacron graft…"*

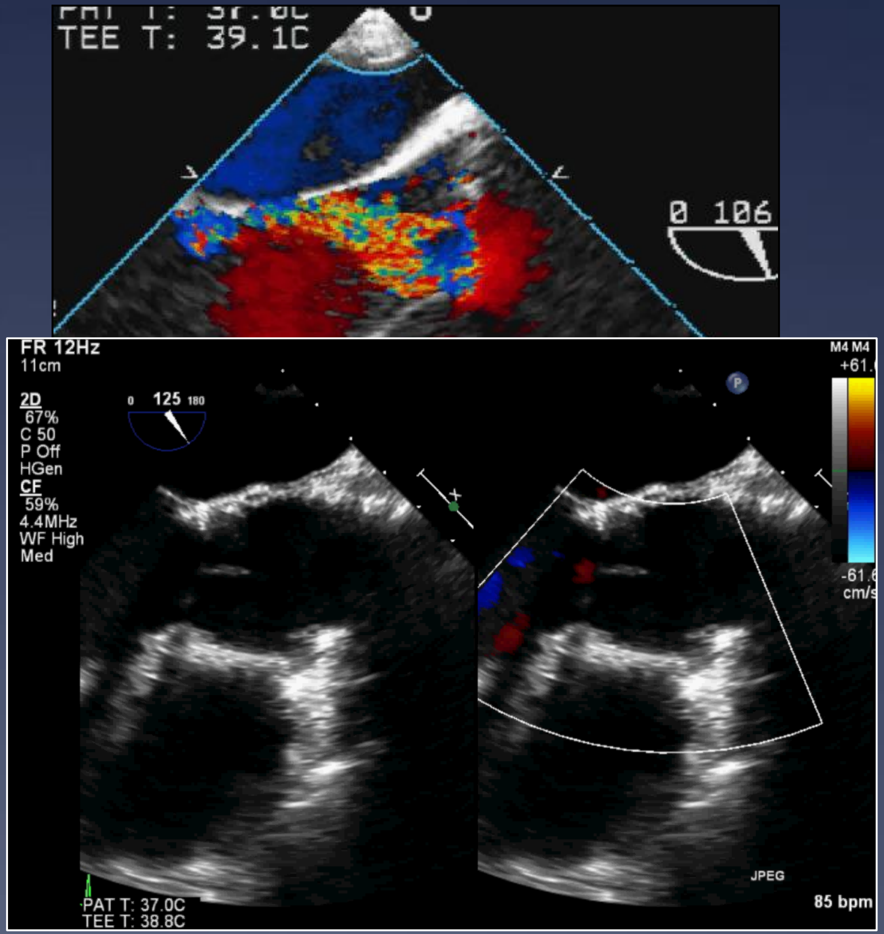




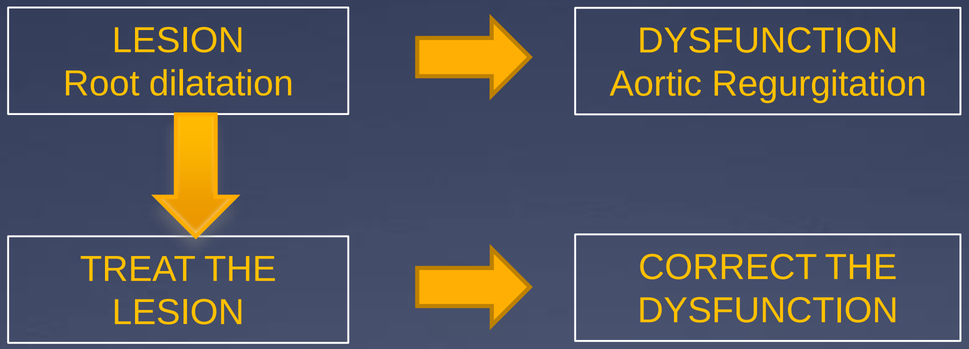
Restoration of the aortic root geometry with a graft restores a normal AV function

TREAT THE LESION, CORRECT THE DYSFUNCTION

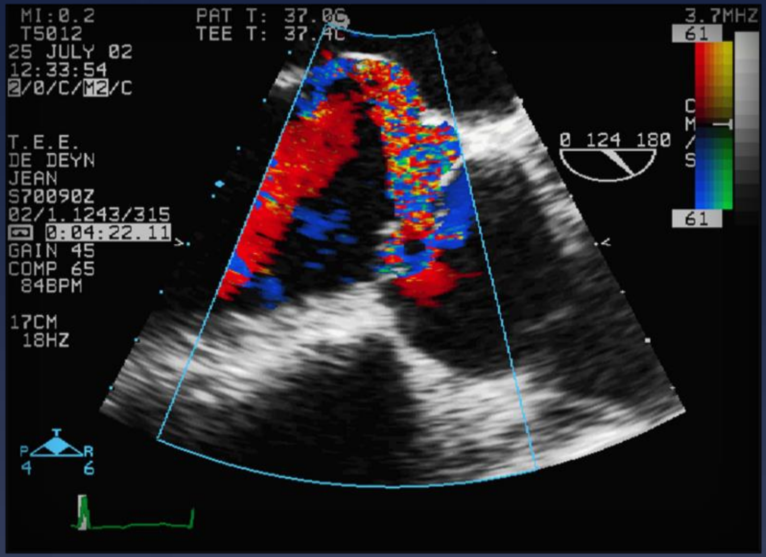




THE FUNCTIONAL APPROACH:



The journey continues with…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JEAN
S70090Z
02/1.1243/315
0:04:22.11
GAIN 45
COMP 65
84BPM
17CM
18HZ
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CM/S
61
P R
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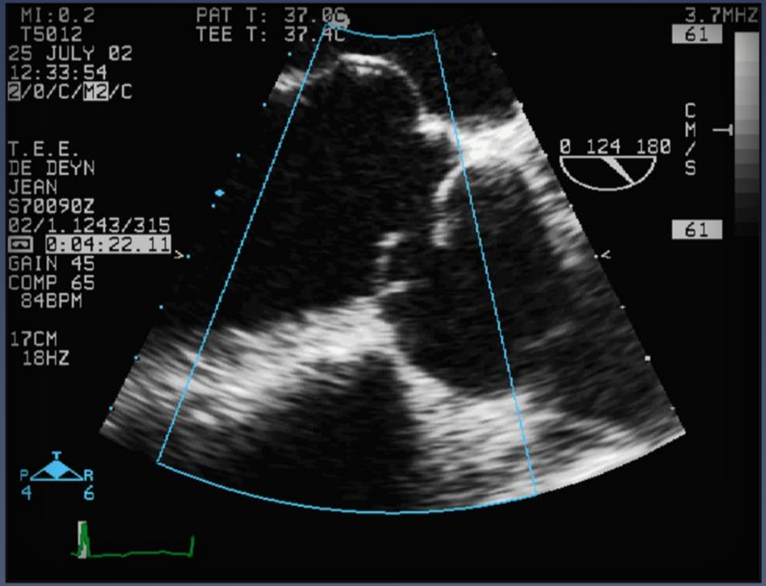
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GAIN 45
COMP 65
84BPM
17CM
18HZ
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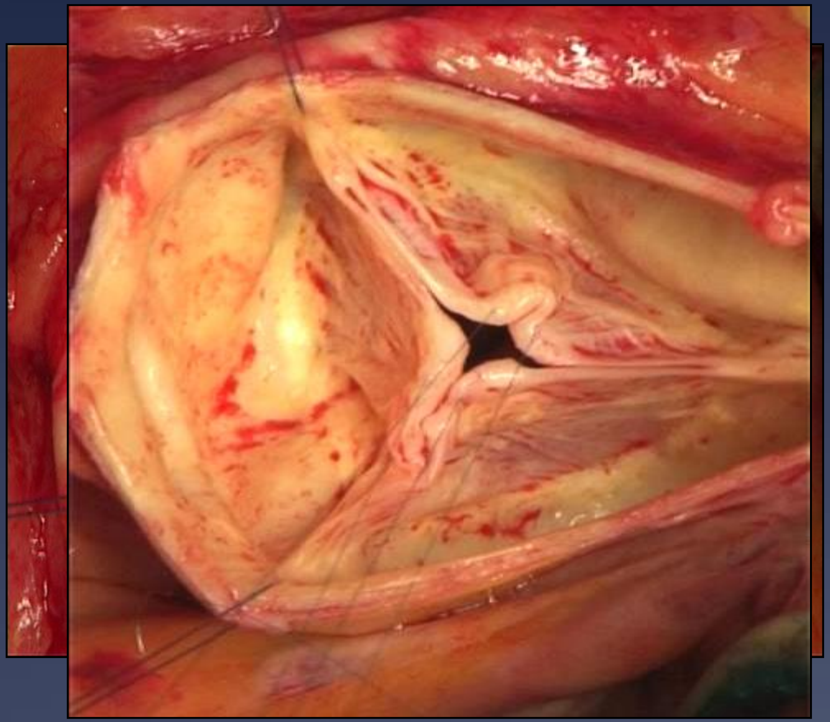
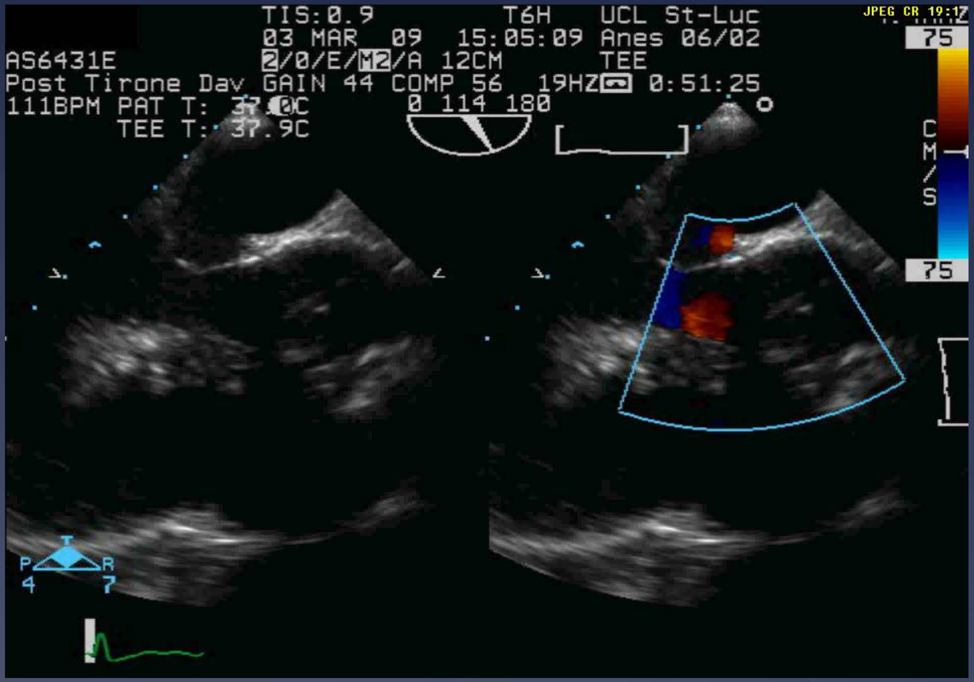
Dysfunctional Aortic Valve

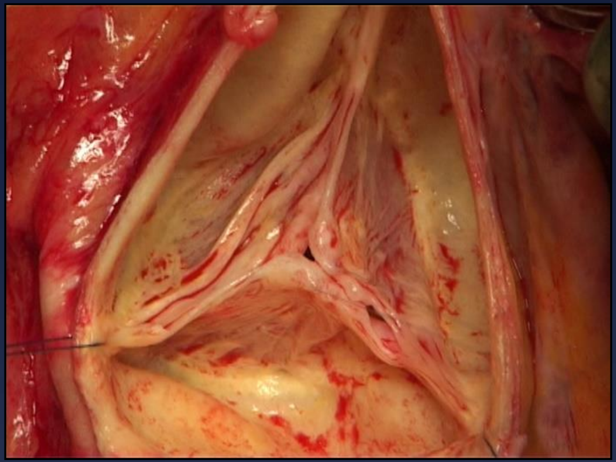
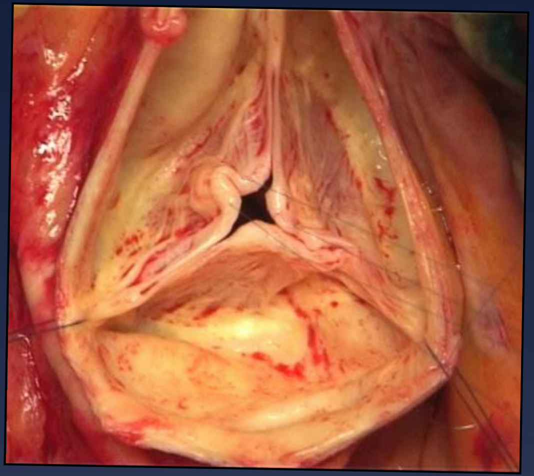
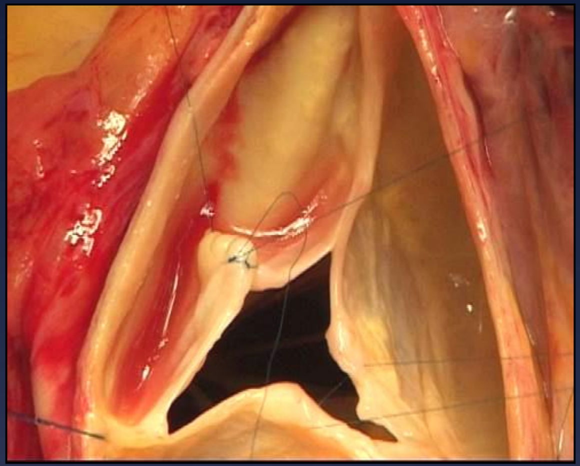
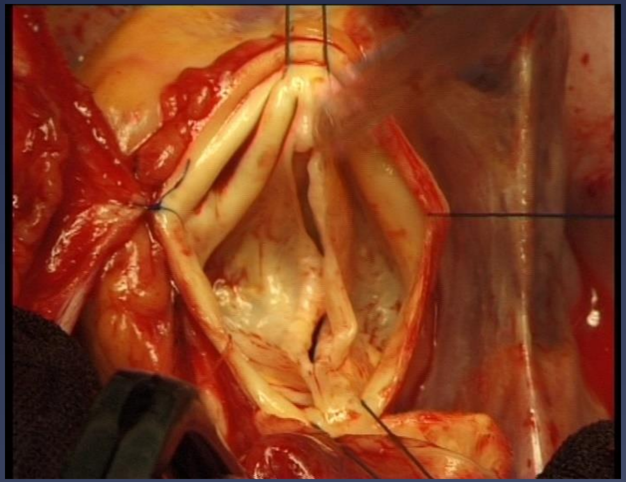
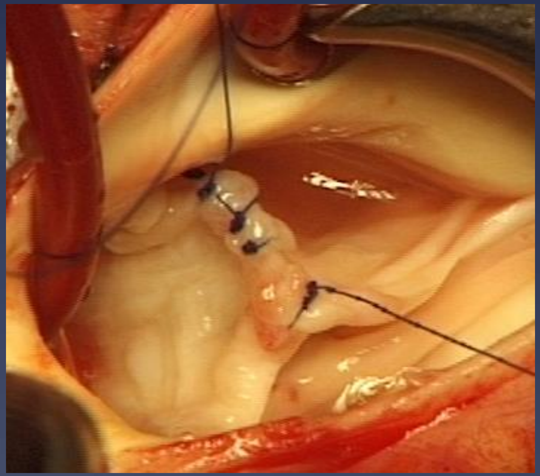
2nd important observation: we can have Aortic Insufficiency despite a normal size aorta and (almost) normal leaflets





AV prolapse is an **elongation** of the cusp free margin; shortening of the free margin restores a normal function

TREAT THE LESION, CORRECT THE DYSFUNCTION

Leaflet prolapse:excess length of free margin, shortening (plication) correct prolapse and AR

THE FUNCTIONAL APPROACH:

LESION
Excess free margin

→ DYSFUNCTION
Cusp prolapse

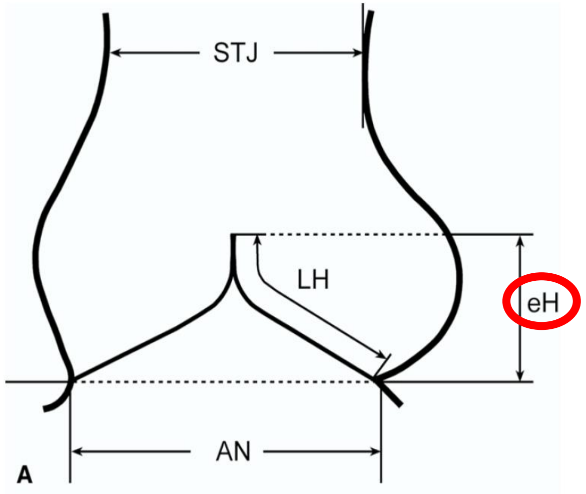
↓

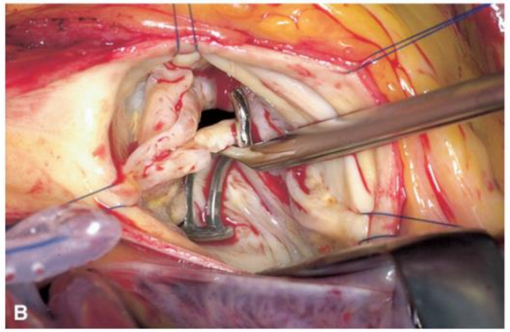
TREAT THE LESION
Shortening of the free margin

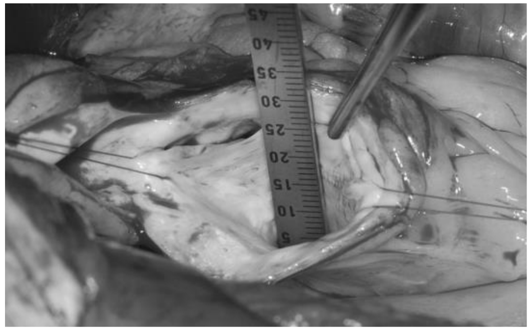
→ CORRECT THE DYSFUNCTION

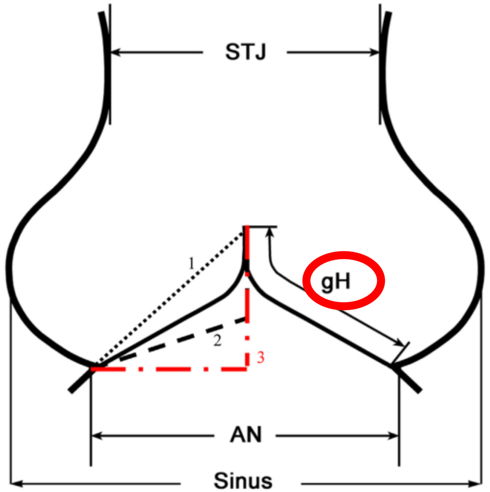
Aortic valve & root anatomy: *Application for valve repair*

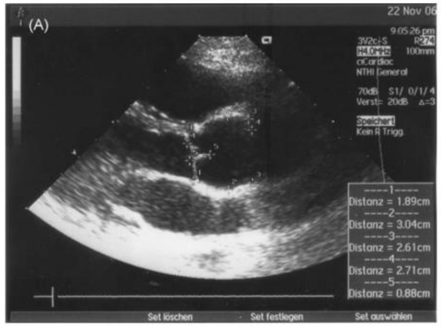
Effective height (eH) & Geometric height (gH)

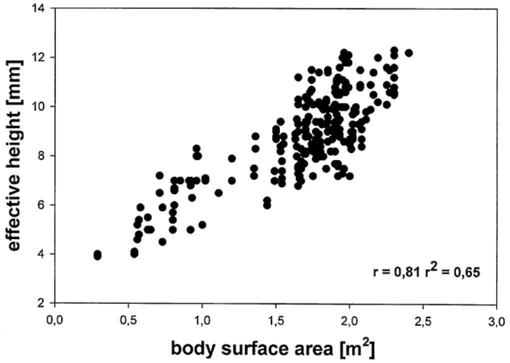


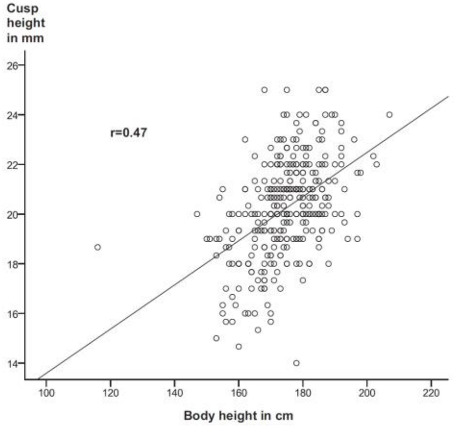


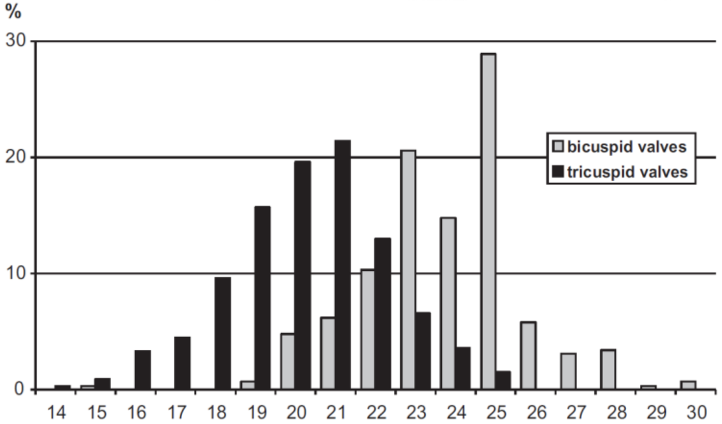








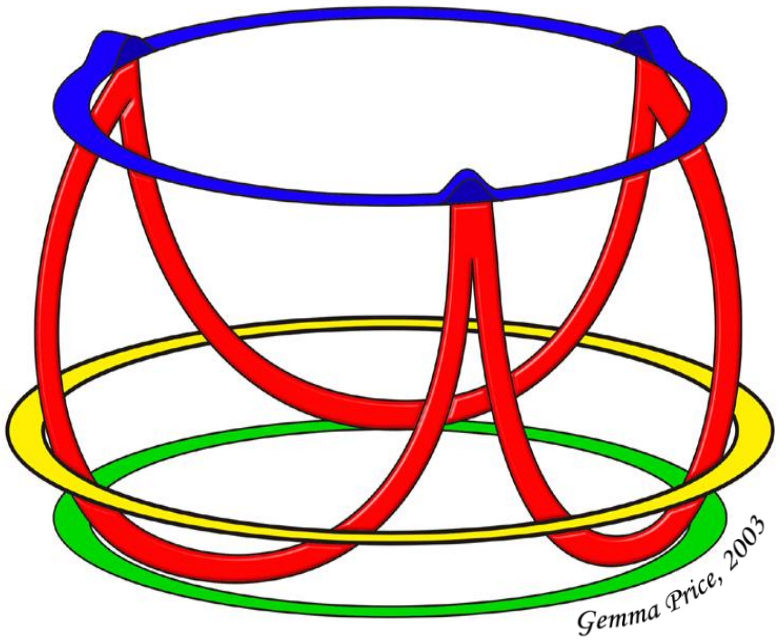




Schäfers H.J., JTCVS 2006; 132:436-8
Bierbarch B.O., Shäfers H.J., EJCTS. 2010; 38:400-406
H.J. Schäfers, J Thorac Cardiovasc Surg 2013;146:269-74

Aortic valve & root anatomy: *Concept of 3D annulus*

Aortic root = 3D support apparatus of the AV



Robert Anderson

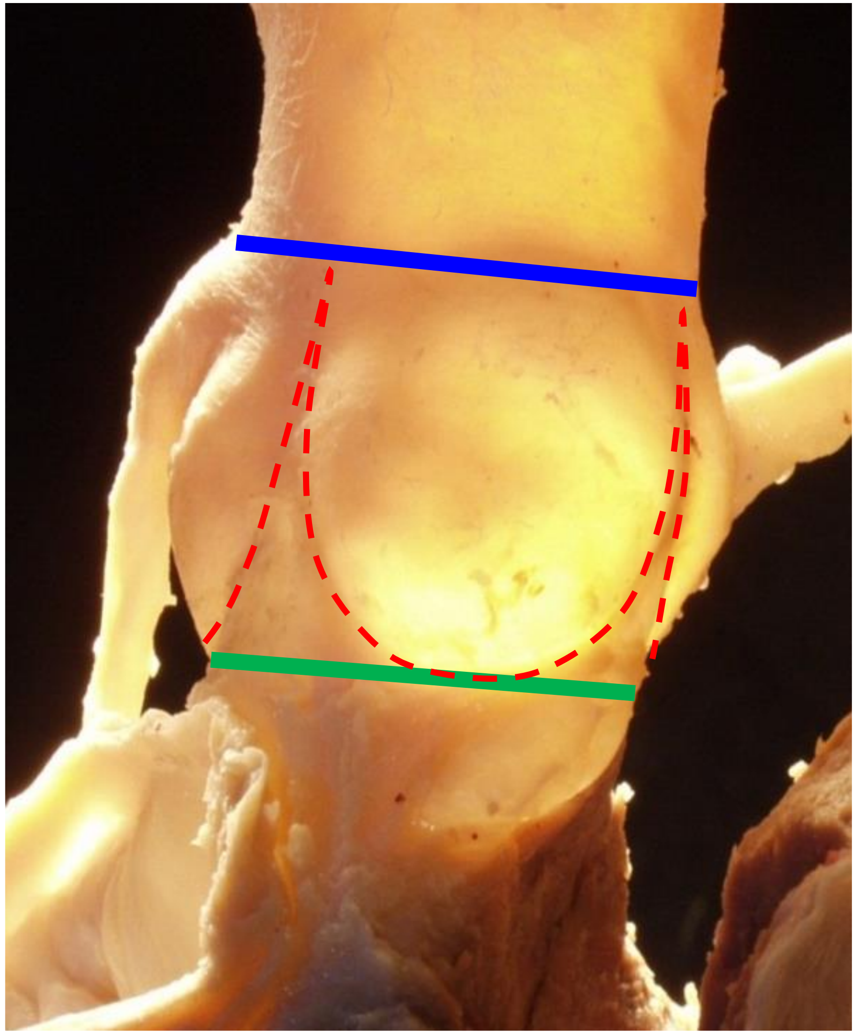
STJ

+

Cusp insertion

+

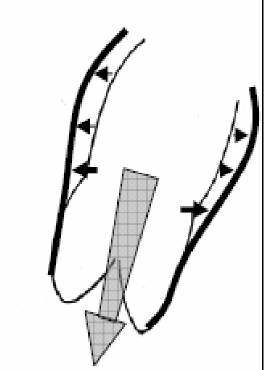
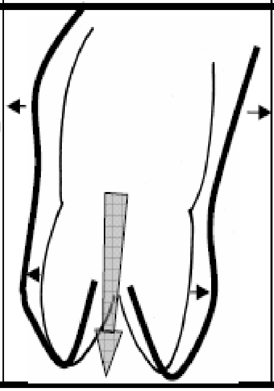
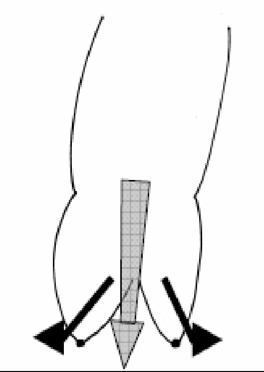
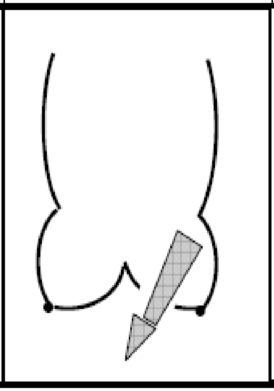
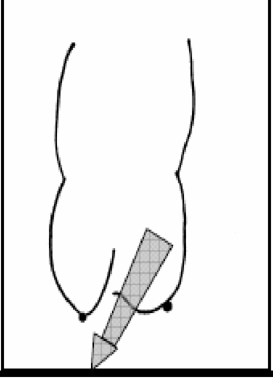
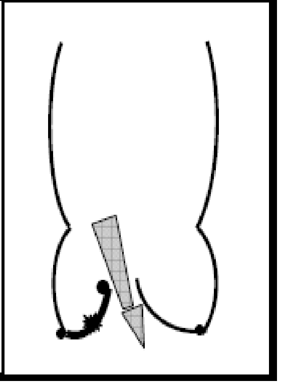
VAJ & **Basal ring**



