Re-implantation Should be the Standard Technique

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Homburg, September 17th, 2015

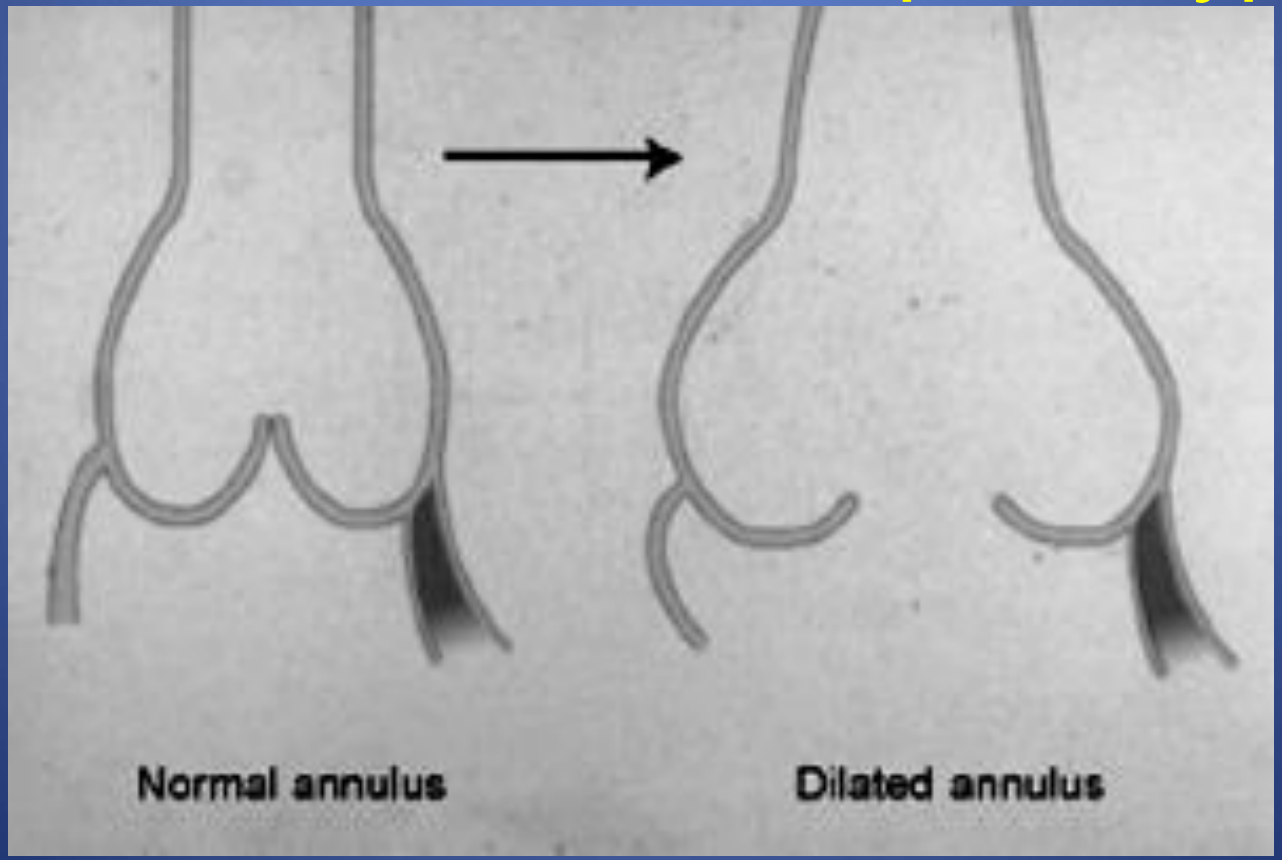