Aortic root and valve: a functional unit

…lost of geometrical relationship leads to aortic insufficiency

Functional Classification of AI

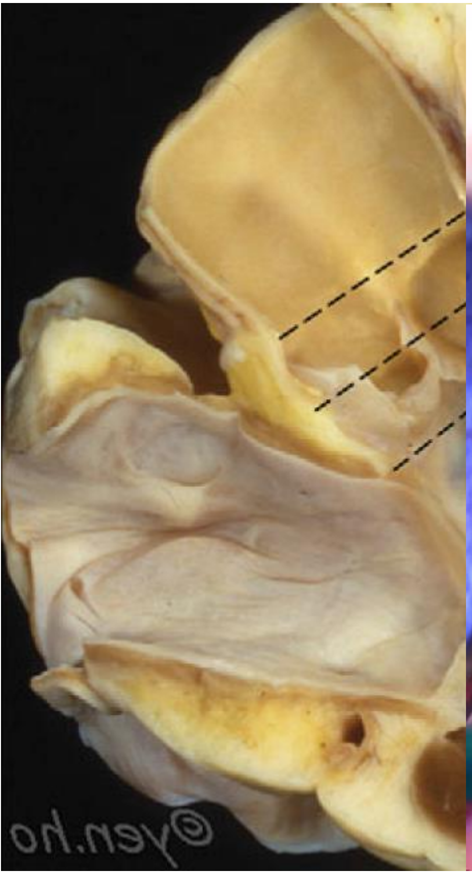
AI Class	Type I Normal cusp motion with FAA dilatation or cusp perforation				Type II Cusp Prolapse	Type III Cusp Restriction
	Ia	Ib	Ic	Id		
Mechanism						

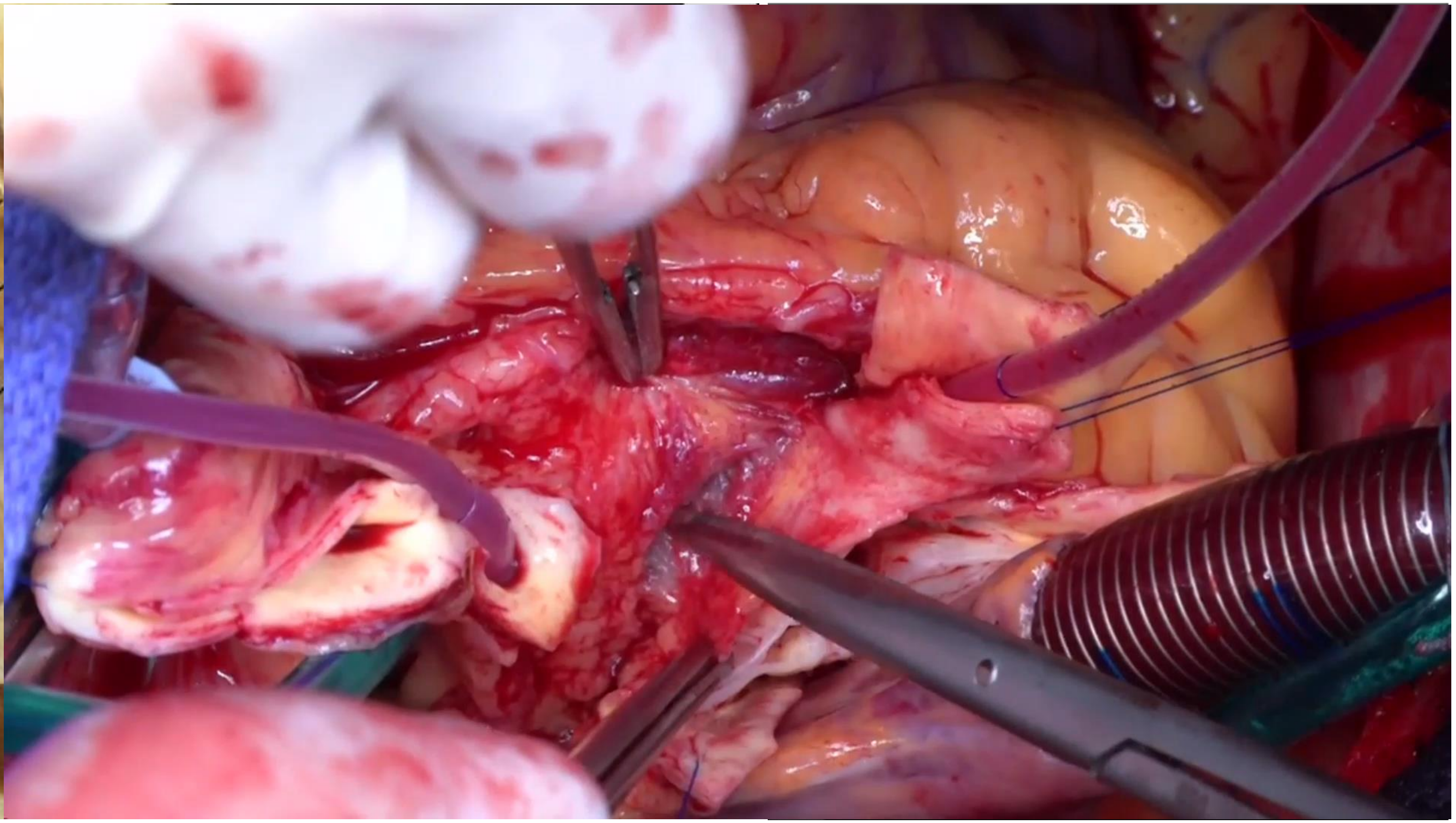
El Khoury Classification Cur. Op. Card. 2005

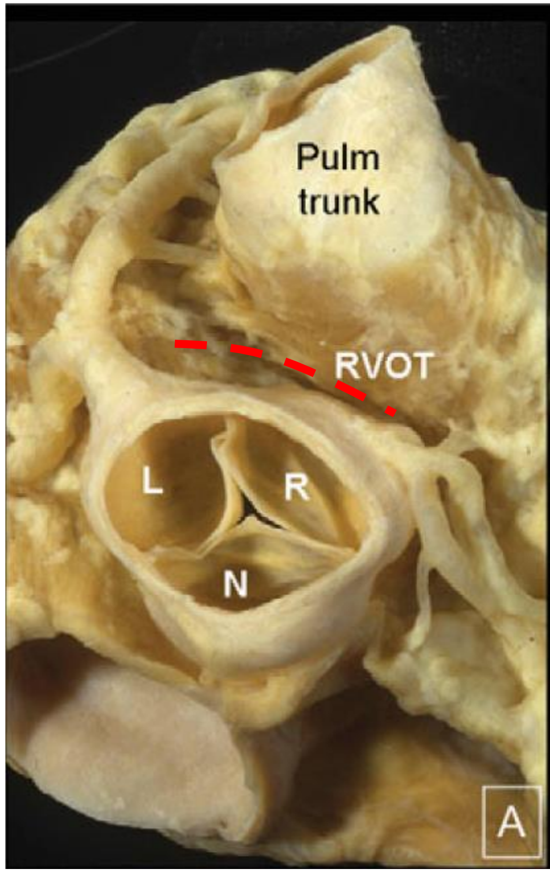
AV anatomy: Content

1. Aortic root
   - Surrounding structures
   - Valsalva Sinus
   - **Important structures**
   - Coronary ostia
   - Conduction bundle
   - Ventriculo-aortic junction
2. Aortic cusp
   - Cusp and coaptation surface
   - Geometric height
   - Free margin length

AV anatomy: *Surrounding structures*

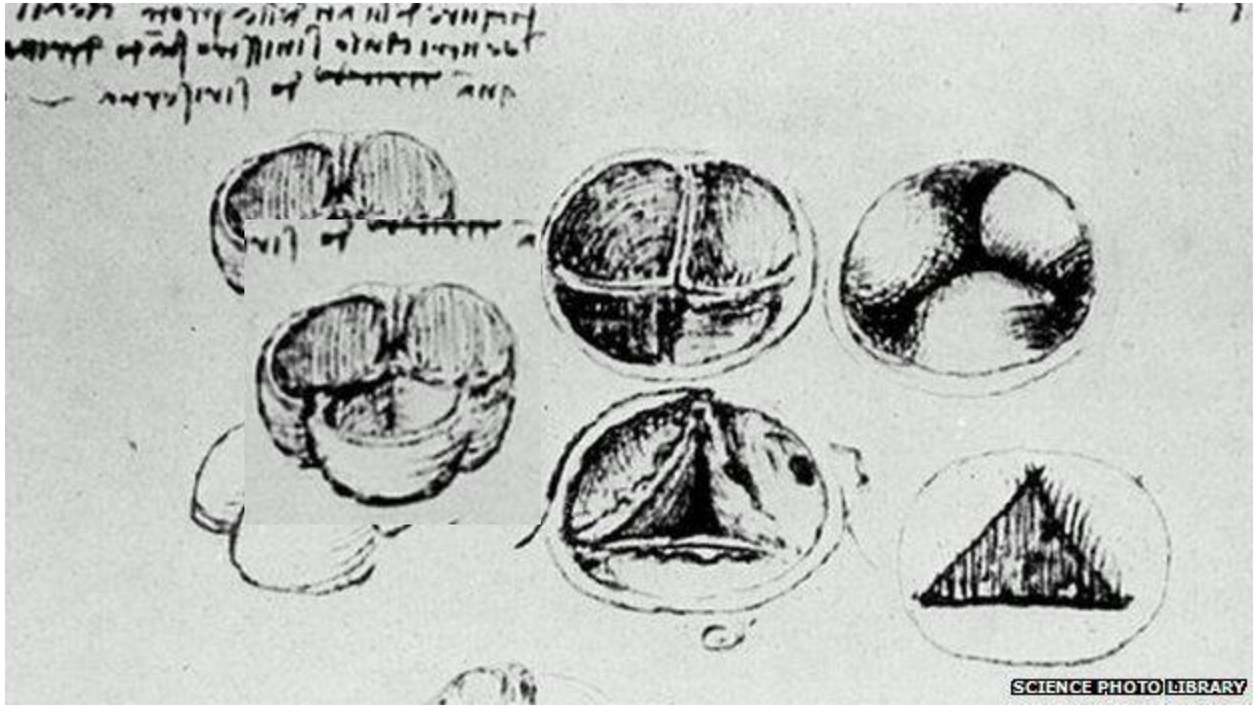


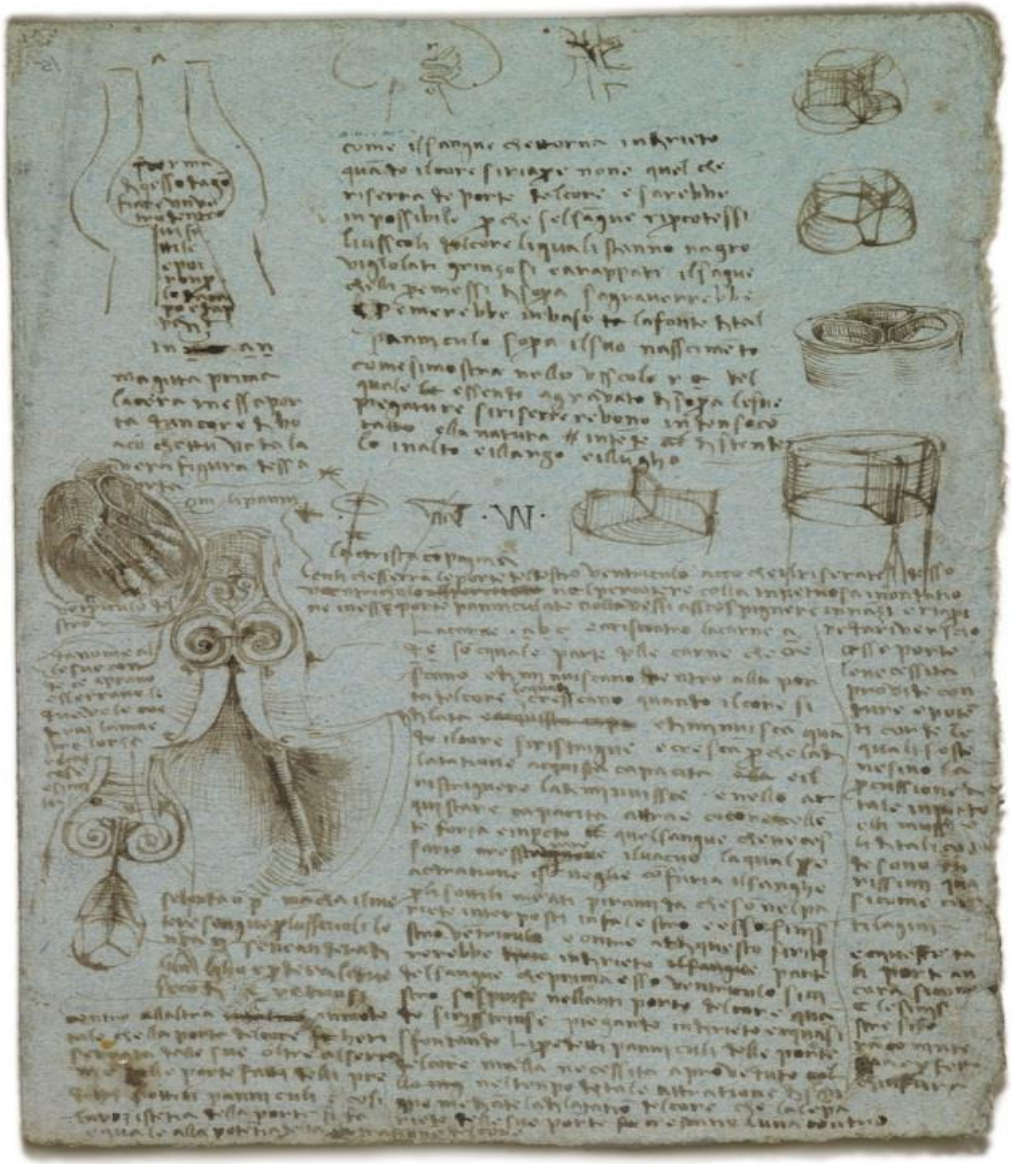




Ho Y., Anderson R. Eur J Echocardiogr. 2009;10(1):i3-10.

Aortic valve & root anatomy: *analyses of a genius*

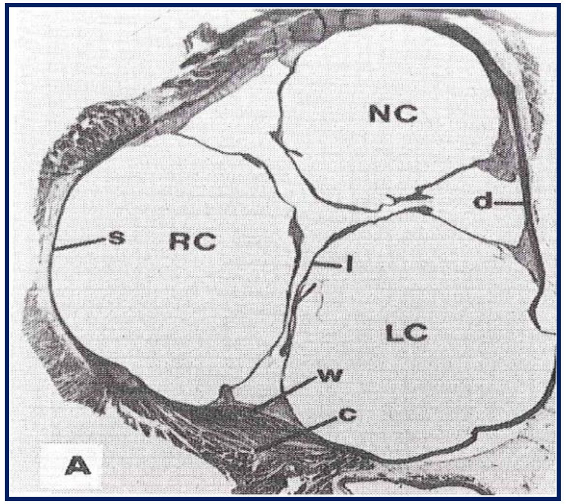




Leonardo Da Vinci 1452-1519.

Aortic valve & root anatomy: *analyses of a genius*

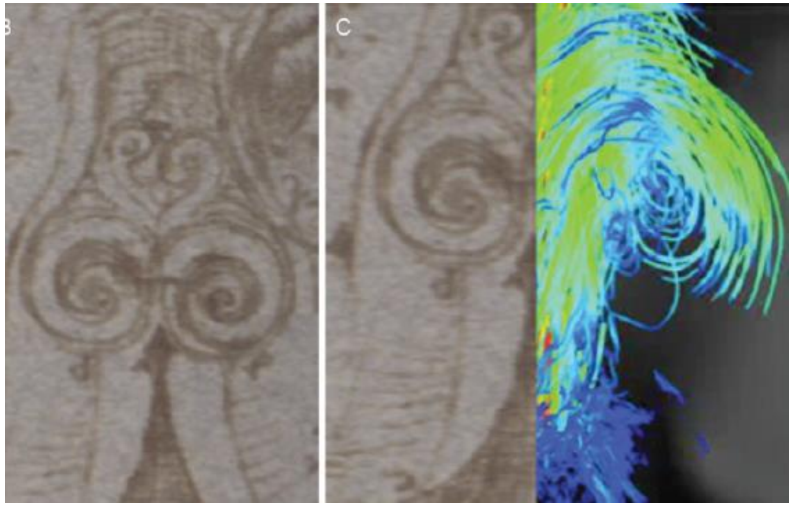
Semi-spherical configuration



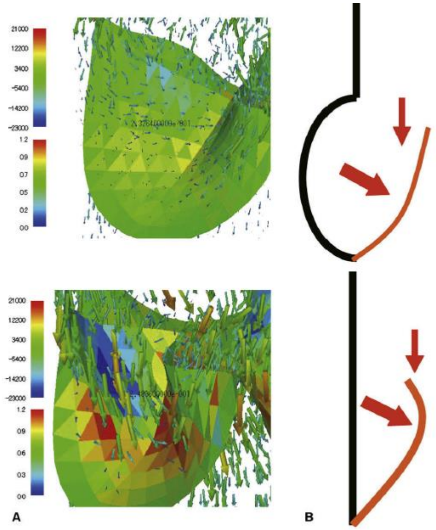
Transverse section of aortic root approximately halfway between base of the leaflet and sinus rim. The section shows three leaflets enclosing corresponding aortic sinuses and leaflet attachments to the wall. The root wall at this level consists of smooth muscle-elastc tissue (s), myocardium (c), or dense collagenous tissue (d). (Original magnification X 2,5)

Thubrikar Mano, The Aortic Valve; CRC Press1990

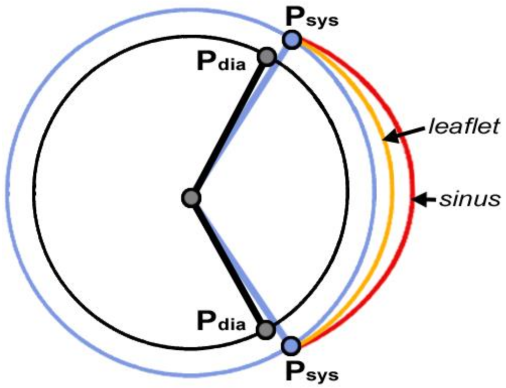
The role of the Valsalva sinuses



Bissell M. Eur Heart J. 2014

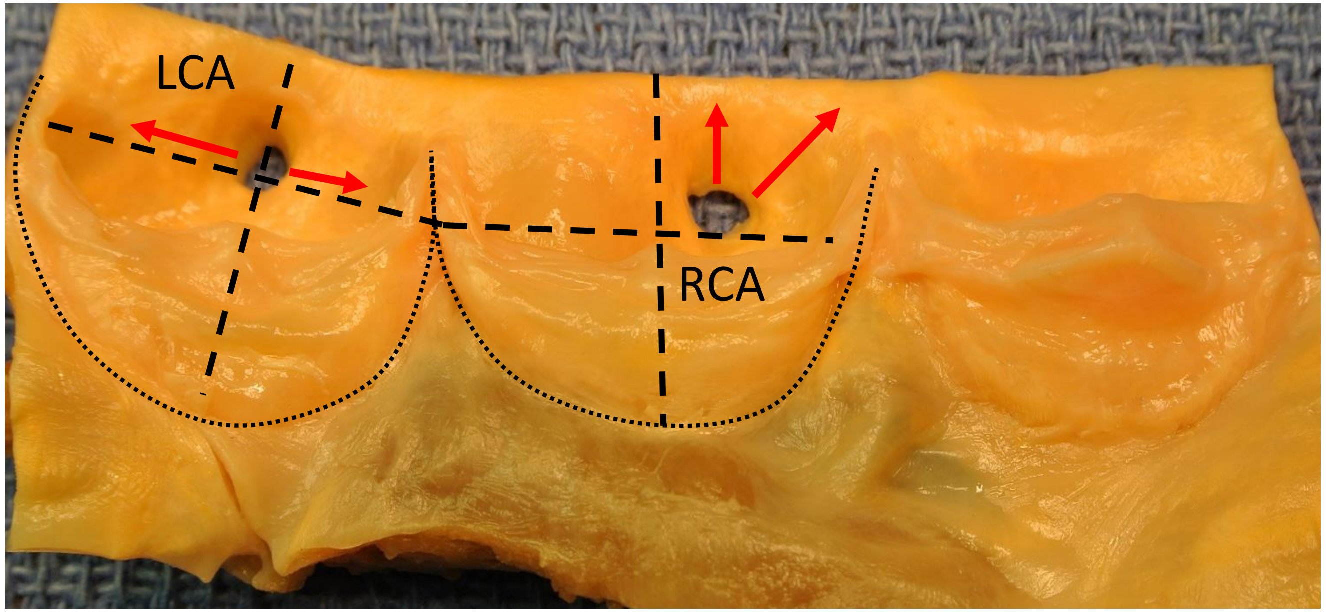


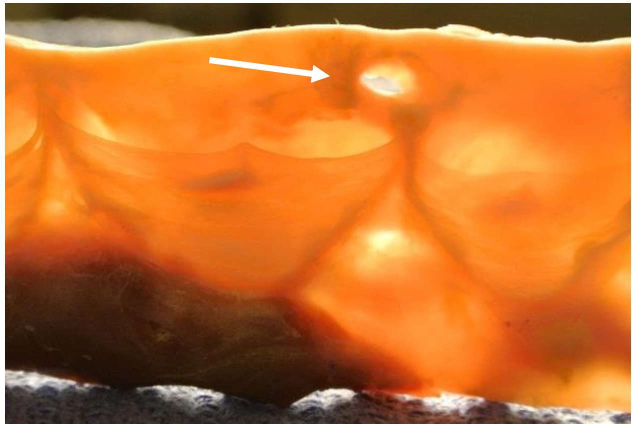
Katayama JTCVS 2008

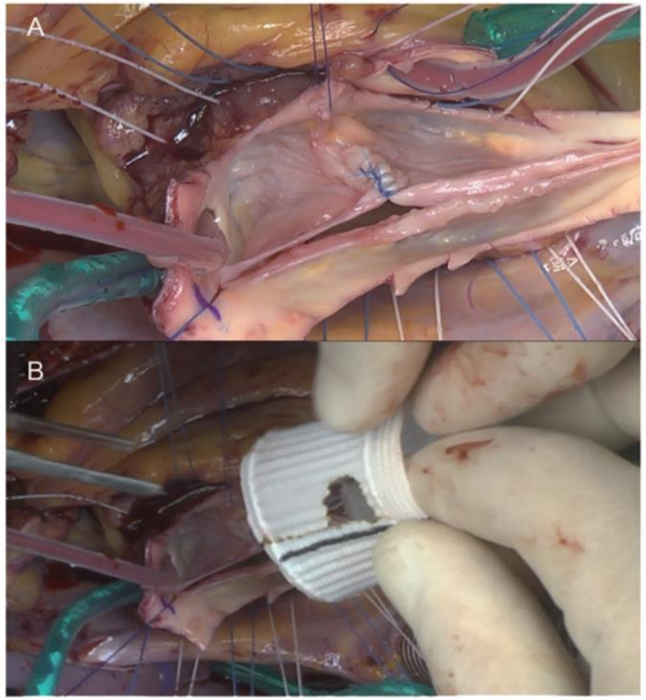


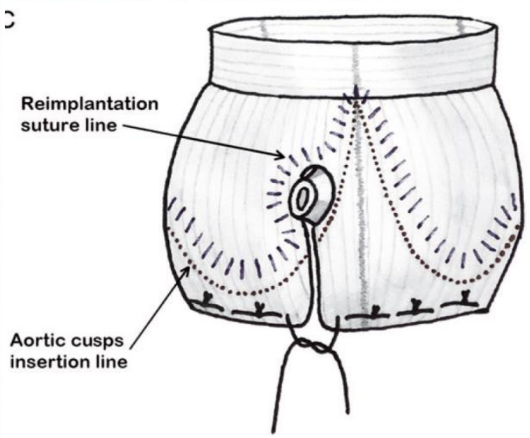
- *Extensible*
- *Maximal leaflet opening*
- *Induce closure & release stress*
- *Coronary perfusion*