The Chaim Sheba Medical Center at Tel Hashomer · Est. 1948 · The Hospital of Israel

The Leviev Heart Center

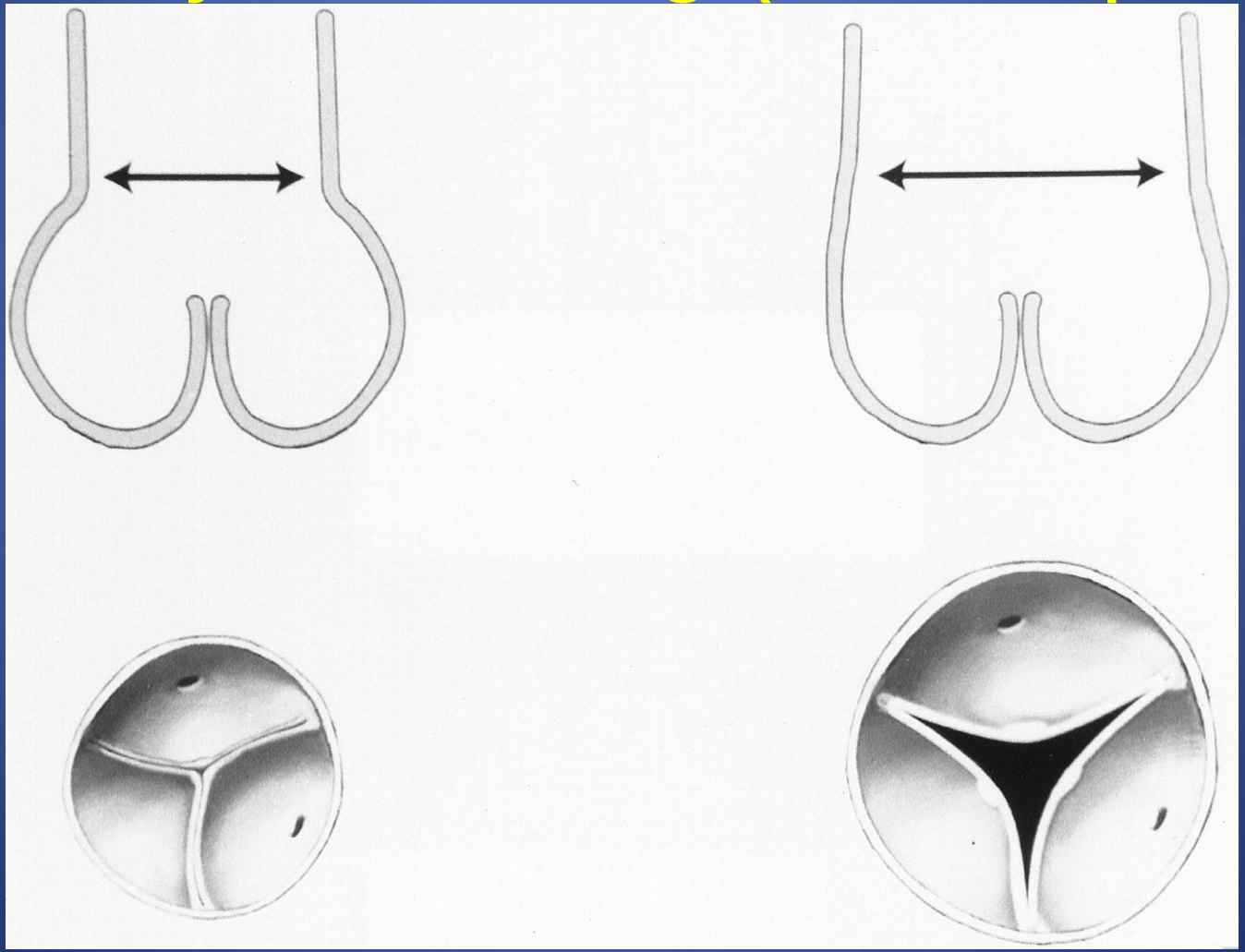
Important Factors to Compare

- Different phenotypes
- Surgical complexity
- Operative times (CPB, Cross-clamp)
- Early outcomes: morbidity & mortality
- Long term outcomes: freedom from re-op, freedom from recurrent AI
- Sub-populations: connective tissue (Marfan etc)

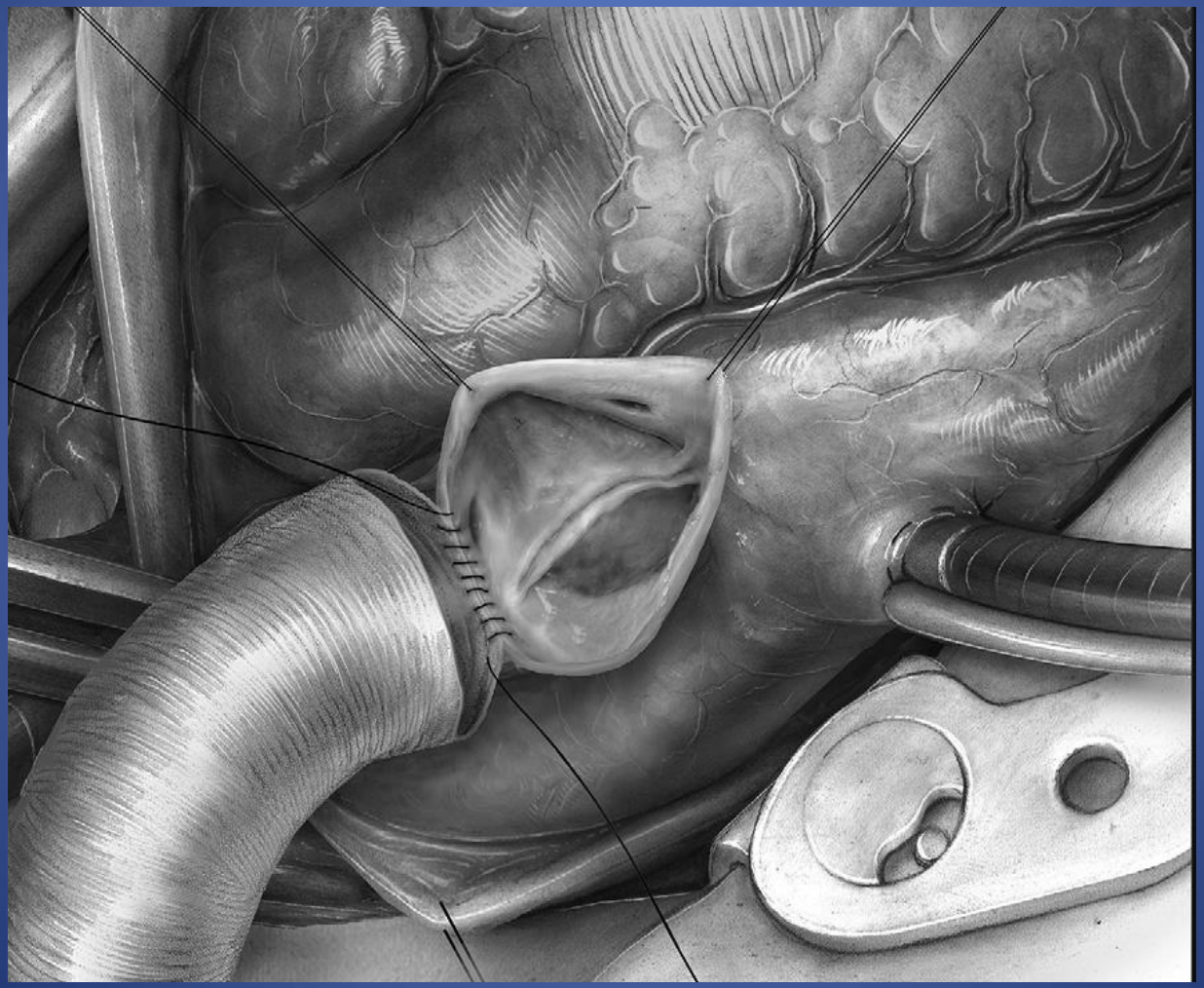
“Type 1” Root, Younger (10-40y), Hereditary connective synd. (Marfan, BAV with “root phenotype”)



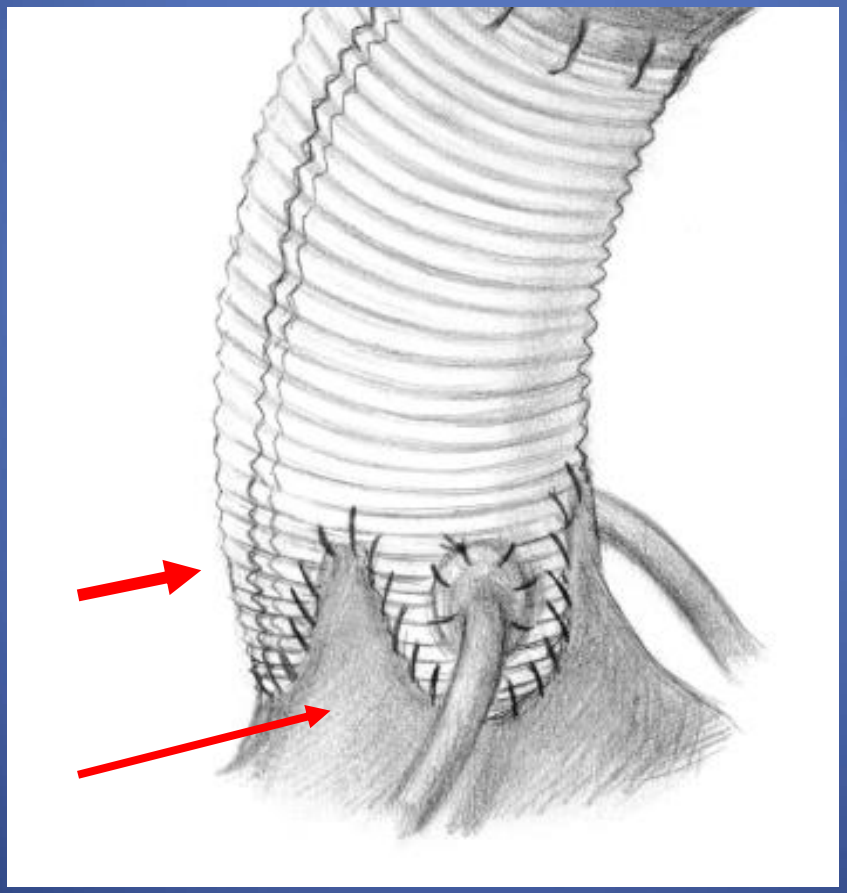