Aortic valve & root anatomy: *Coronary arteries*



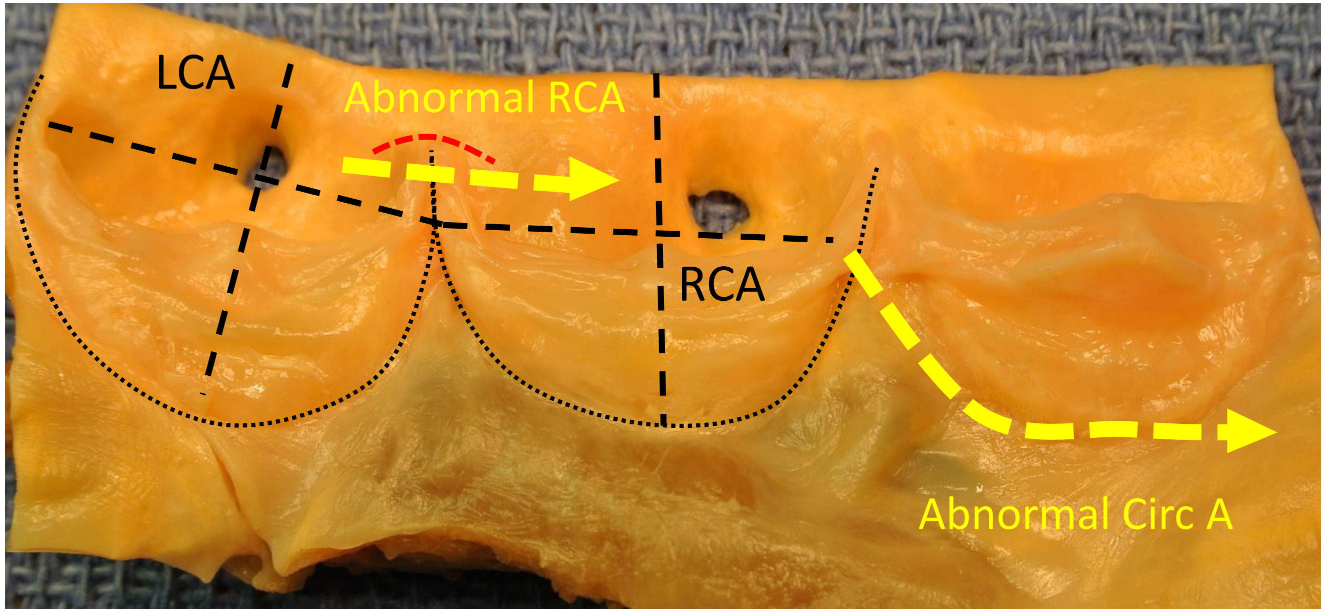


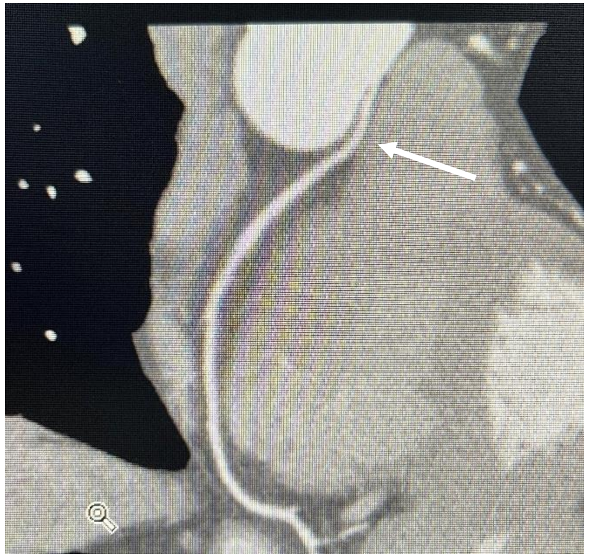


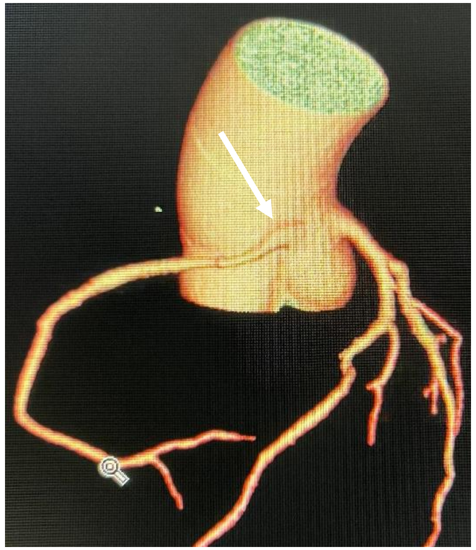


J. Hechadi, EJCTS 45 (2014) 937–938

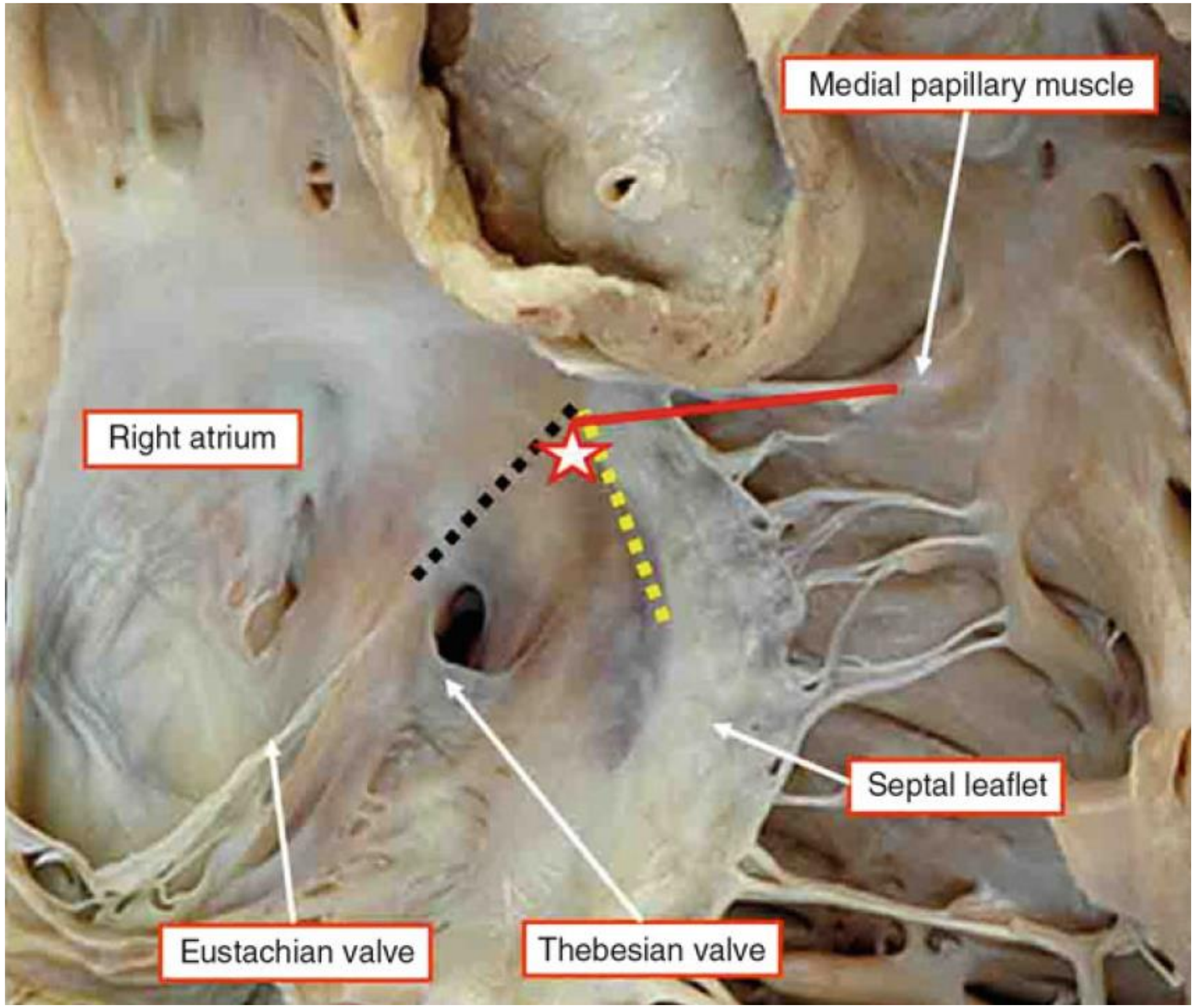
Aortic valve & root anatomy: *Coronary arteries*

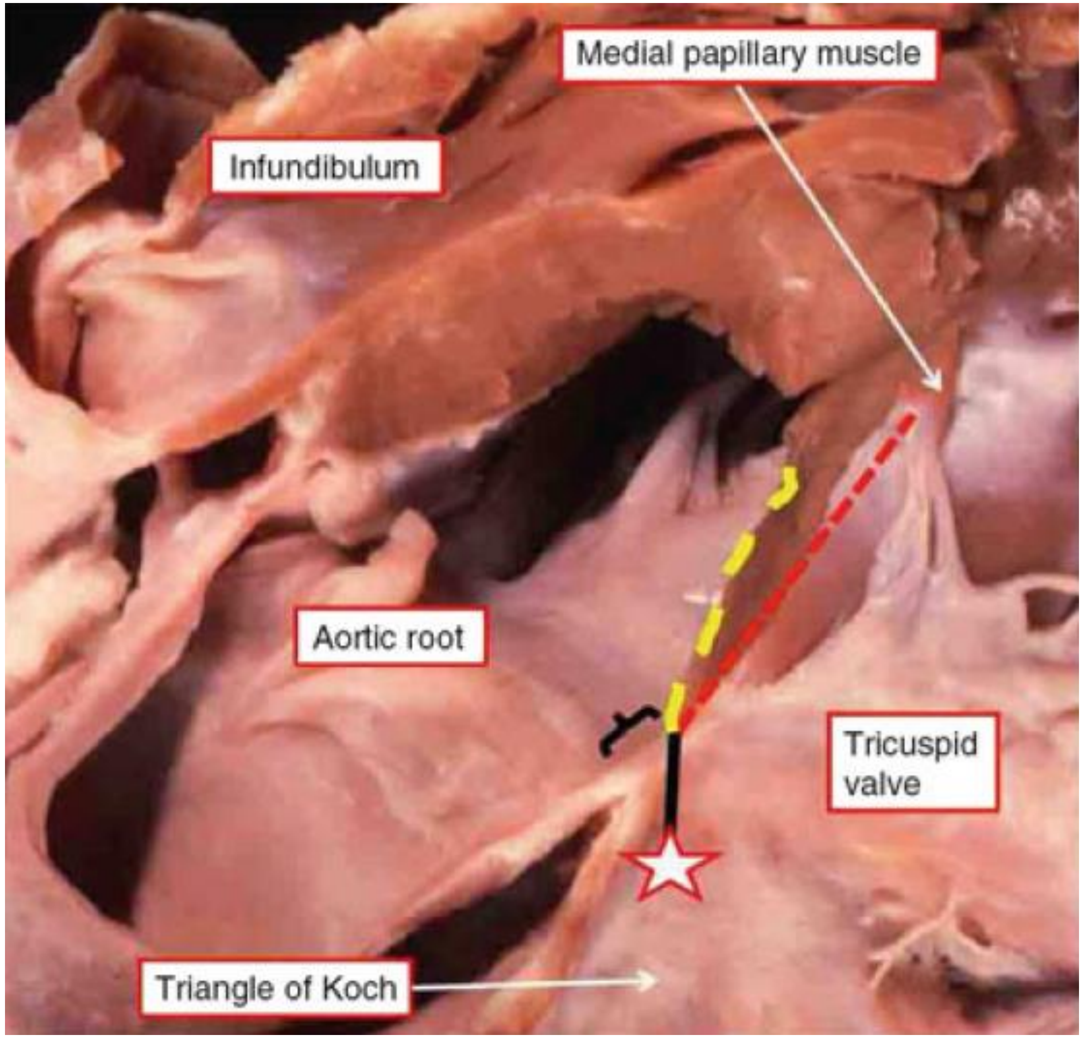






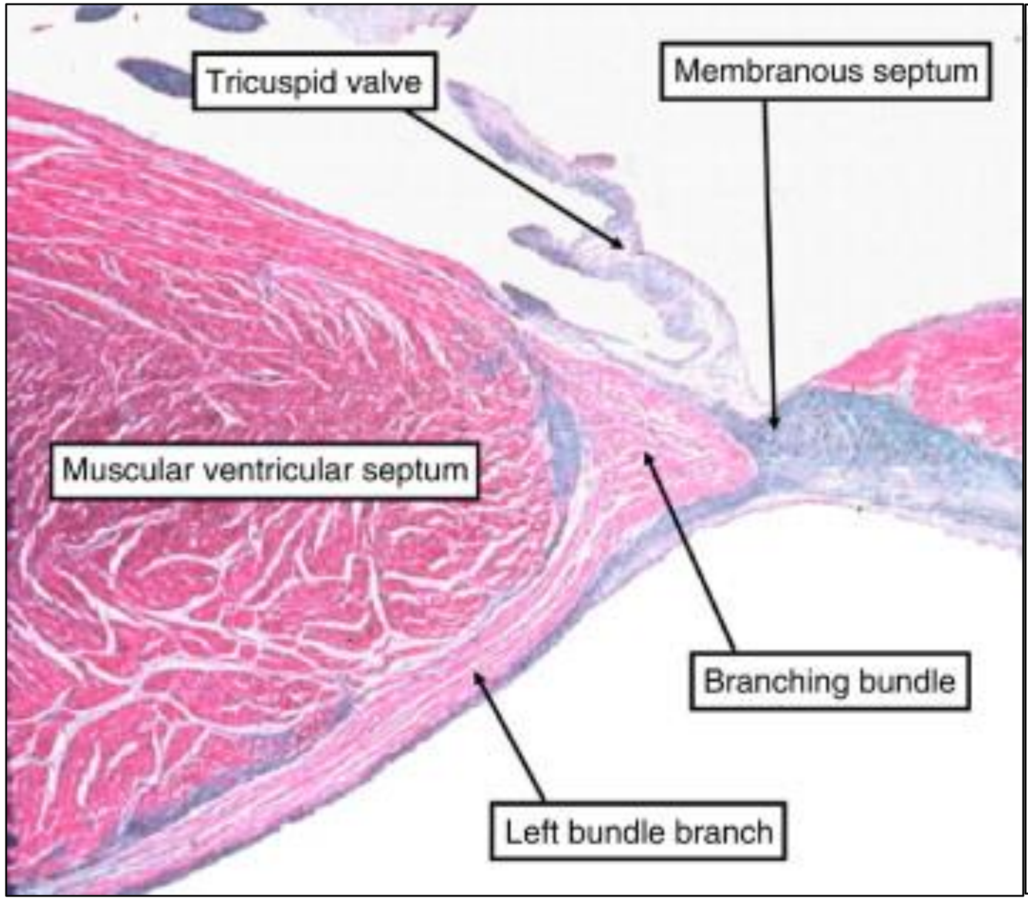
Aortoventricular conduction system



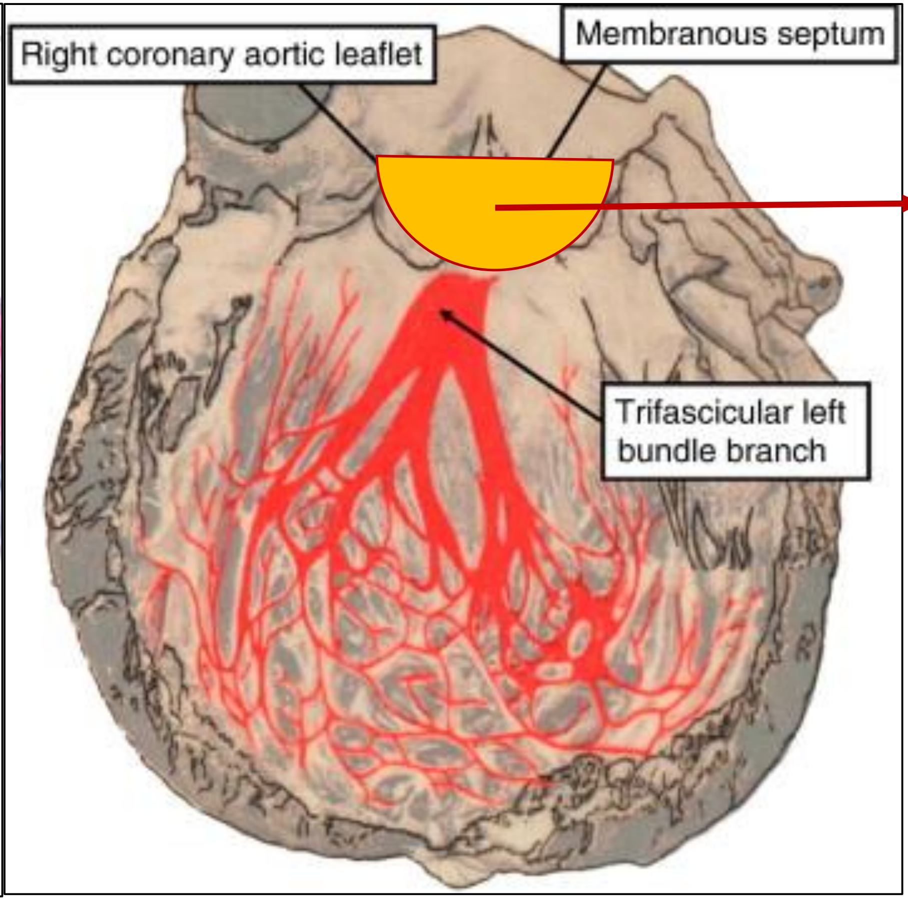


R. Anderson et al. Normal Cardiac Anatomy, Textbook of Pediatric and Congenital Cardiology, Cardiac Surgery and Intensice Care.© Springer-Verlag, London 2014

Aortoventricular conduction system



B. Wilcox, A. Cook, R. Anderson,
Surgical Anatomy of the Heart, 3rd Edition



R-N fusion BAV

Monograph of Tawara,1906

Aoric valve & root anatomy: *Normal annulus size*

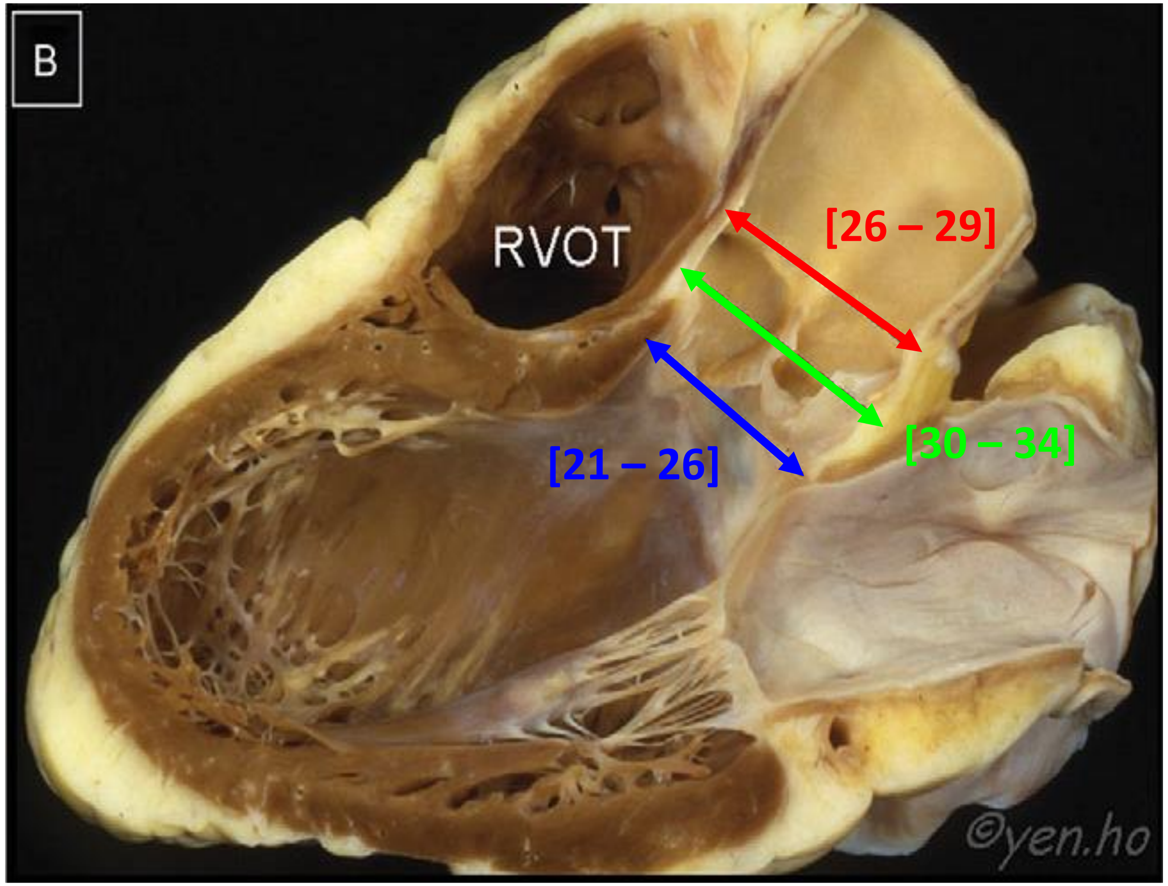
- **[21 – 26] mm (13 mm/m²)**

In adults, VAJ size is influenced by:

- **BSA**
- Height
- Weight
- Age

\+

- Athletes



Ho Y. Eur J Echocardiogr. 2009;10(1):i3-10.

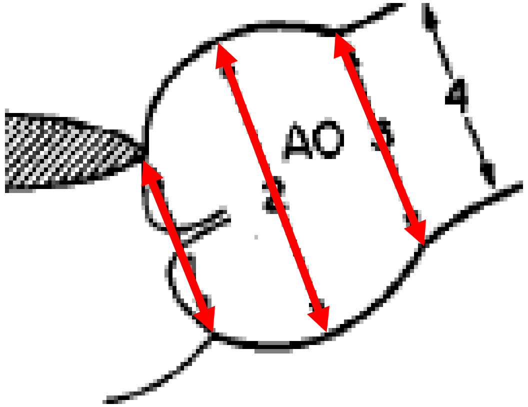
- *Roman MJ. Am. J. Cardiol. 1989*
- *Kim M, Hypertension 1996*
- *Aslani A. Am. J. Card. 2007*
- *D'Andrea A. Am. J. Cardiol. 2010*
- *Bierbach B.O. EJTCS 2010*
- *Jakrapanichakul D. J. Med. Assoc. Thai. 2011*

Aortic root size in chronic AI

- 127 pts with chronic AR, 74% TAV, 16% BAV

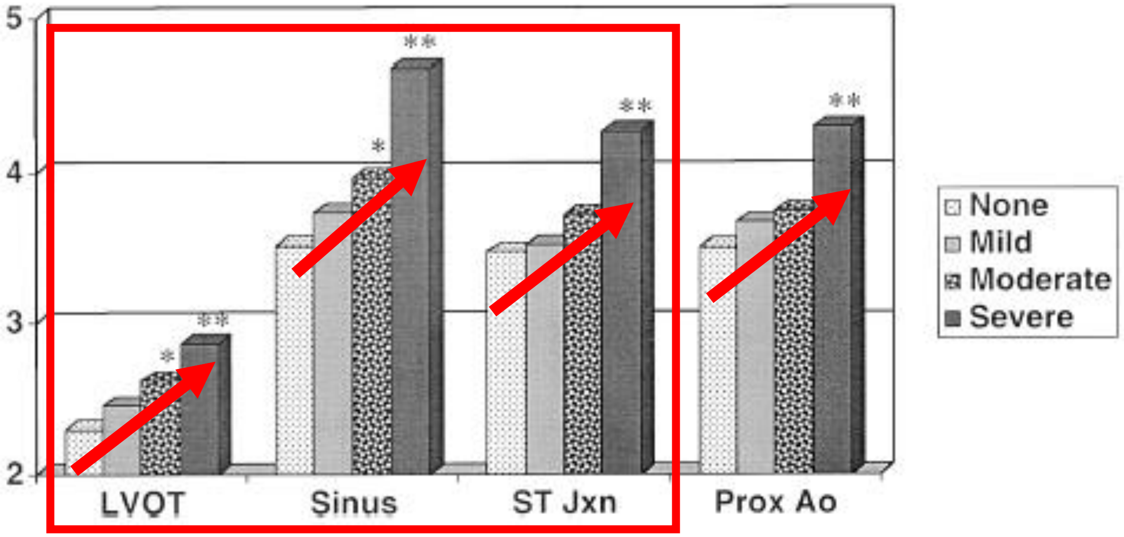
Table II. Degree of AR and aortic root size indexed by body surface area at follow-up study

	Mild AR (cm/m^2) (n = 67)	Moderate AR (cm/m^2) (n = 45)	Severe AR (cm/m^2) (n = 15)	p Value*
Aortic anulus	1.29 ± 0.23	1.38 ± 0.23	1.39 ± 0.11	0.055
Valsalva sinuses	1.89 ± 0.34	2.04 ± 0.31	2.09 ± 0.32	0.025
Supraaortic ridge	1.49 ± 0.30	1.71 ± 0.35	1.76 ± 0.43	0.001
Ascending aorta	1.97 ± 0.42	2.16 ± 0.49	2.19 ± 0.47	0.049