“Type 2” aneurysm:
Older > 40-50 y
primary ascending (tubular part)



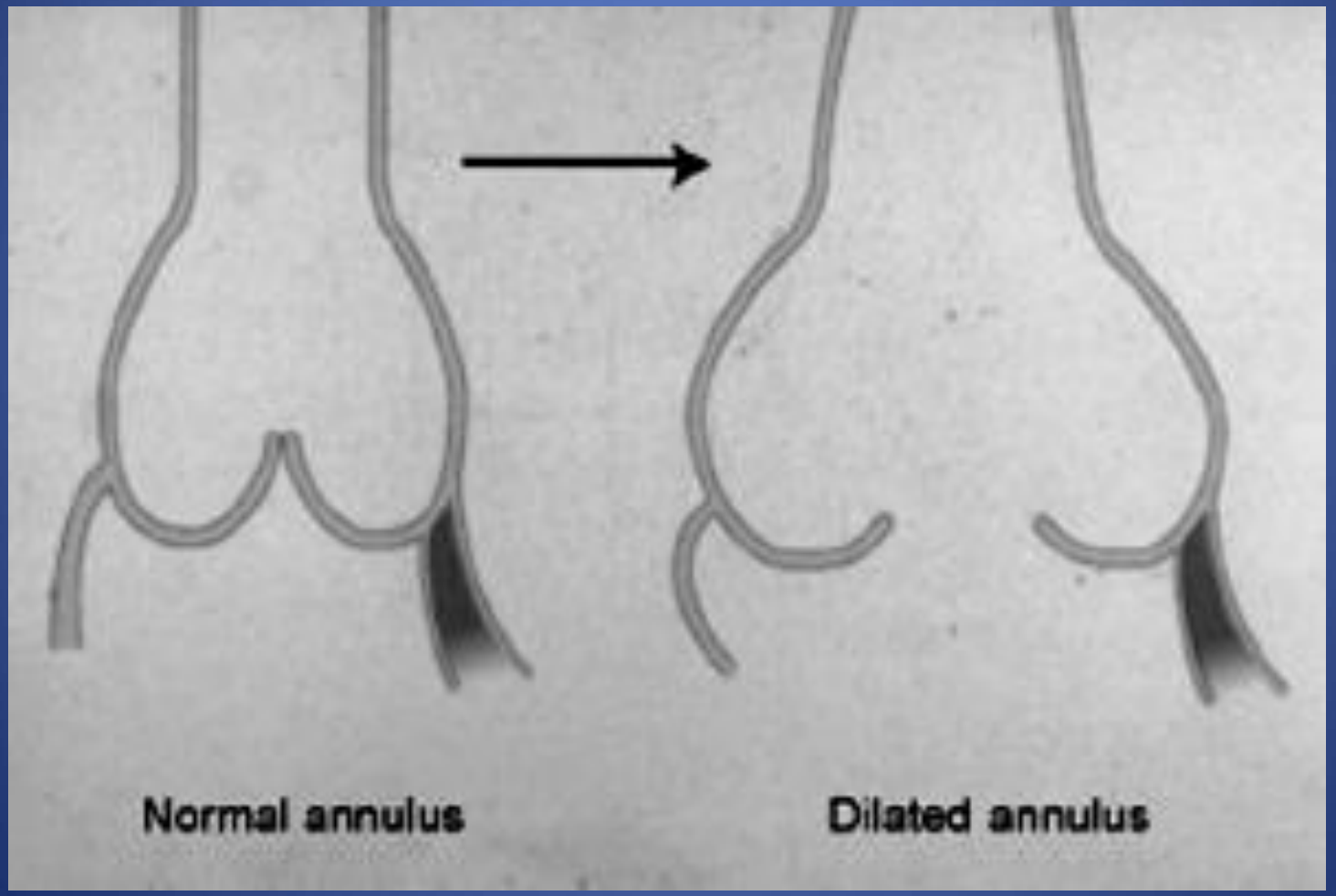
Ascending Aorta Replacement



Root Remodeling (M. Yaacoub)