Padial LR. Am. Heart. J. 1997

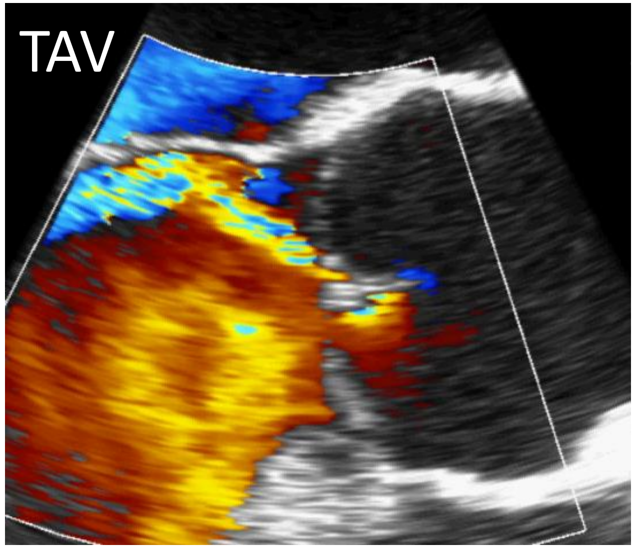
- 84 pts BAV with AR

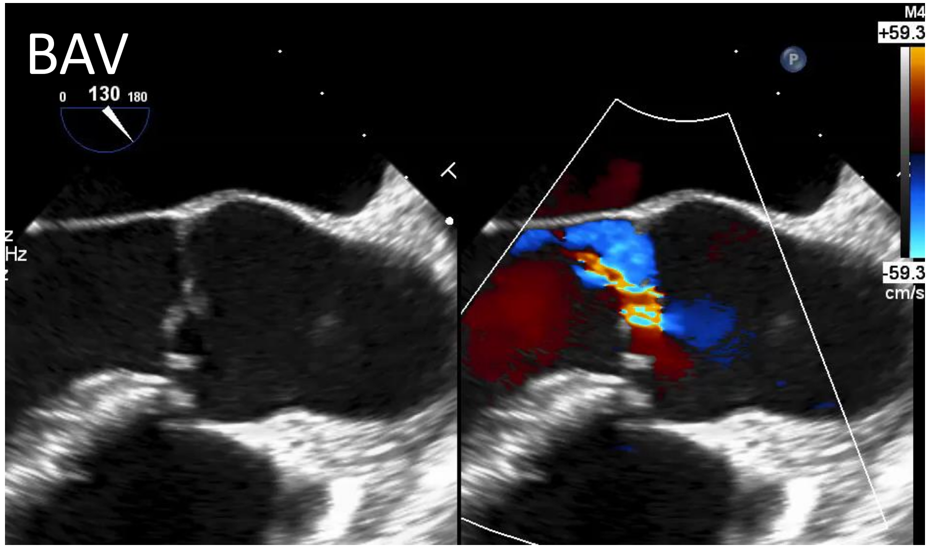


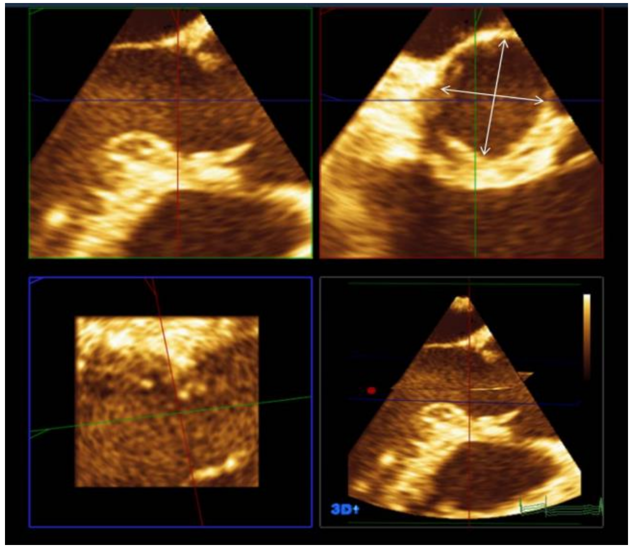
Keane M.G. Circulation. 2000

- *Many patient with severe AI present mild/moderate root dilatation (≥40mm)*
- *Repair = restore mismatch between valve and root size*

Annulus size in chronic AI







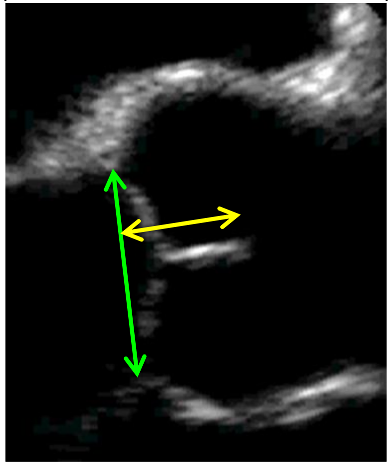
	Normal TAV N=32	TAV repair		BAV repair	
		AI ≤ 1	AI ≥ 2	AI ≤ 1	AI ≥ 2
2D echo	22.8 ± 2.4	23.4 ± 2.5	27.2 ± 3.9*	26.6 ± 2.6*	31.3 ± 3.8$^{\$\&}$
3D small Ø	21.8 ± 2.5	22.5 ± 3.4	26.1 ±4.5*	25.3 ± 2.4	29.2 ± 3.3$^{\$\&}$
3D long Ø	26.9 ± 2.2	25.4 ± 3.8	28.3 ± 4.8	27.8 ± 1.7	32.1 ± 4.3$^{\$\&}$

* p < 0.05 vs TAV without AR; $ p < 0.05 vs TAV with significant AR; & p < 0.05 vs BAV without AR

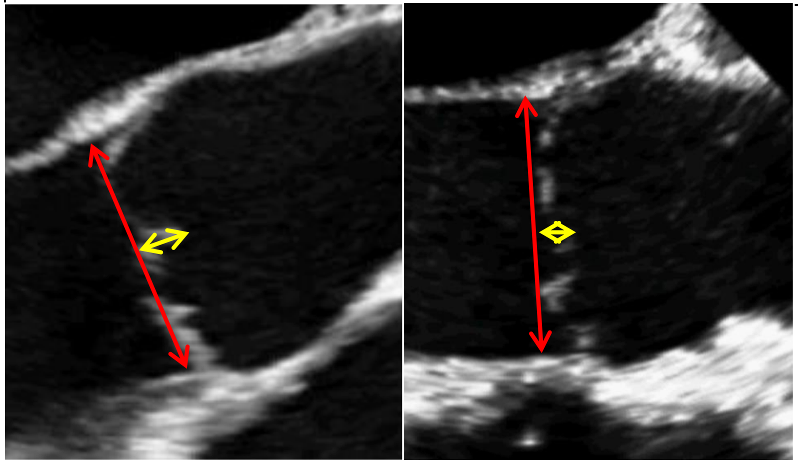
Watremez C., St-Luc, Brussels

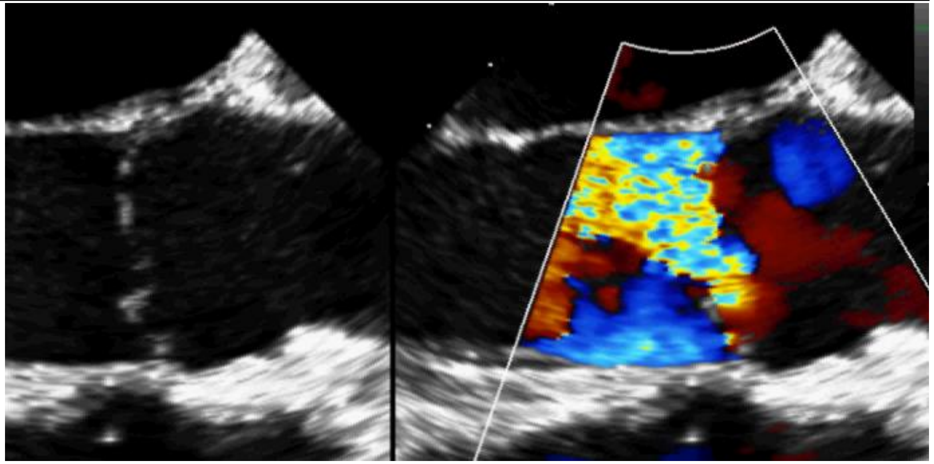
Impact of annulus dilatation on AV function

Normal

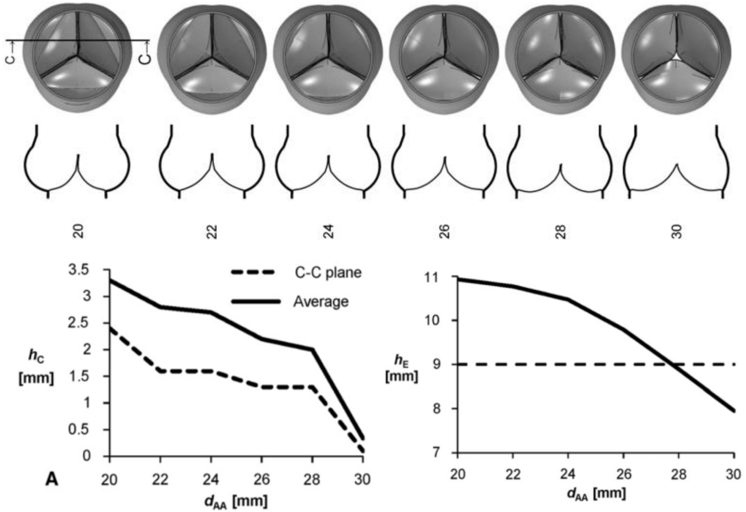


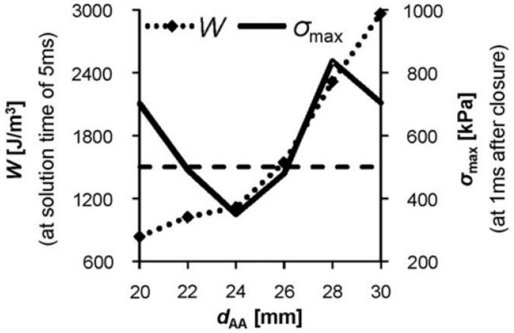
Dilated Annulus





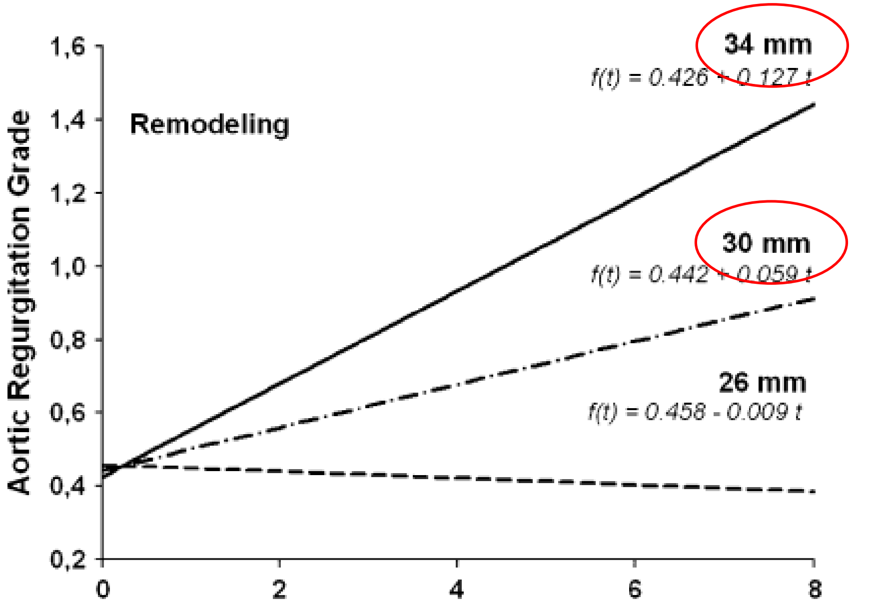
↑VAJ size → ↓↓ Coapt length, ↓ Effective height → ↑ Stress → ↑ free margin length, Rupture fenestration → AI & Prolapse



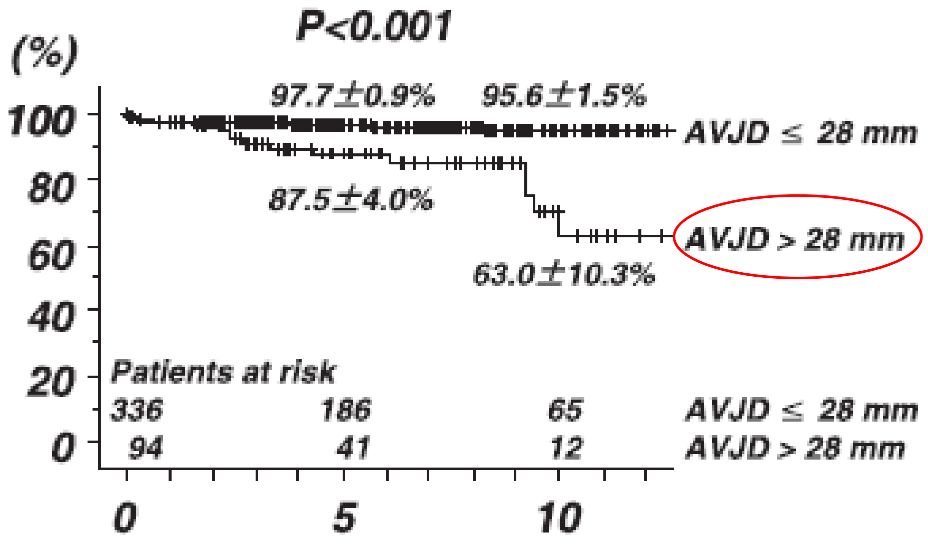


Marom G. JTCVS 2013

Effect of annulus size on AV repair durability



T. Hanke, H. Sievers, JTCVS 2009



T. Kunihara, JTCVS 2012

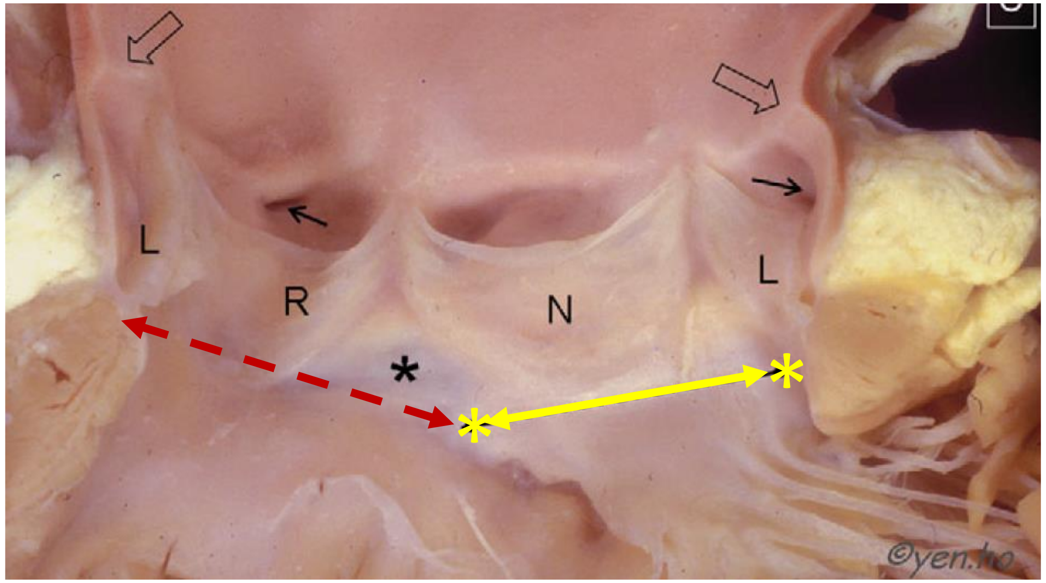
TABLE 2. Risk factors by multivariate Cox regression analysis (−2 log-likelihood function = 161.87, chi-square = 72.79, *P* < .001)

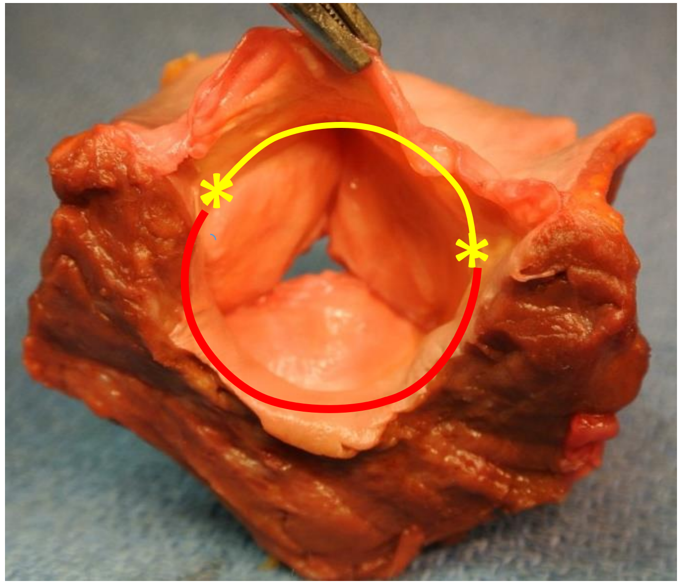
Variable	*P* value	HR	95% CI
Diameter of AV junction (mm)	<.001	1.43	1.21-1.69
Use of annuloplasty	.01	1.28	1.89-66.26
Myocardial ischemia (min)	.04	0.96	0.93-1.00
Effective height	<.001	0.58	0.43-0.79
Use of pericardial patch	<.001	6.24	2.30-16.90

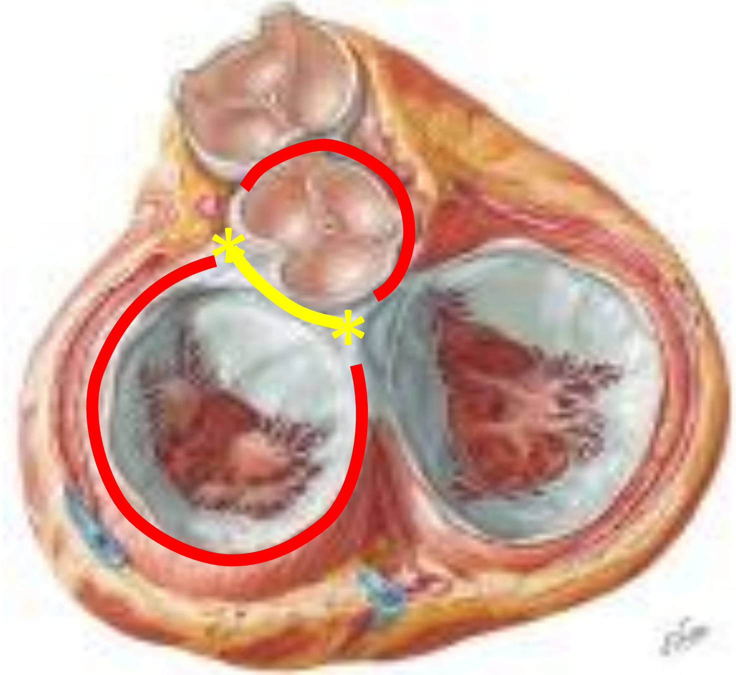
AV, Aortoventricular; *CI*, confidence interval; *HR*, hazard ratio.

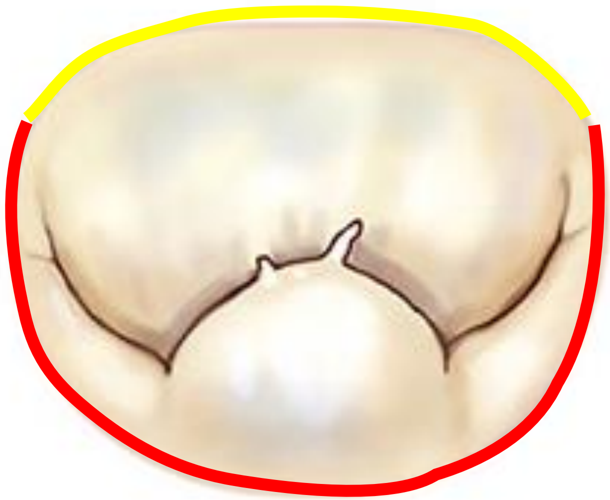
H-J. Schäfers, JTCVS 2016

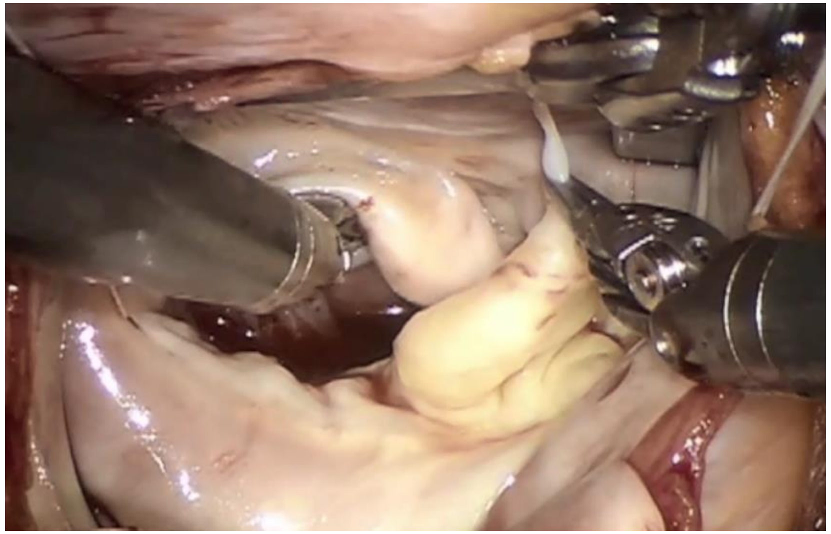
Which part of the AV annulus dilate ?





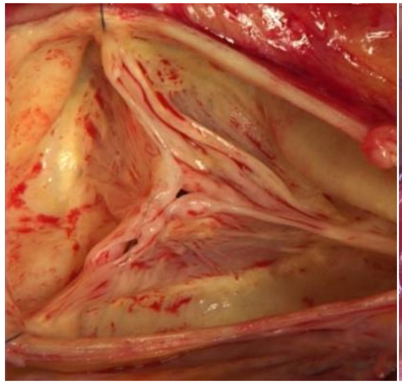
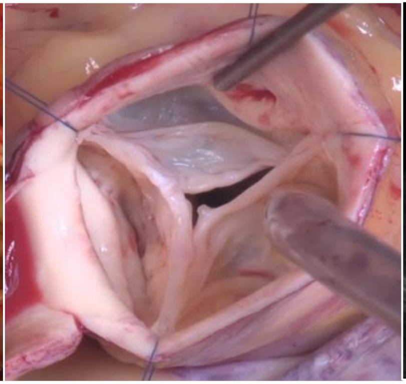
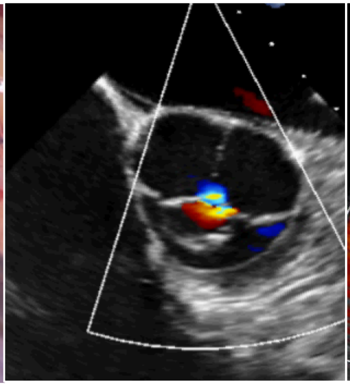
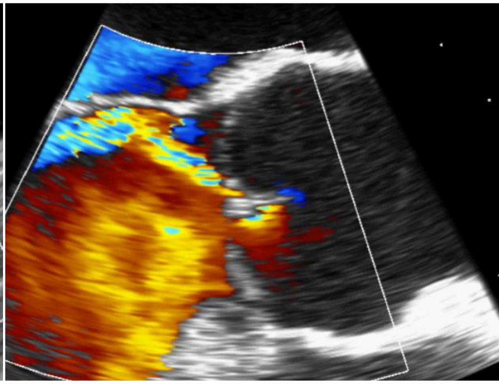




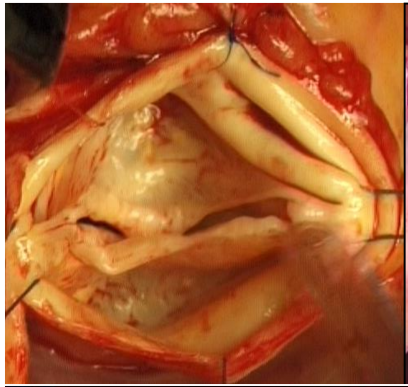
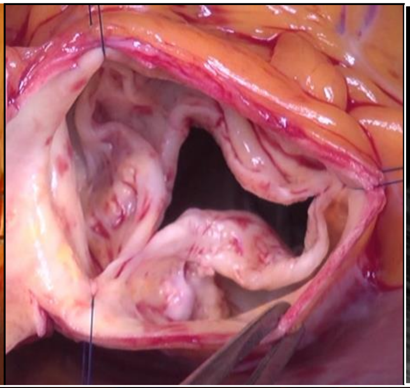
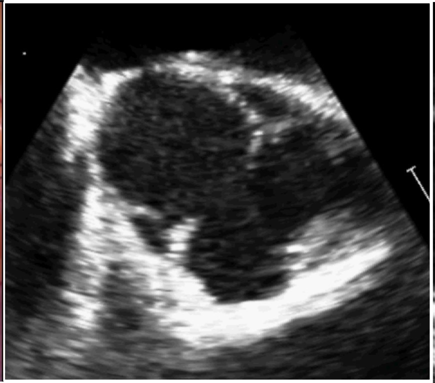
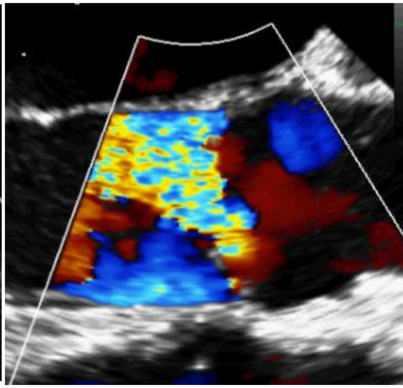


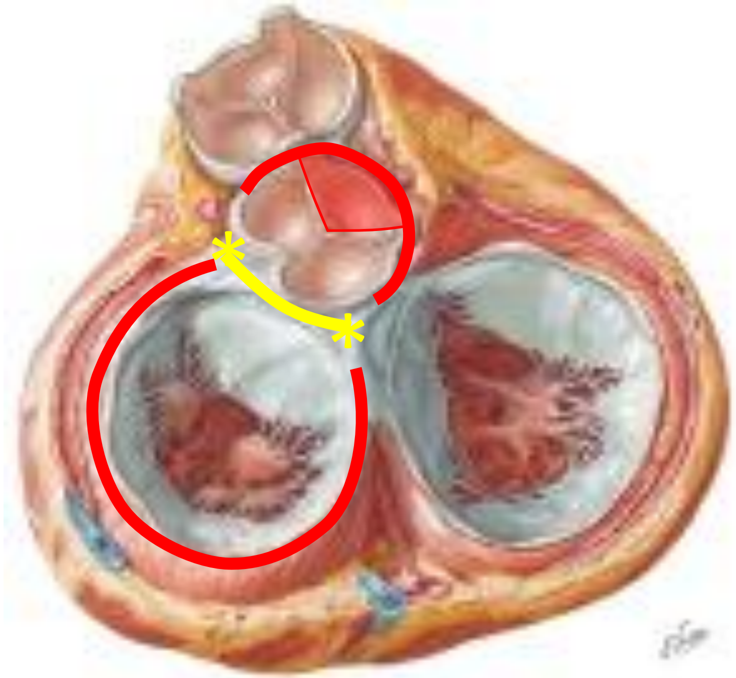
Which part of the AV annulus dilate ?

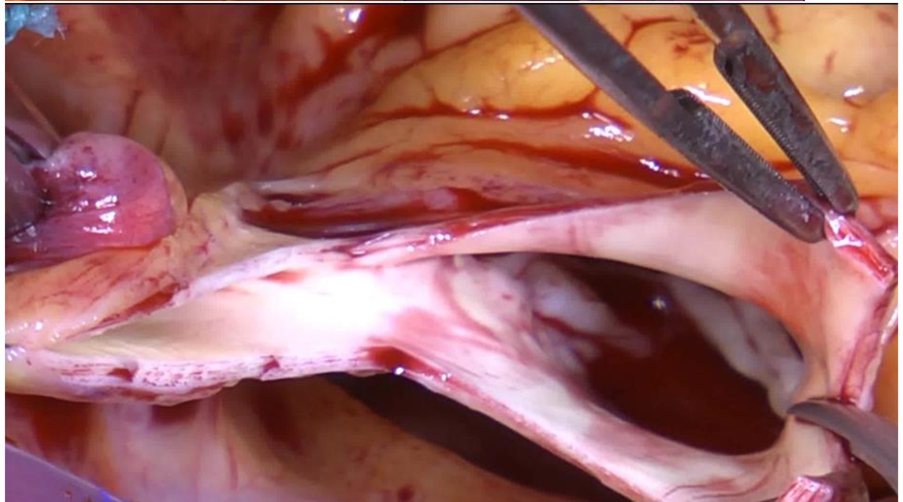
TAV prolapse: **RCC 76%**
LCC 21%
NCC 3%

BAV prolapse: **L/R ≈ 100%**

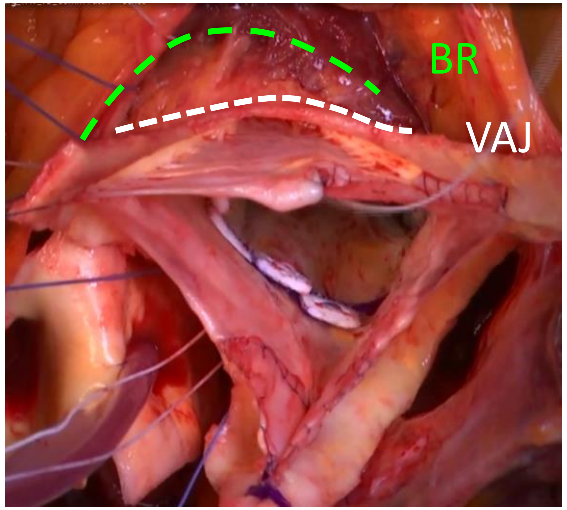





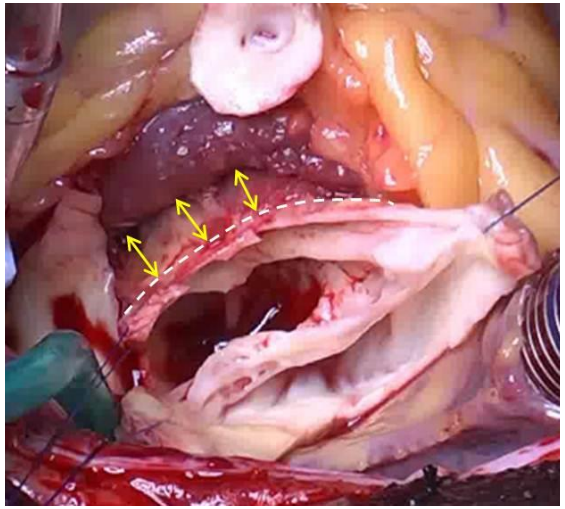


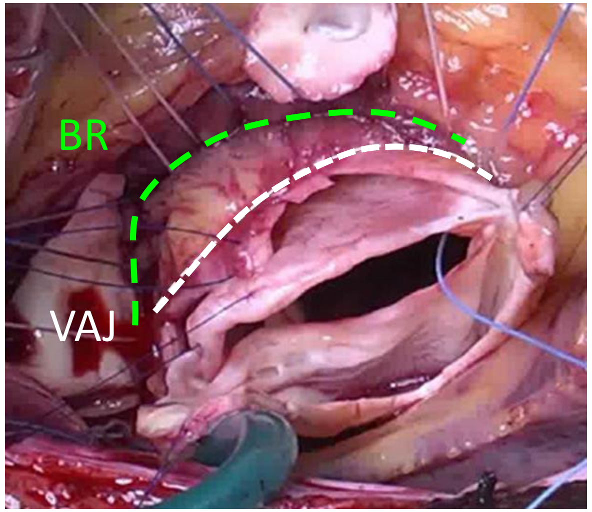


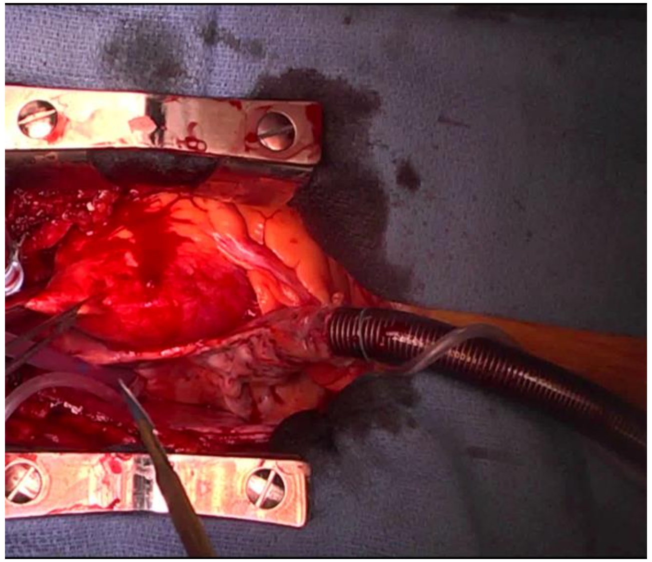
Reimplantation technique: « *Deep external root dissection* »

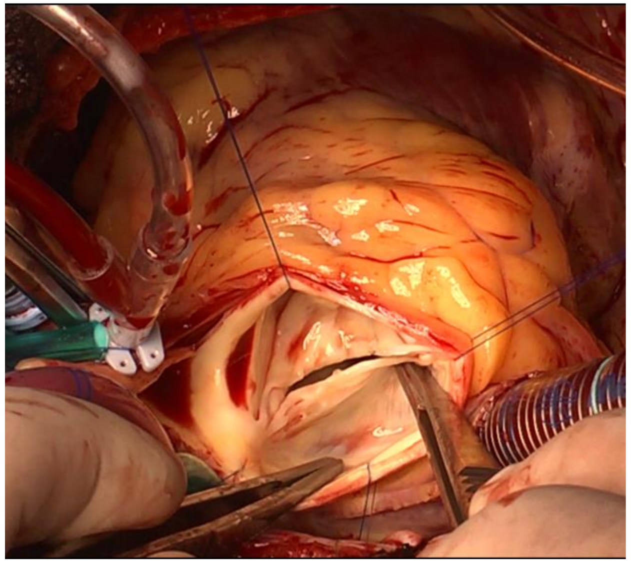
In any case to reach the basal ring you need to dissect beyond the anatomical VAJ



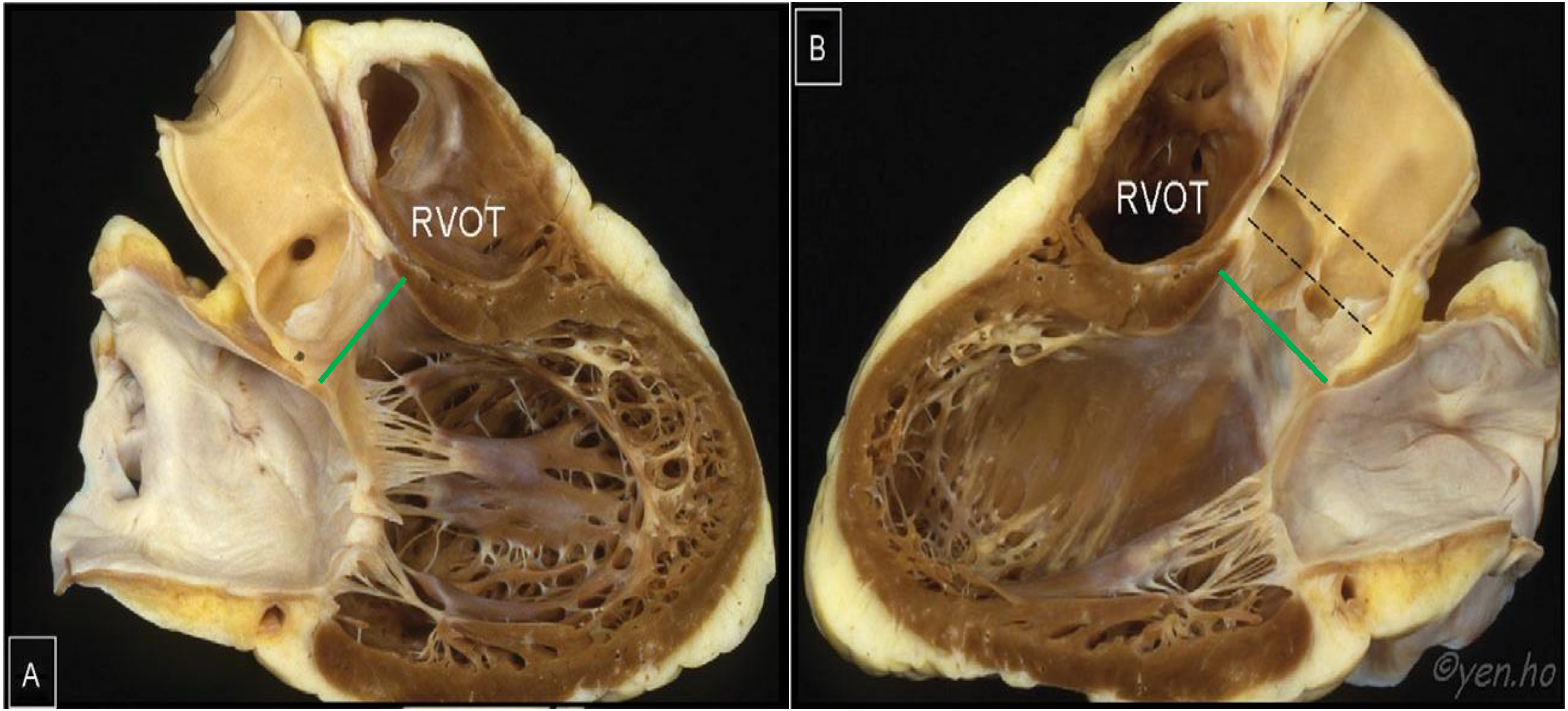






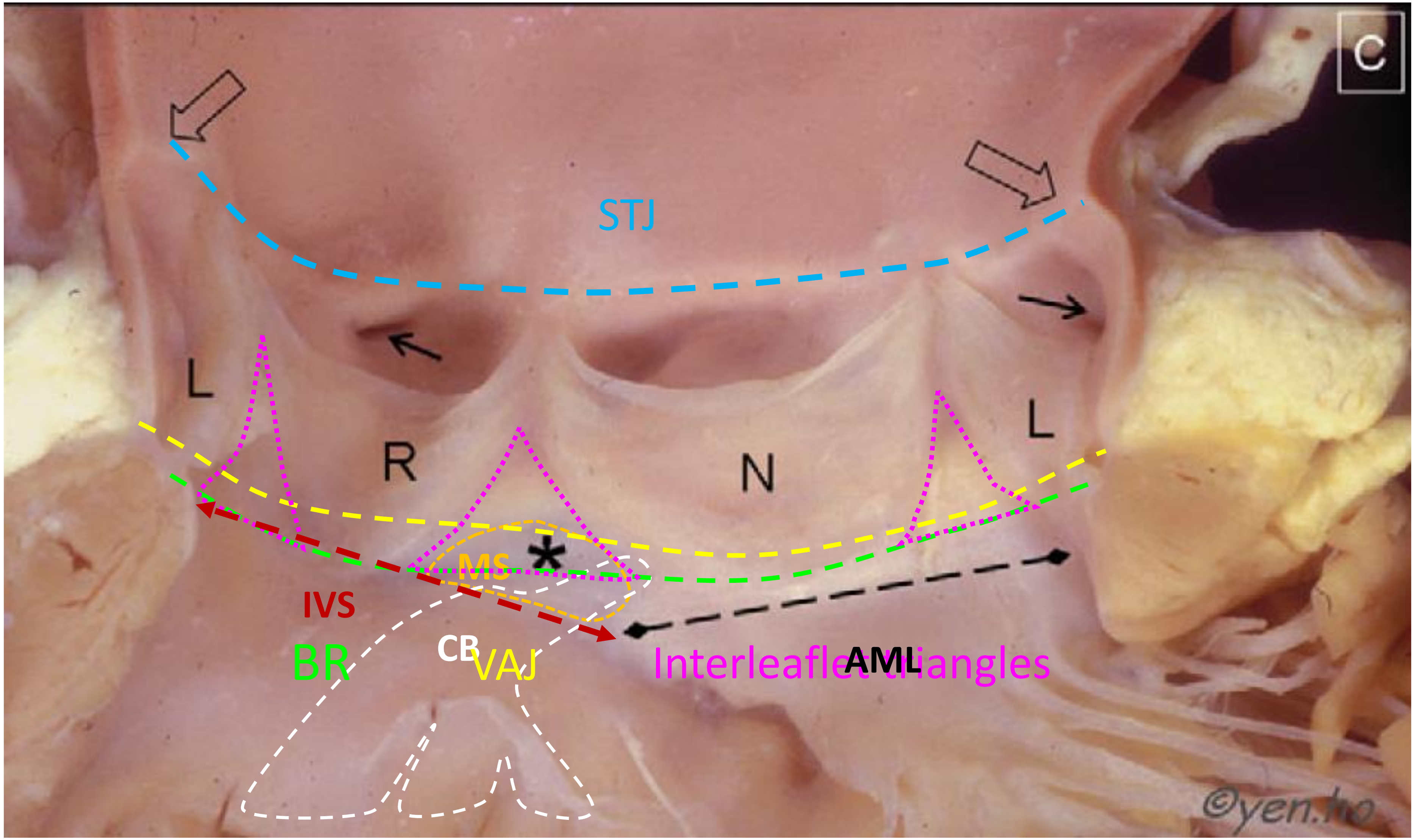


Aortic valve & root anatomy: the VAJ and the basal ring



Ho Y. Eur J Echocardiogr. 2009;10(1):i3-10.

Aortic root anatomy



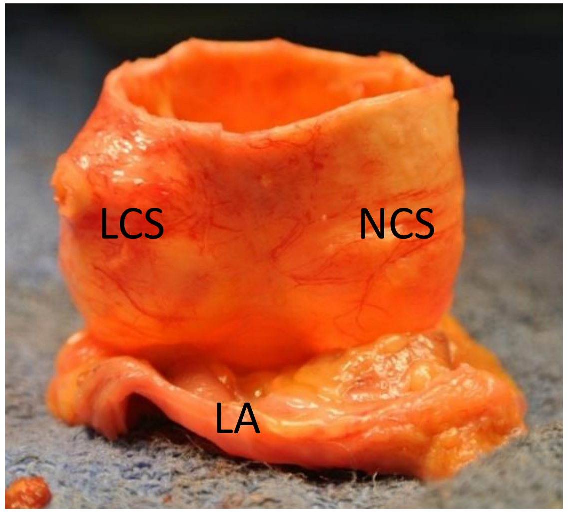
Adapted from Ho S.Y., Anderson R. Eur J Echocardiogr. 2009;10(1):i3-10.

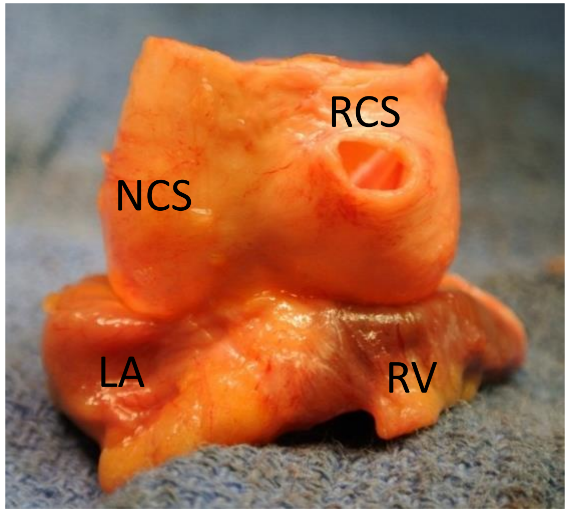
Aortic root anatomy: *VAJ & BR relationship*

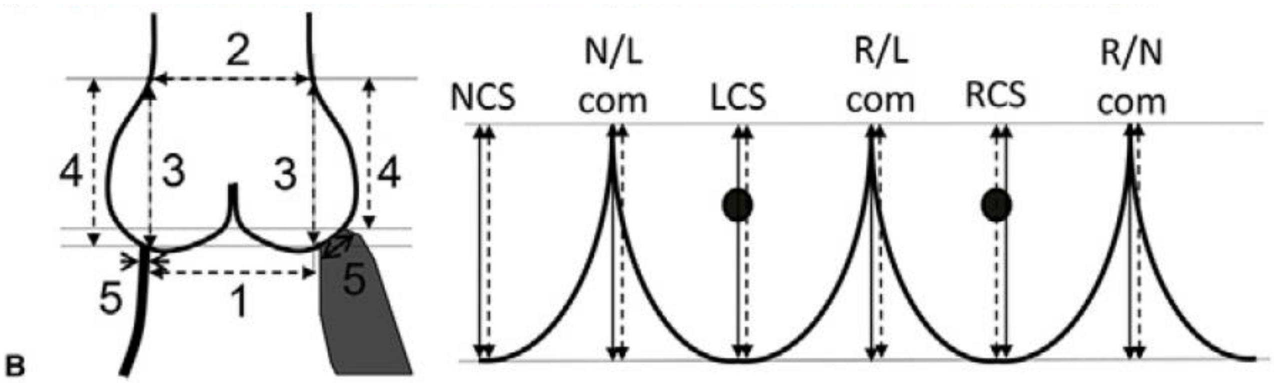
Surgical anatomy of the aortic root: Implication for valve-sparing reimplantation and aortic valve annuloplasty

Laurent de Kerchove, MD, PhD,[a,b] Ramadan Jashari, MD,[c] Munir Boodhwani, MD, MMSc,[d] Khanh Tran Duy, Ir, PhD,[e] Benoit Lengelé, MD, PhD,[f] Pierre Gianello, MD, PhD,[g] Zahra Mozala Nezhad, MD,[a] Parla Astarci, MD, PhD,[a] Philippe Noirhomme, MD,[a] and Gebrine El Khoury, MD[a]

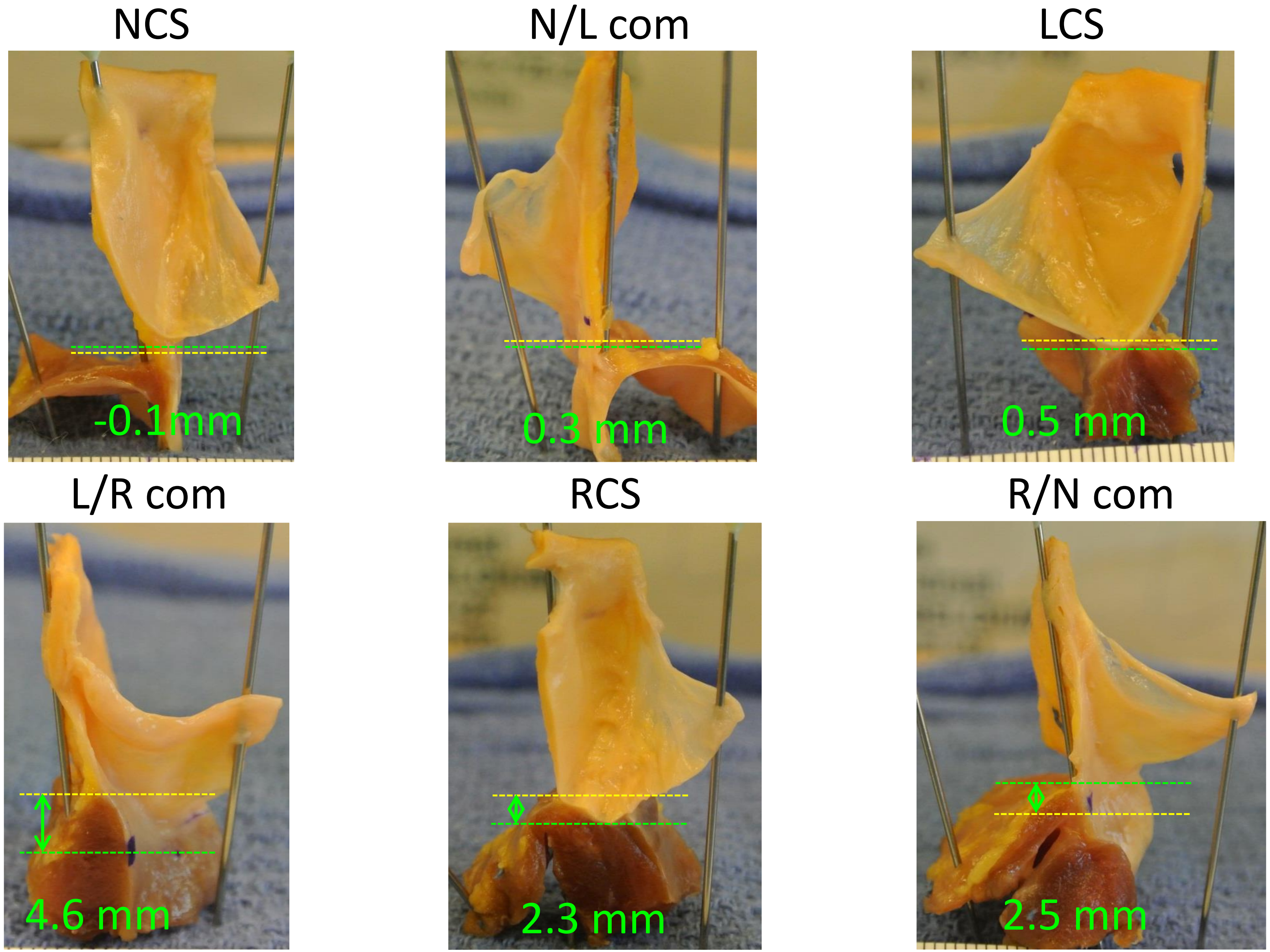
- 59 aortic root specimens: 42 homograft (mean age: 45±23yo), 17 donor (85±6yo)





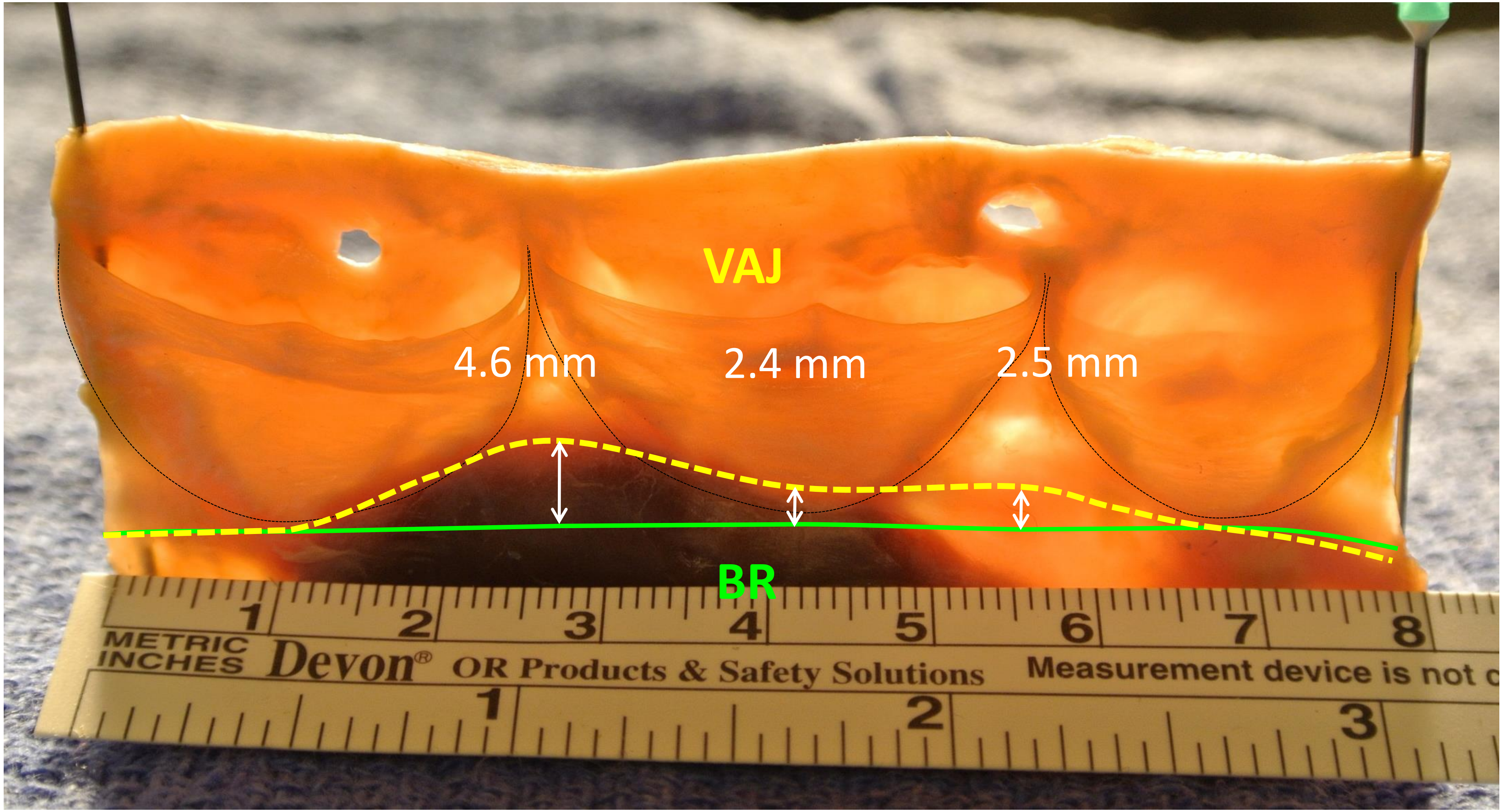


J Thorac Cardiovasc Surg 2015;149:425-33



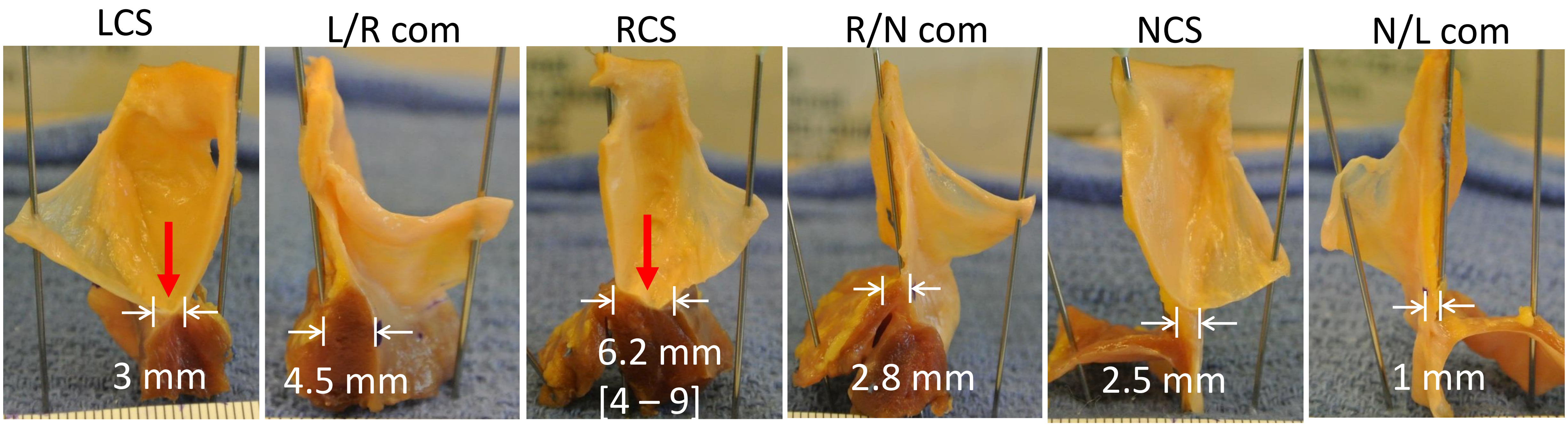
De Kerchove, J Thorac Cardiovasc Surg 2015; 149:425-33