Type 1-Root Phenotype



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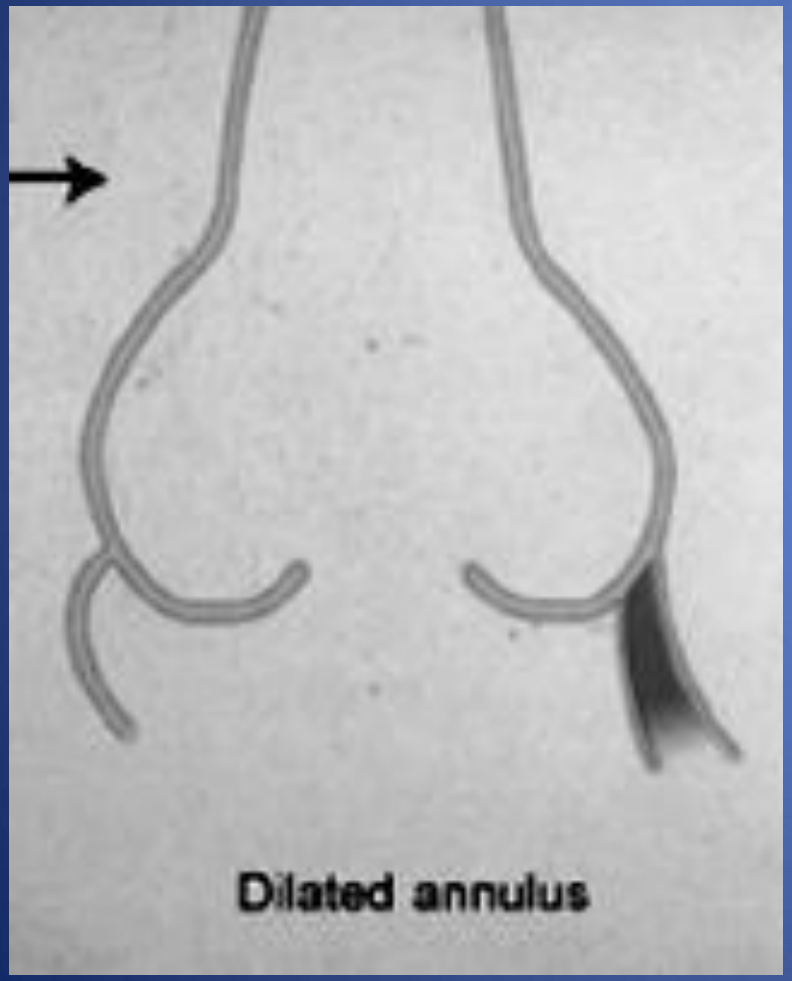
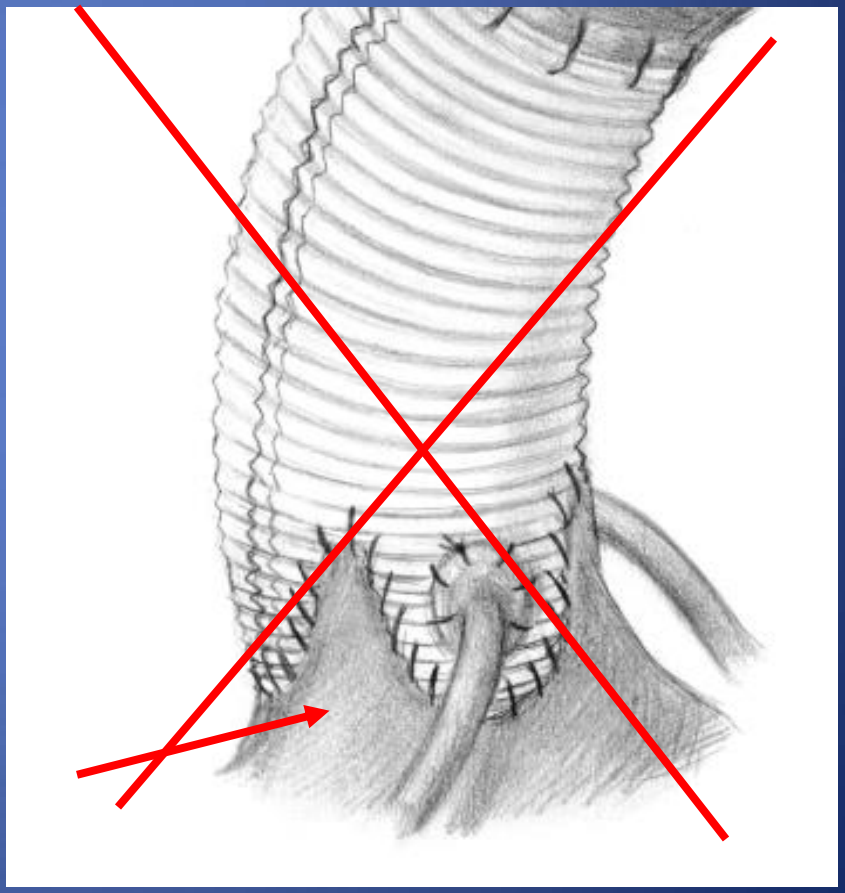
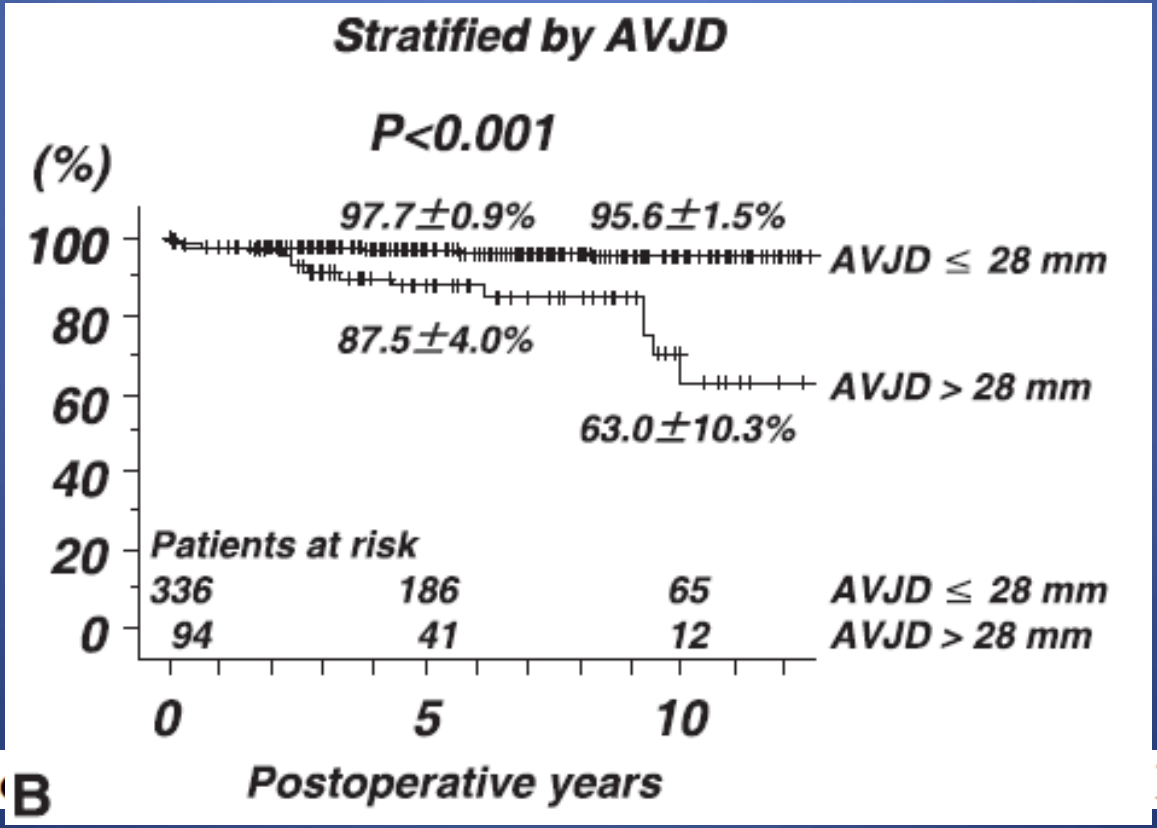