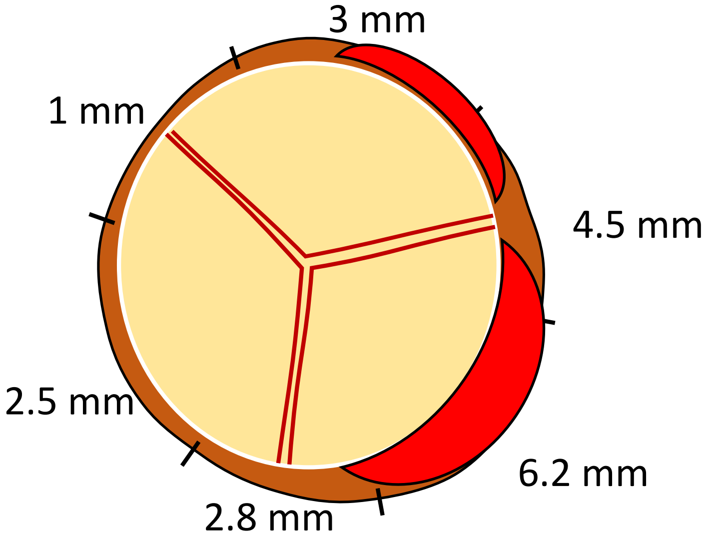
Aortic root anatomy: *VAJ & BR relationship*



De Kerchove, J Thorac Cardiovasc Surg 2015; 149:425-33

Aortic root anatomy: *VAJ thickness (Mean 3.2mm)*

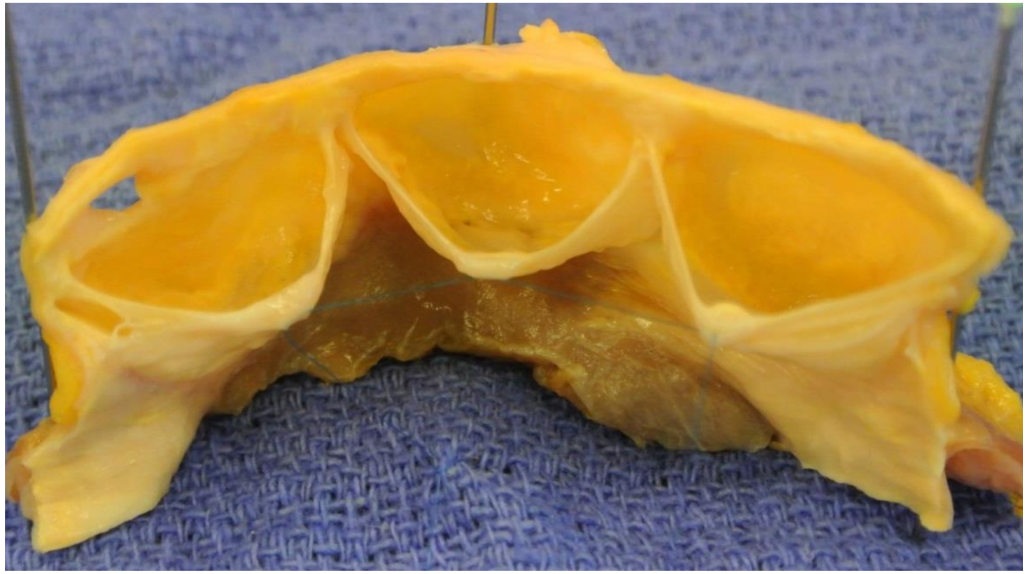
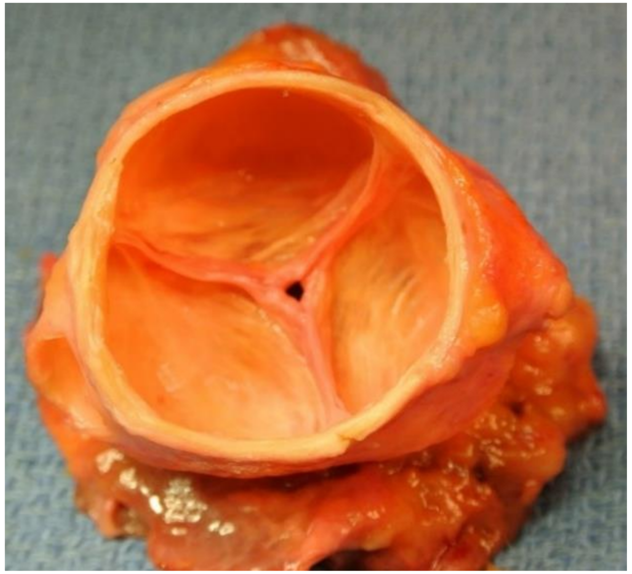
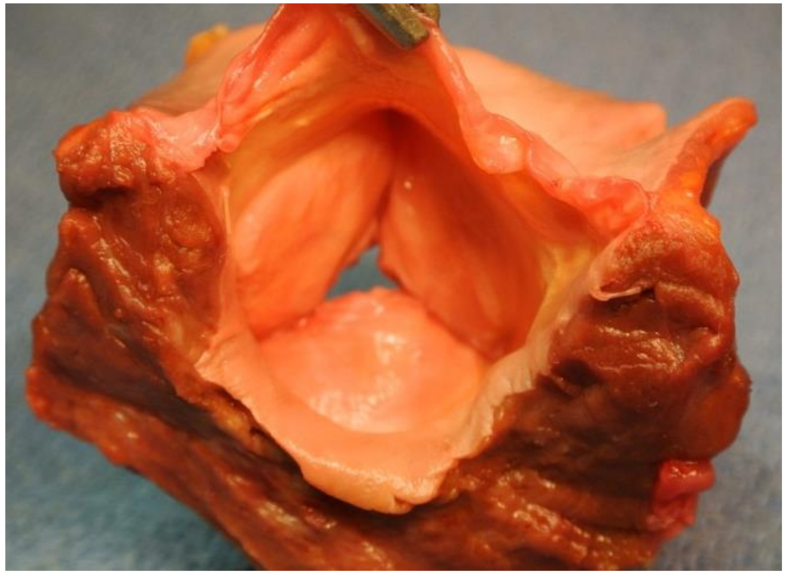




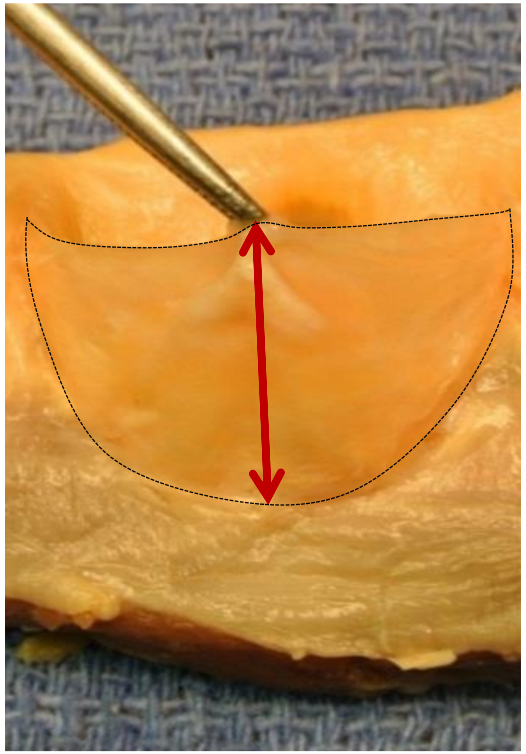
Width of myocardial crescents/inclusion in LCS and RCS:

Study	Methods	RCS (mm)	LCS (mm)
Sands, ATS 1969	Necropsy, pressurized + cryo	**3.2**	**1.4**
L. de Kerchove, EJCTS 2017	Cryo homograft, fresh donor	**6.2**	**3**
H. Toh, Semin Thoracic Surg 2020	CT multiplanar reconstruction	**6.4**	**2.9**

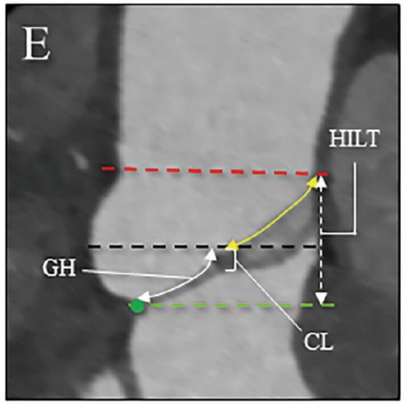
Aortic valve leaflet structure

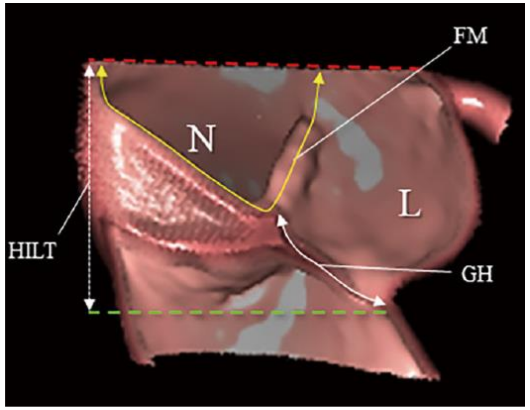




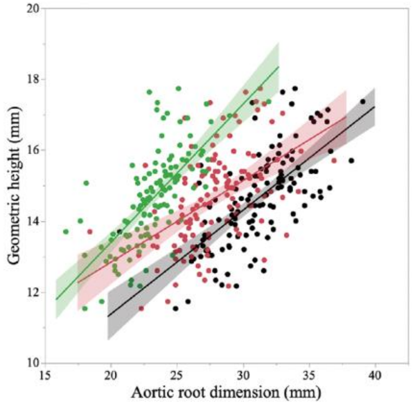
Aortic Valve leaflet: *Geometric Height (gH)*



Study	Methods	Average gH (mm)
Swanson, Circ Res 1974	Cadaver, pressurized + cryo	18
N. Khelil, ATS 2015	Cadaver, fresh (n=20)	20
L. de Kerchove, EJCTS 2017	Cryopreserved homograft (n=25)	19
HJ. Schäfers, JTCVS 2013	Patient with AI or aneurism (n=621, TAV=329, BAV=286)	20 (TAV), 24 (BAV)
Y. Izawa, Circ J 2021	Computed tomography (n=123)	15
M. Jelenc, JCS 2022	Computed tomography (n=74)	16

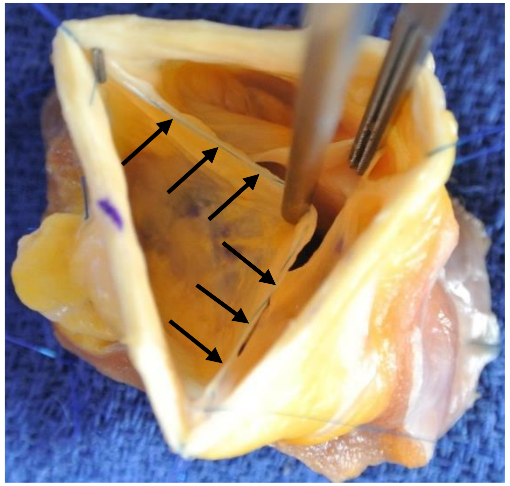




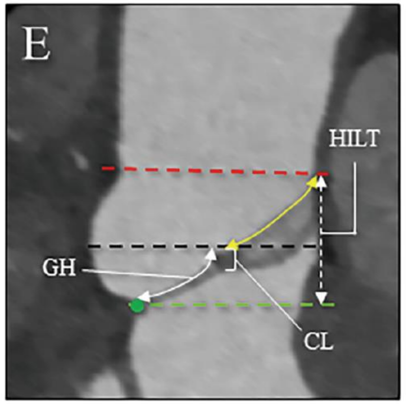


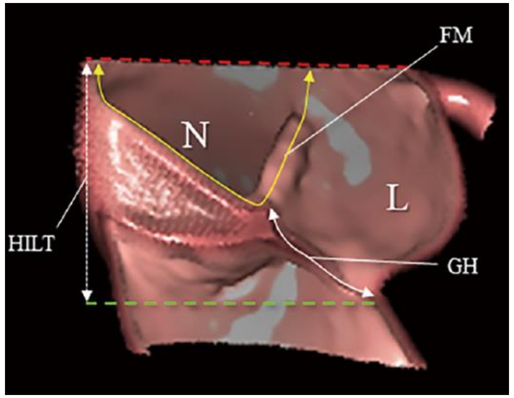
- NCL ≥ LCL ≥ RCL
- Correlate with root/body size

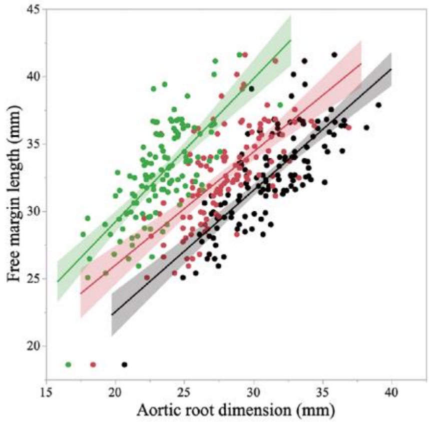
Aortic Valve leaflet: *Free edge length (FEL)*



Study	Methods	FEL (mm)
Swanson, Circ Res 1974	Cadaver, pressurized + cryo	30-34
Silver, Am J Cardiol 1985	Cadaver, formalin	31
T. David, JTCS 1994	Cryopreserved homograft	32
L. de Kerchove, EJCTS 2017	Cryopreserved homograft (n=25)	34
Y. Izawa, Circ J 2021	Computed tomography (n=123)	32.6
M. Jelenc, JCS 2022	Computed tomography (n=74)	34





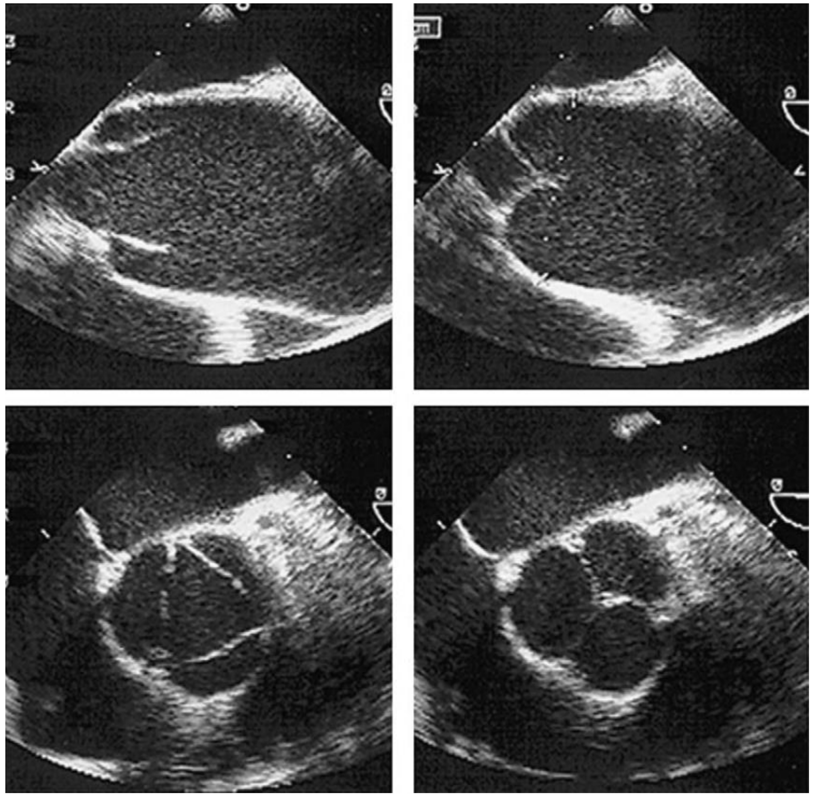


- RCL ≥ NCL ≥ LCL
- Correlate with root/body size

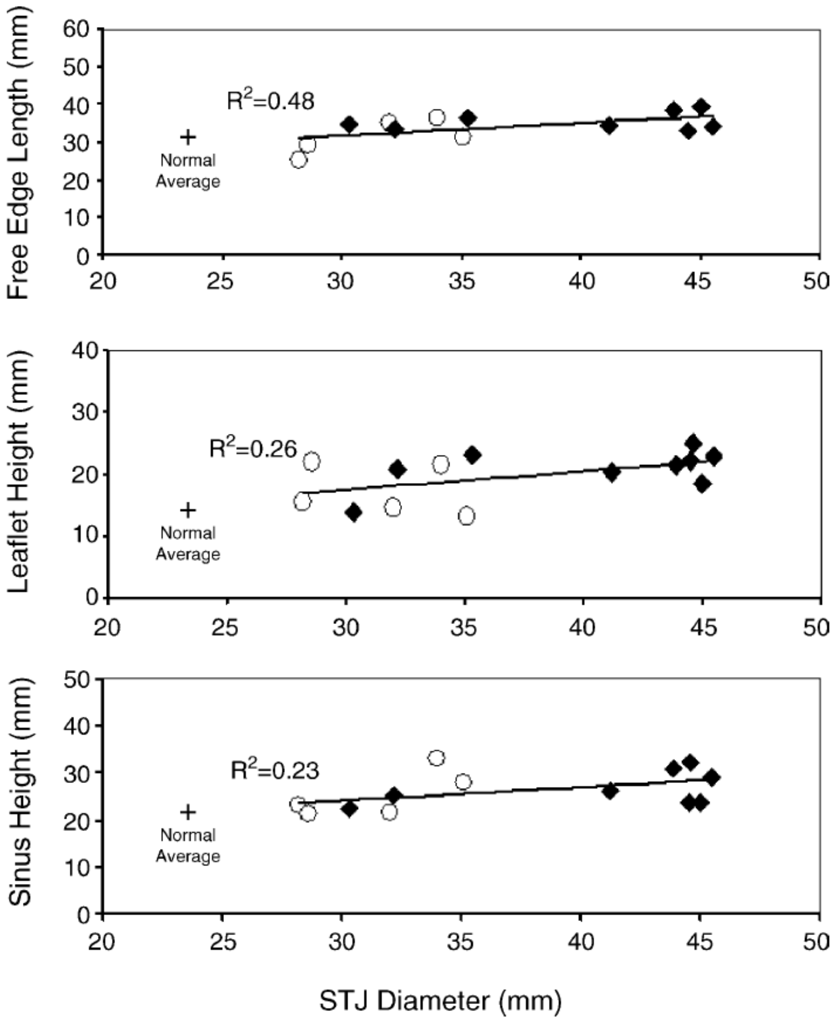
Aortic root dilatation may alter the dimensions of the valve leaflets ☆

Mano J. Thubrikar [a], Michel R. Labrosse [a,*], Kenton J. Zehr [b], Francis Robicsek [a], Geoffrey G. Gong [a], Brett L. Fowler [a]

- Free margin length and cusp height measured with TEE in 14 patients with dilated root and AI



"...the sinotubular junction may not be clearly defined... Also, the free edge of the leaflet may not lie in the plane of the short-axis view. Both factors contribute in reducing the accuracy of the measurements."

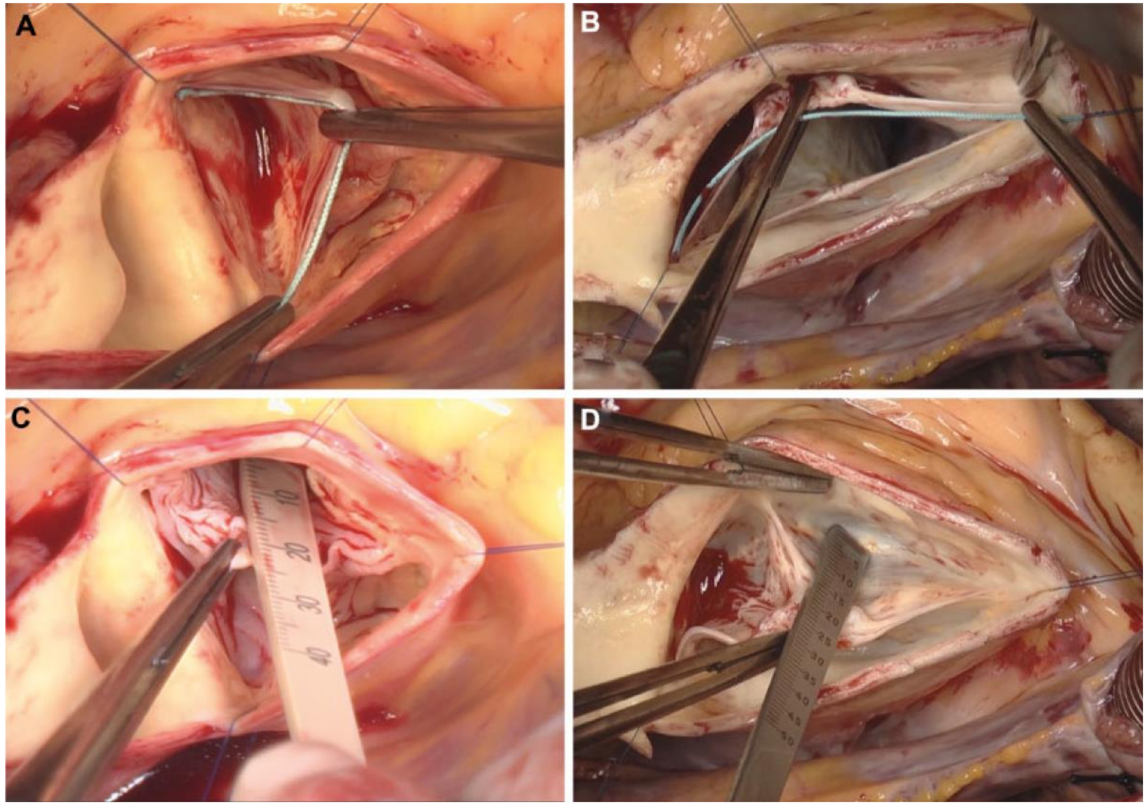


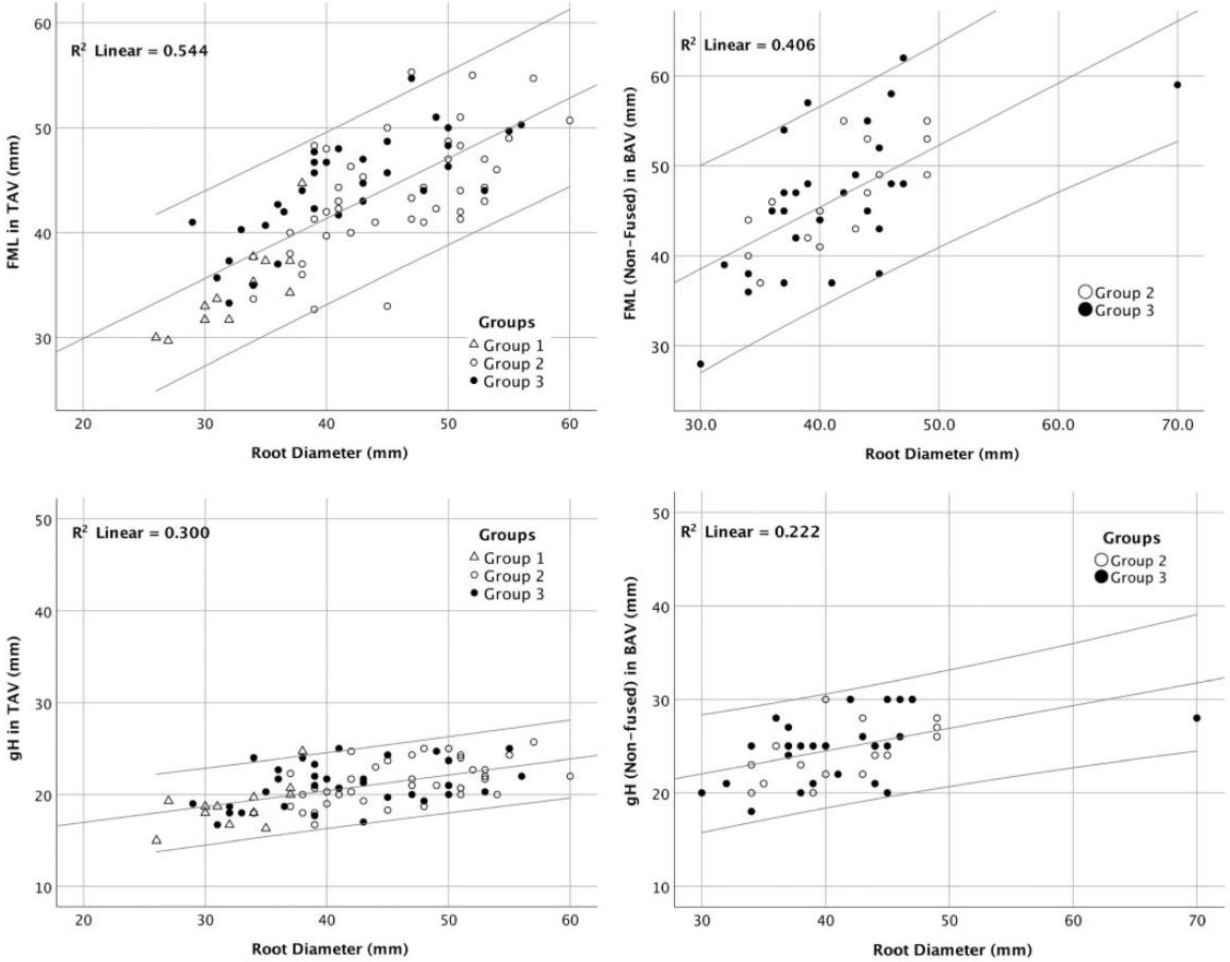
M. Thubrikar, Eur J Cardiothor Surg, 2005; 28: 850 - 856

Free margin length and geometric height in aortic root dilatation and leaflet prolapse: implications for aortic valve repair surgery

Saadallah Tamer[a], Stefano Mastrobuoni[a], Michel van Dyck[b], Emiliano Navarra[a], Xavier Bollen[c], Alain Poncelet[a], Philippe Noirhomme[a], Parla Astarci[a], Gebrine El Khoury[a] and Laurent de Kerchove[a,*]

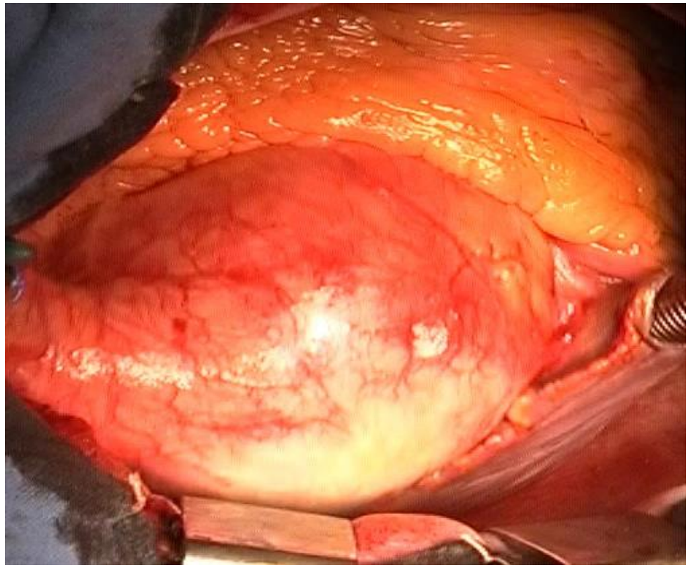
- Free margin length and cusp height measured intraoperatively in 132 patients operated for AI and or root dilatation

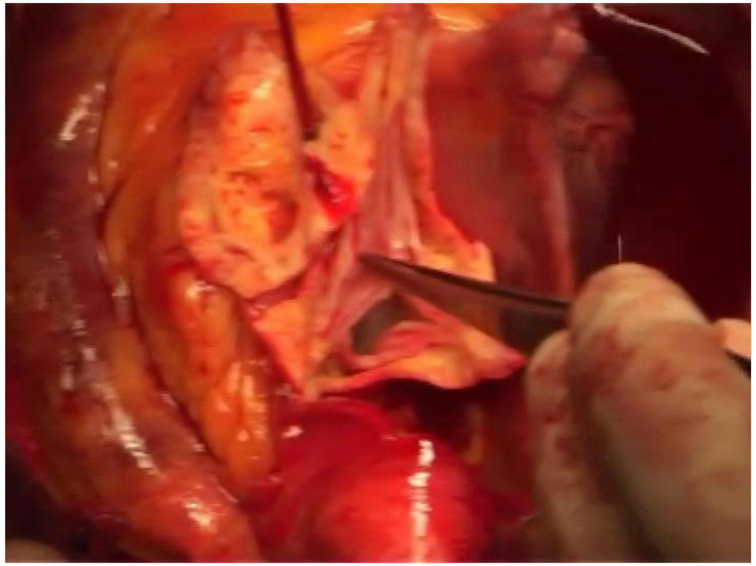


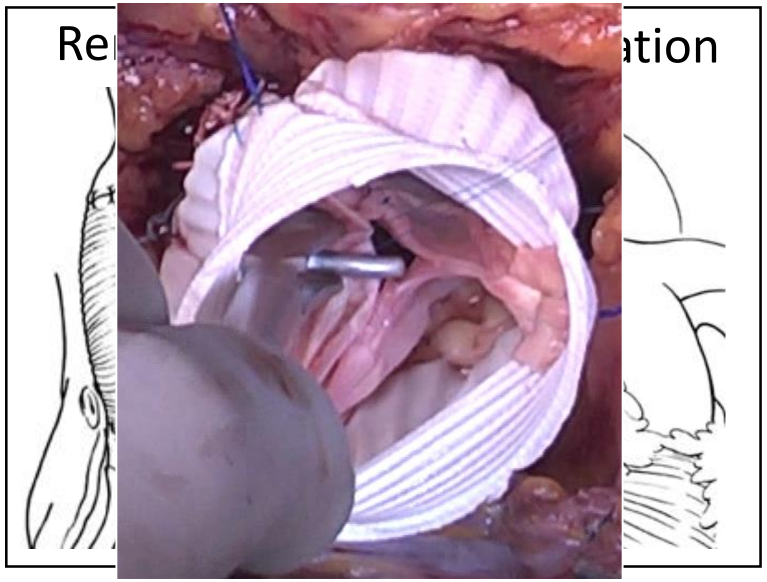


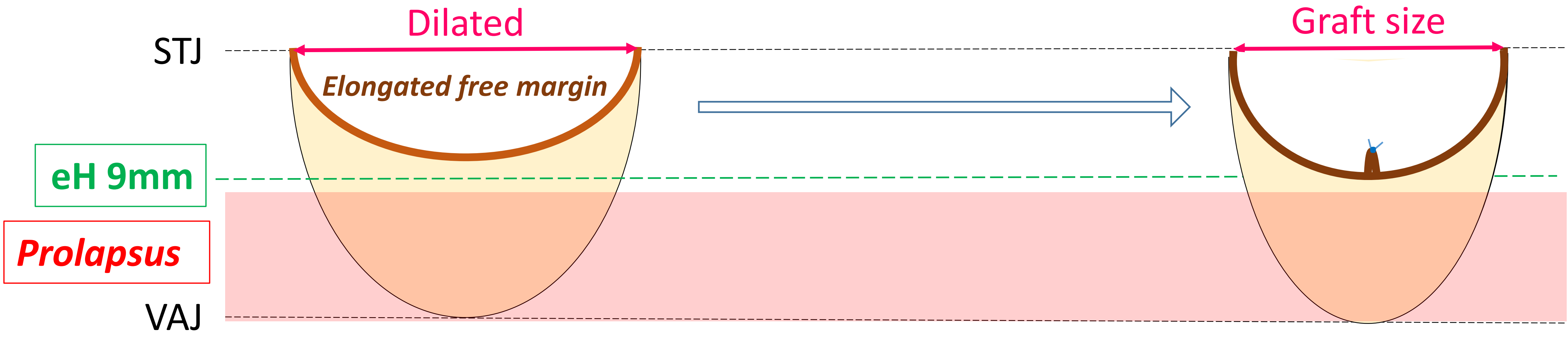
L. De Kerchove, Eur J Cardiothor Surg, 2019

Aortic root dilatation: impact on the aortic valve

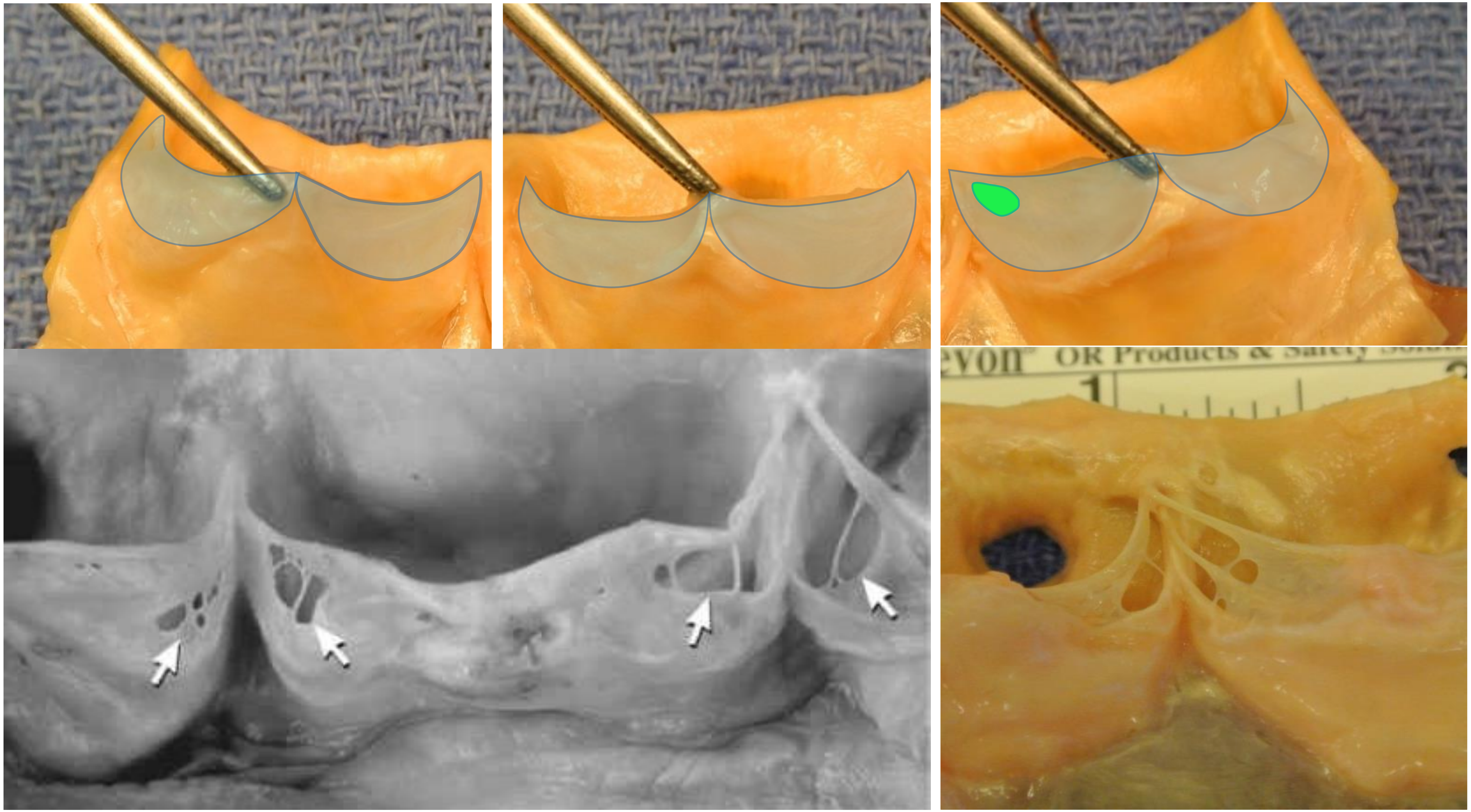




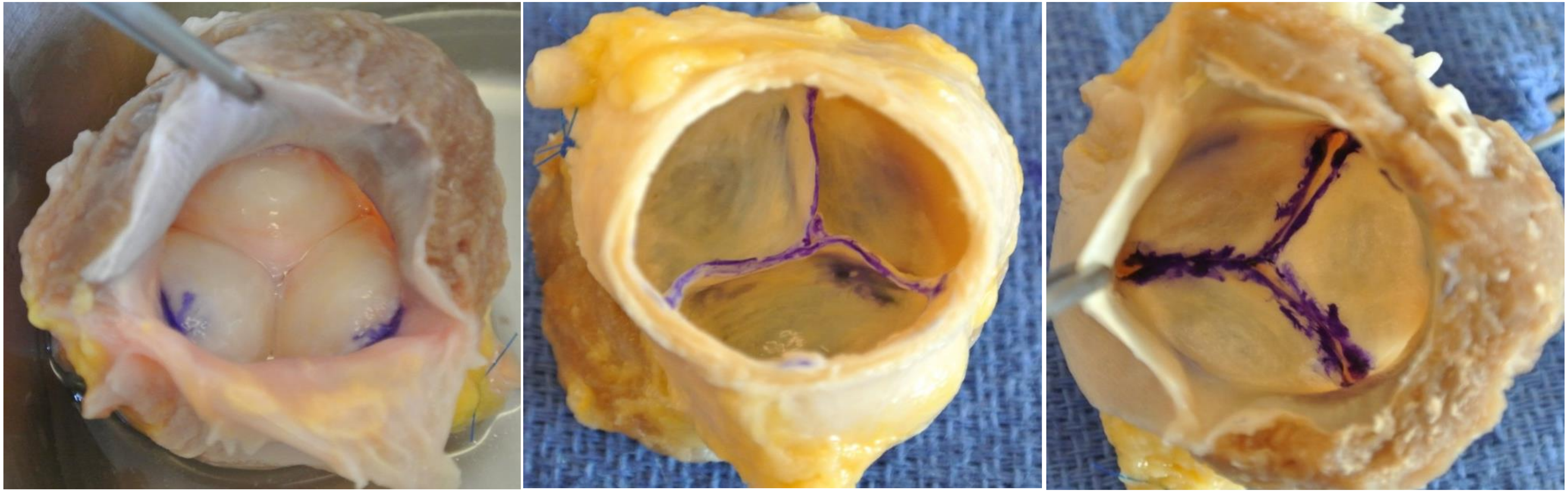




Aortic Valve leaflet: *Cusp and coaptation surface*

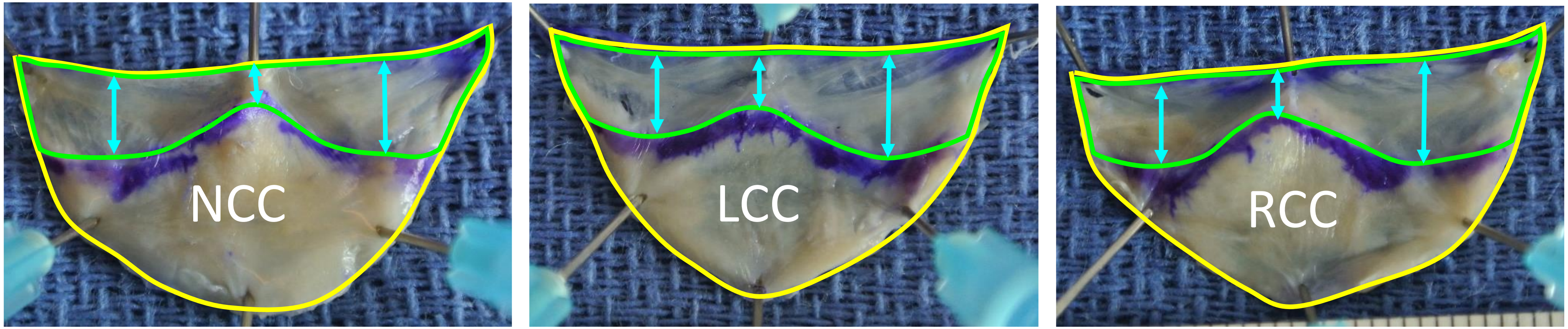


Aortic Valve leaflet: *Cusp and coaptation surface*



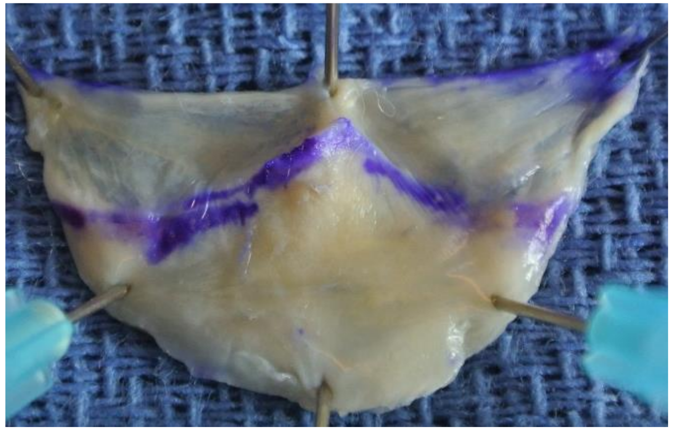
L. de Kerchove, EJCTS 2017

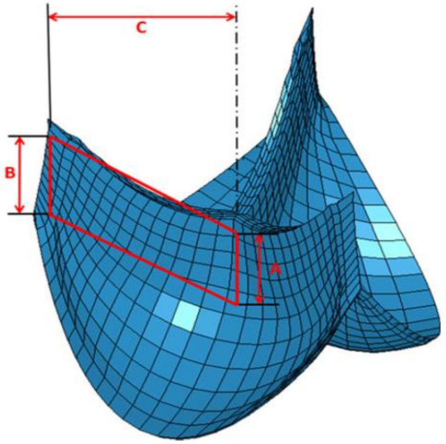
Aortic Valve leaflet: *Cusp and coaptation surface*

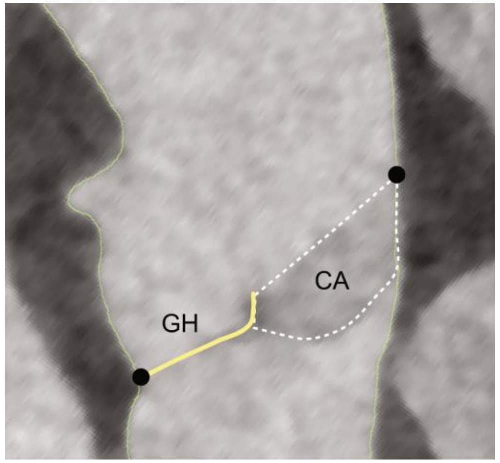


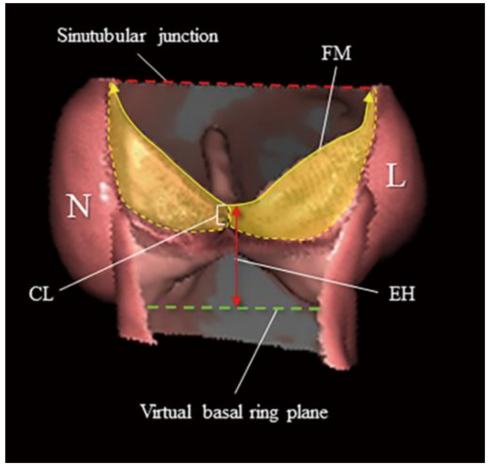
Study	Origin	Cusp area (cm^2)	Coaptation area (cm^2)	Coaptation/ Cusp	Coaptation length lat (mm)	Caoptation length central (mm)
Silver, Am J Cardiol 1985	Cadaver, formalin	3 - 3.8	-	-	-	-
T. David, JTCS 1994	Cryopresrv. homograft	3.0	-	-	-	-
L. de Kerchove, EJCTS 2017	Cryopreserv. homograft (n=25)	3.0	1.2/cusp 1.8/valve	42% cusp surface	6	3

Aortic Valve leaflet: *Cusp and coaptation surface*



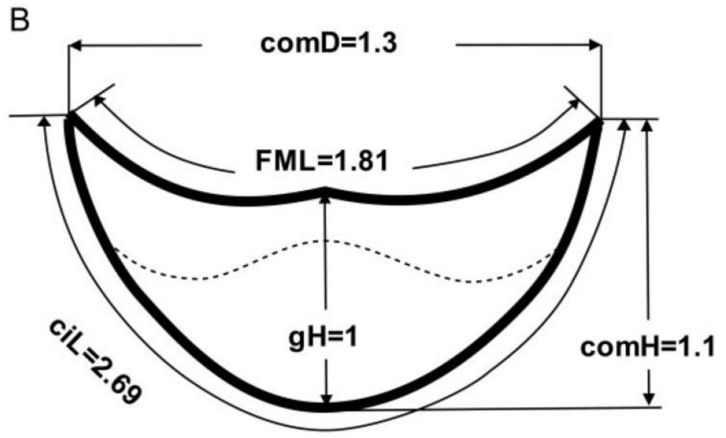


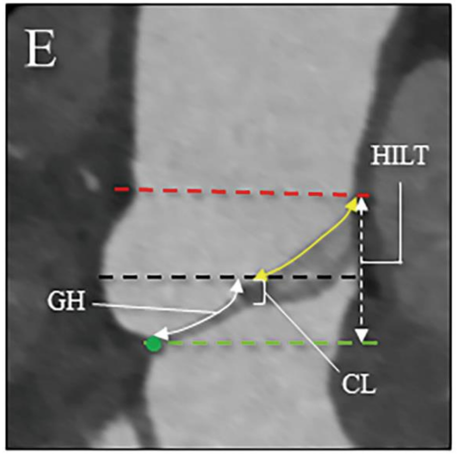


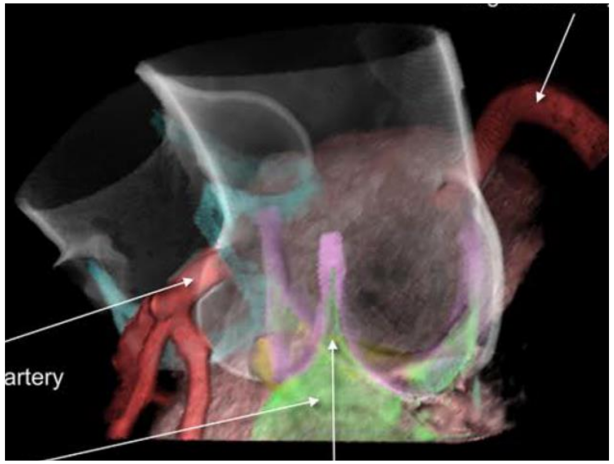


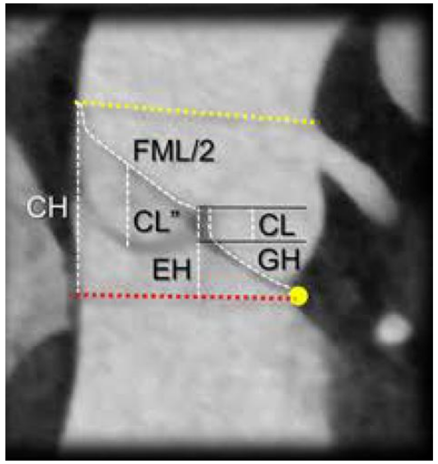
Study	Methods	Coaptation area between adjacent leaflet (cm²)	Coapt length lateral (mm)	Caopt length central (mm)
L. de Kerchove, EJCTS 2017	Cryopreserv. Homograft	0.6	6	3
B. Sohmer, Can J anesth 2012	3D TEE	0.5	-	-
M. Jelenc, J Card Surg. 2022	3D CT	0.8	-	3.7
Y. Izawa, Circ J 2021	3D CT	-	-	3

Aortic Valve leaflet: *Commissure height (≈ interleaflet triangle height)*





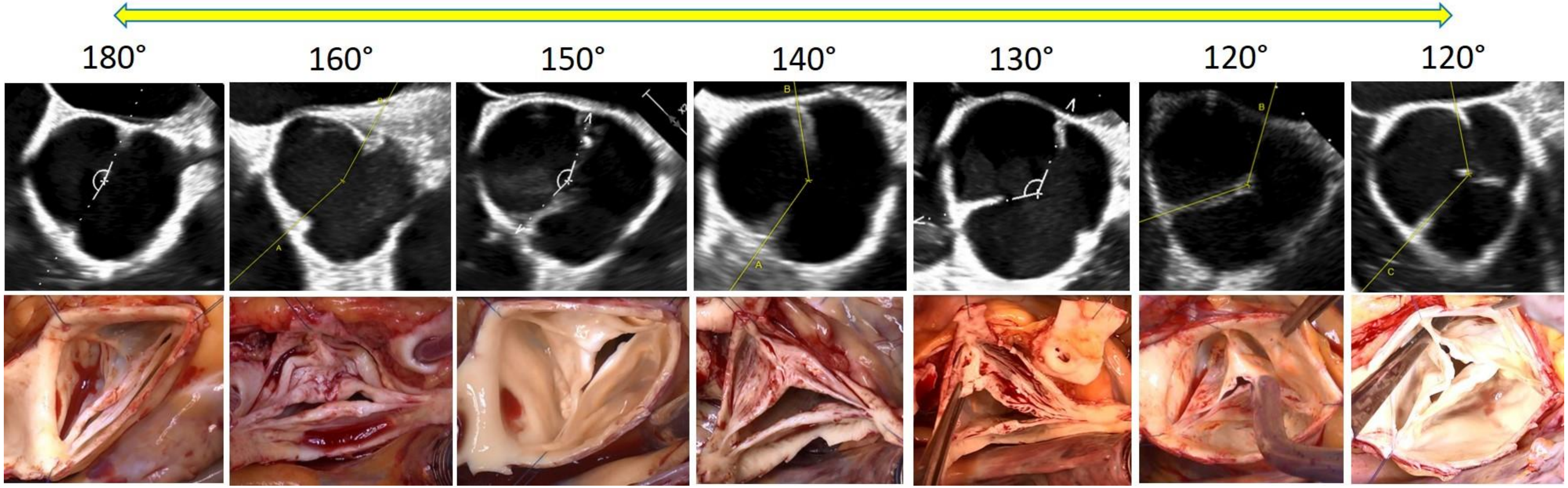




Study	Methods	Com. Height N/L	Com. Height L/R	Com. Height R/N	Com. Height average
L. de Kerchove, EJCTS 2017	Cryopreserv. Homograft (Com H)	20.6	19.7	21.8	20.7
M. Jelenc, J Card Surg. 2022	3D CT (Com H	18.4	18.8	20.6	19.3
Y. Izawa, Circ J 2021	3D CT (ILT)	16.6	17.4	17.9	17.3

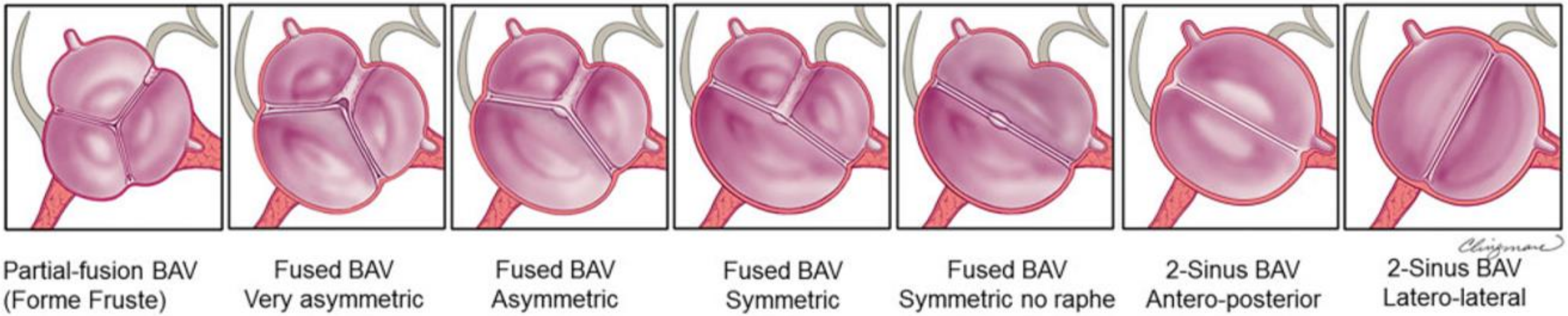
- R/N ≥ R/L ≥ N/L

Spectrum of Bicuspid valve Phenotypes



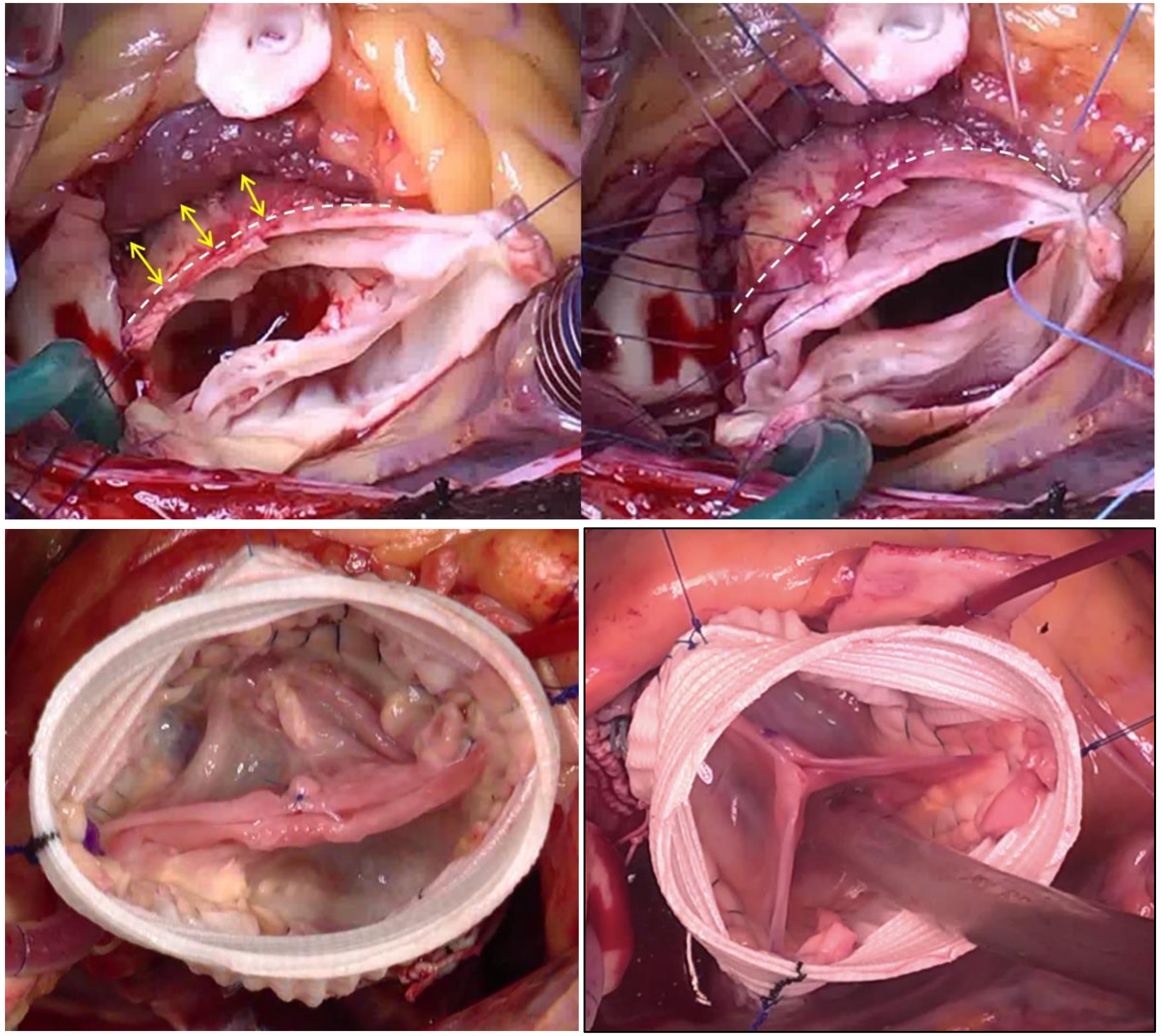
de Kerchove, EJCTS 56 (2019) 351–359

Anatomical Spectrum of BAV



H. Michelena, EJCTS, 60 (2021) 448–476

Thank you



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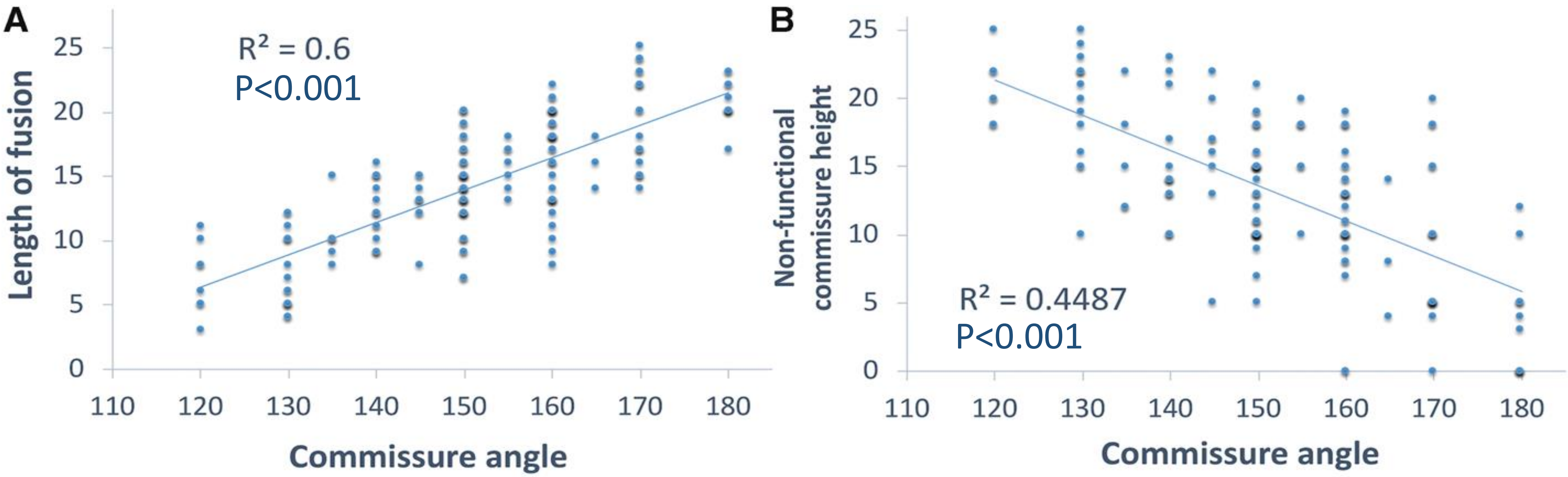
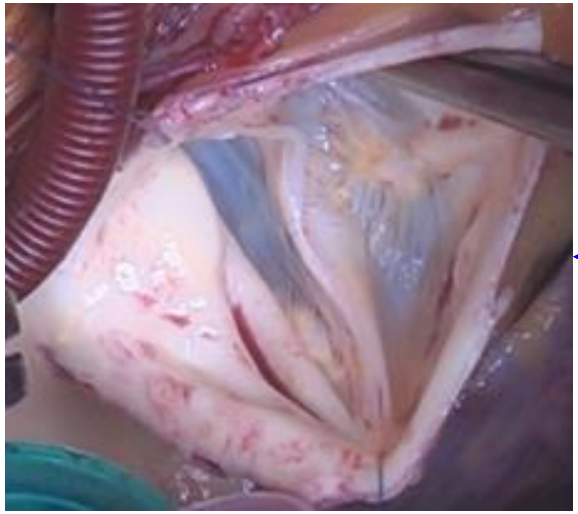
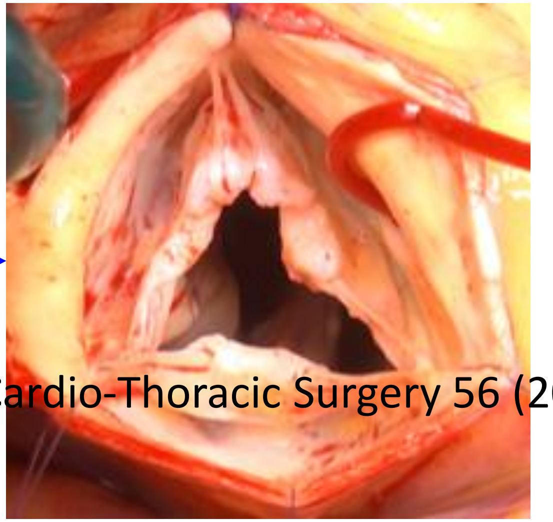
New anatomical repair-oriented BAV classification



180°





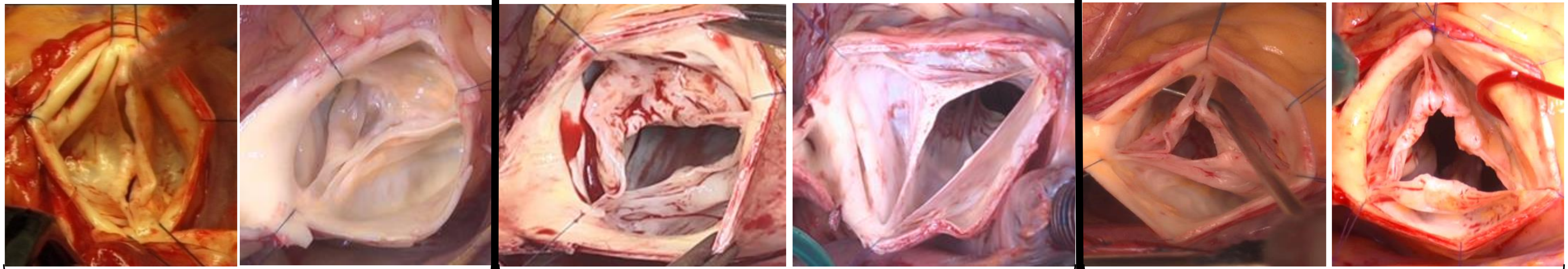
120°

European Journal of Cardio-Thoracic Surgery 56 (2019) 351–359

New anatomical repair-oriented BAV classification

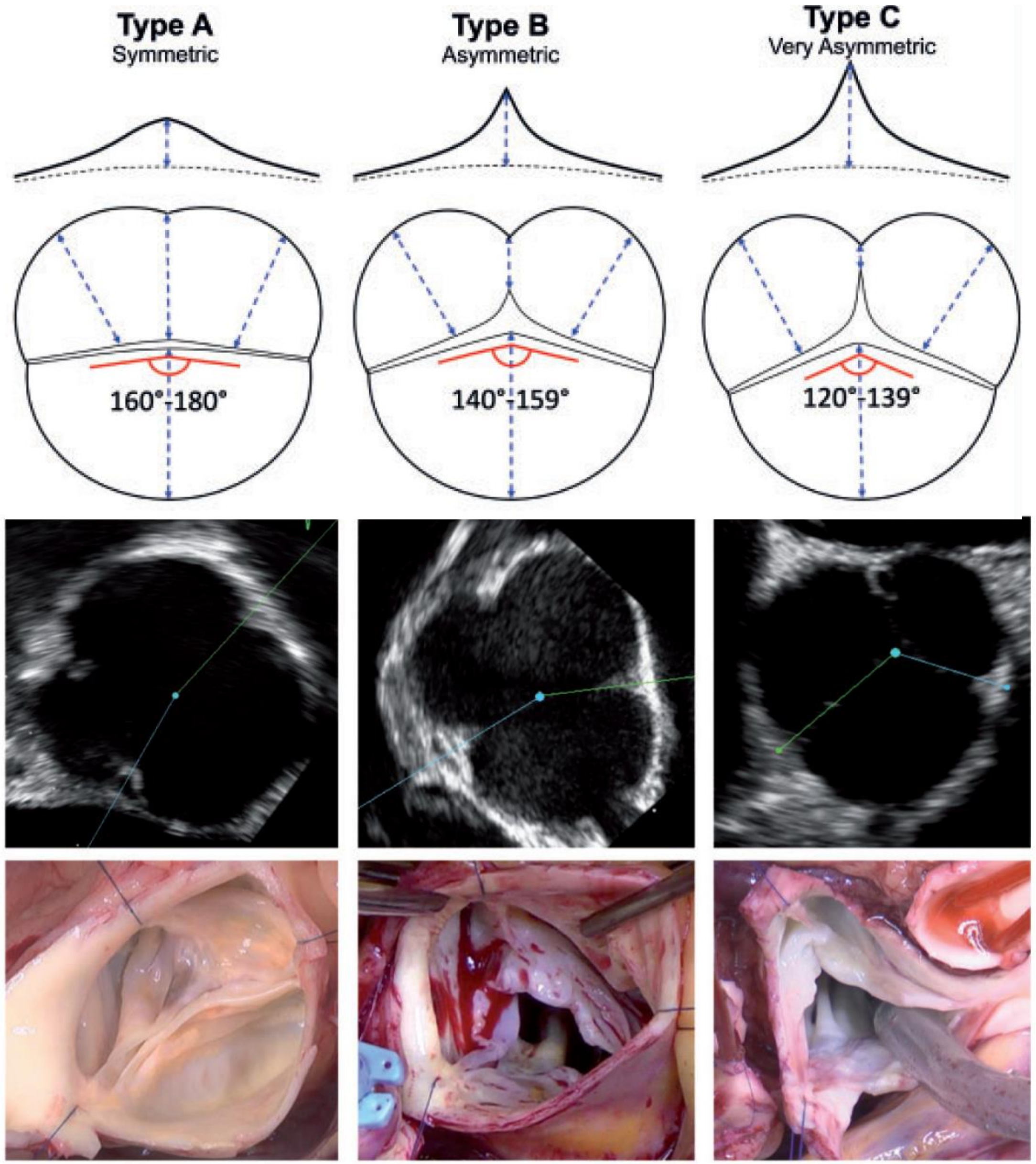
Spectrum of BAV phenotypes

180° — 160° — 140° — 120°



Symmetric BAV	Asymmetric BAV	Very Asymmetric BAV
180°-160°	159°- 140°	139°-120°
N=73 (41%)	N=74 (42%)	N=31 (17%)

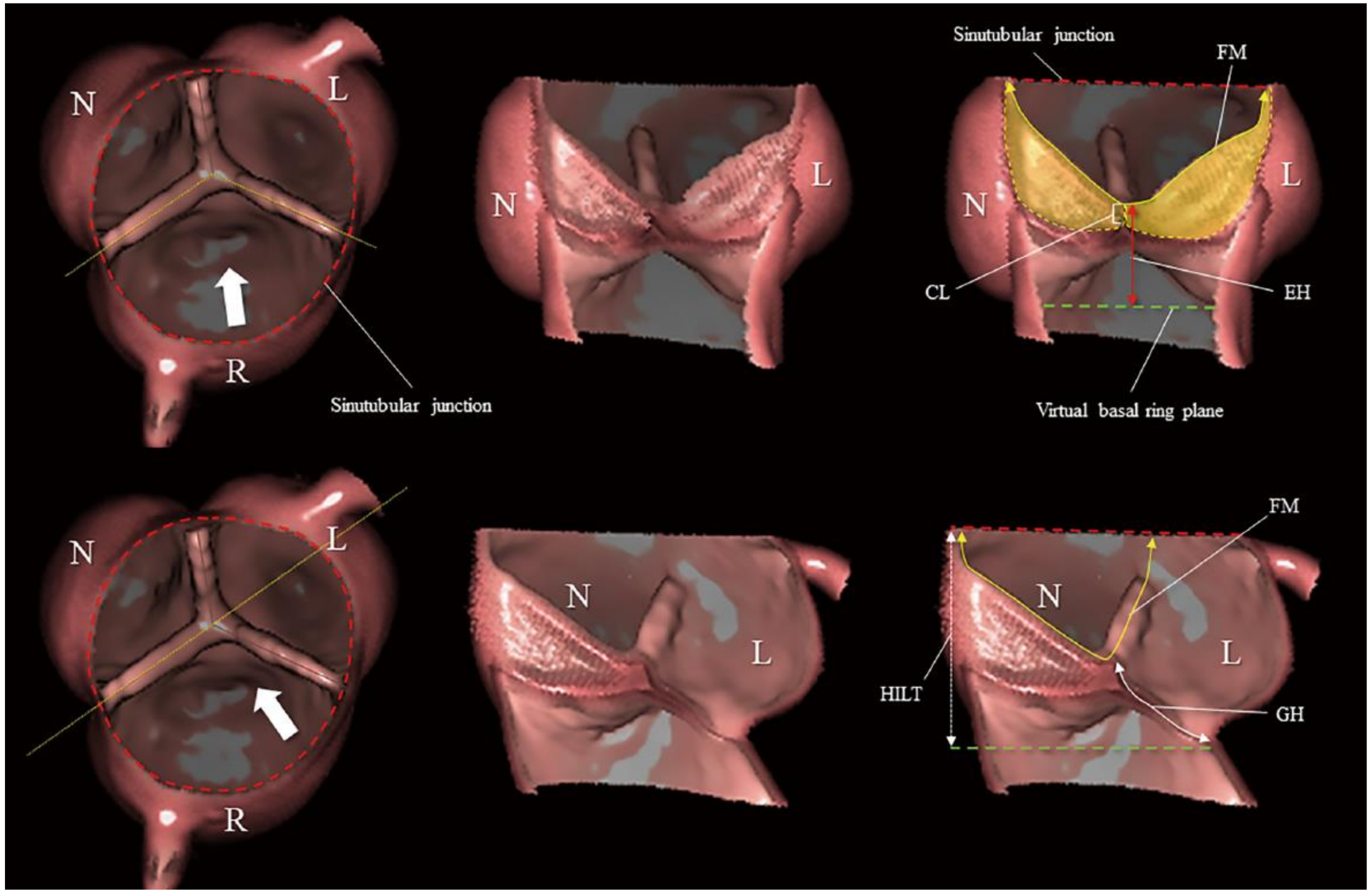
New anatomical repair-oriented BAV classification



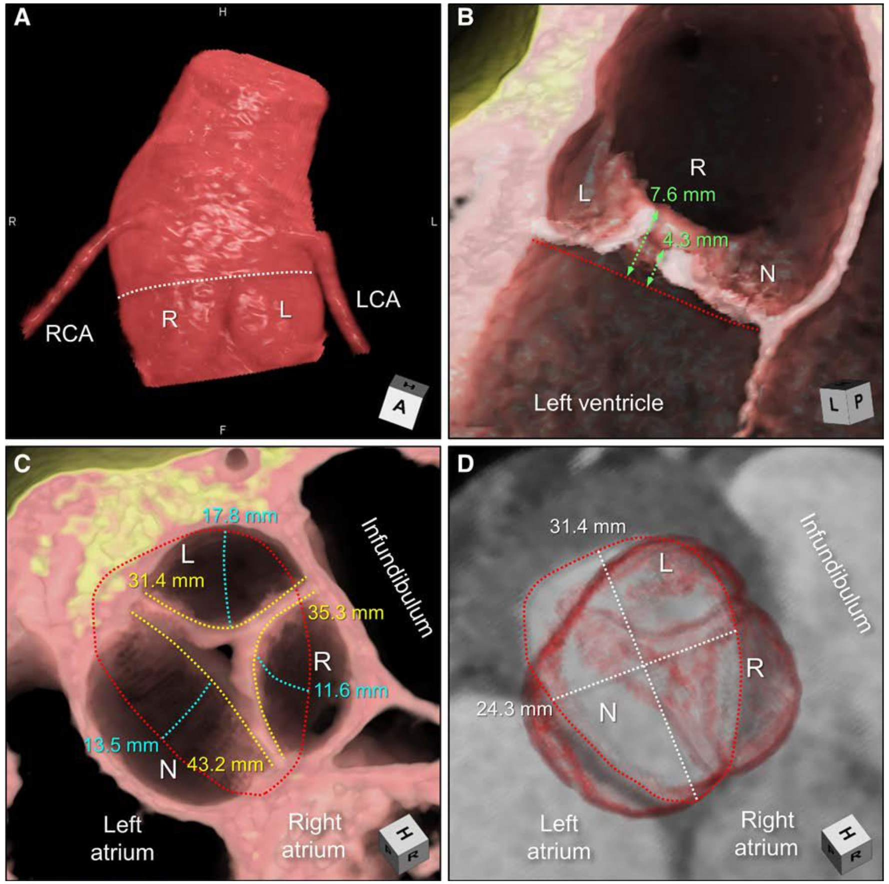
L. de Kerchove, EJCTS, 56 (2019) 351–359

Understanding the Aortic Root Using Computed Tomographic Assessment: A Potential Pathway to Improved Customized Surgical Repair

Justin T. Tretter, MD; Yu Izawa, MD; Diane E. Spicer, BS, PA(ASCP); Kenji Okada, MD, PhD;
Robert H. Anderson, MD, PhD (Hon); James A. Quintessenza, MD; Shumpei Mori, MD, PhD



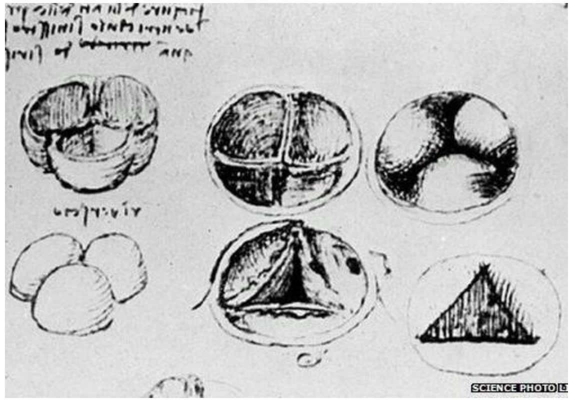
Circ J 2021; **85:** 1059 – 1067

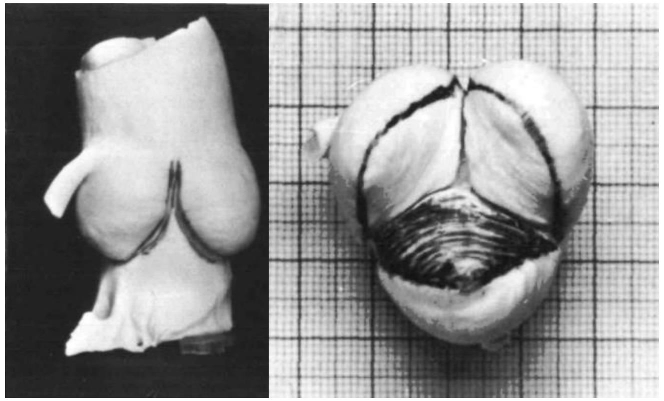


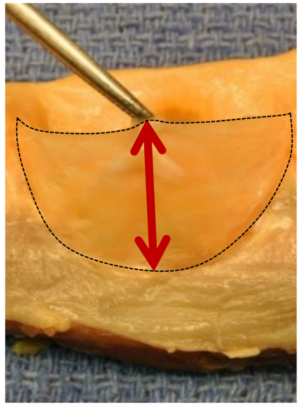
Circ Cardiovasc Imaging. 2021;14:e013134

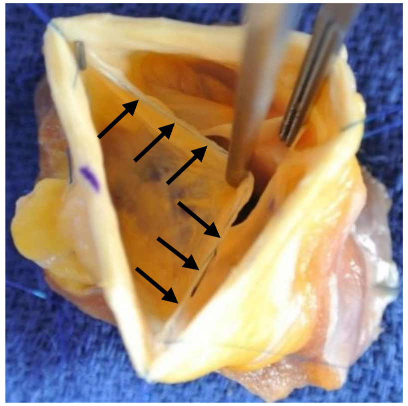
Aortic valve & root anatomy: *Conclusions*

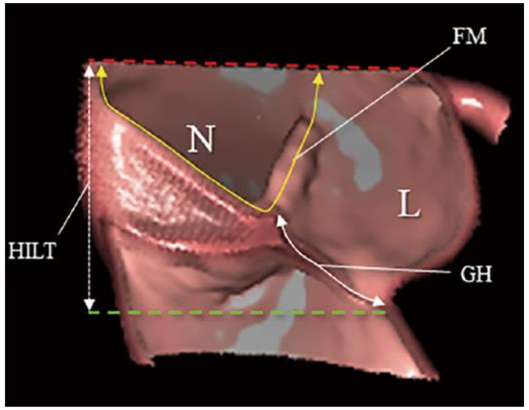
1452 ⟷ *2022*











- Since centuries, human anatomy has passionate scientists and doctors. Evolving technologies and practices have given the opportunity to learn continuously by looking differently, seeing more details and by switching from death to living heart exploration.

- Deep knowledge of human heart anatomy is mandatory to practice aortic valve and root surgery safely and efficiently.

- Reconstructive surgery can restore durably the native AV only by understanding and respecting anatomy of this complex functional unit.