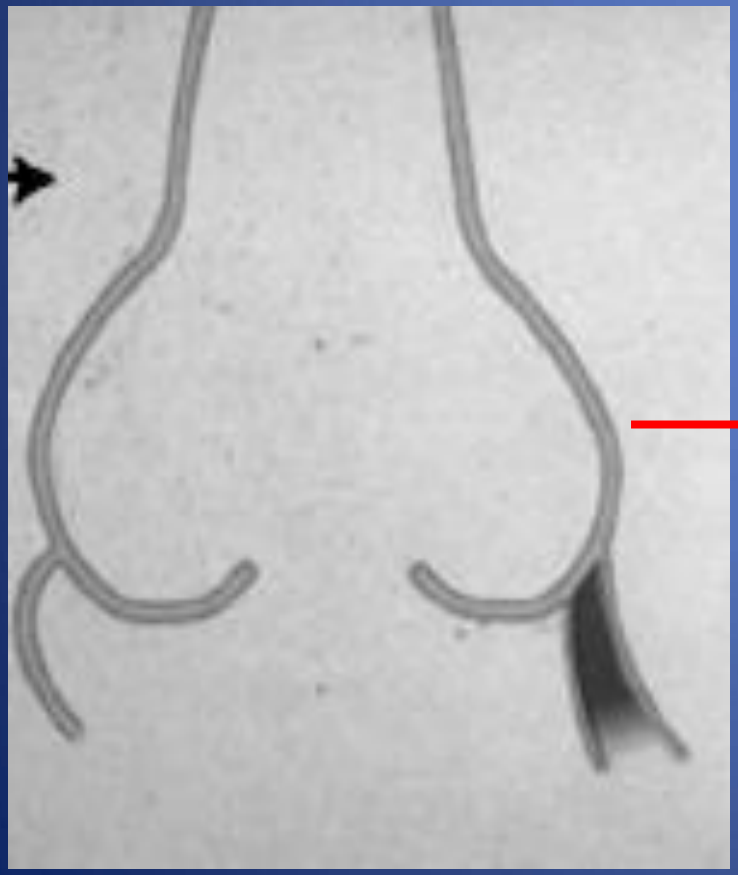
Preoperative aortic root geometry and postoperative cusp configuration primarily determine long-term outcome after valve-preserving aortic root repair

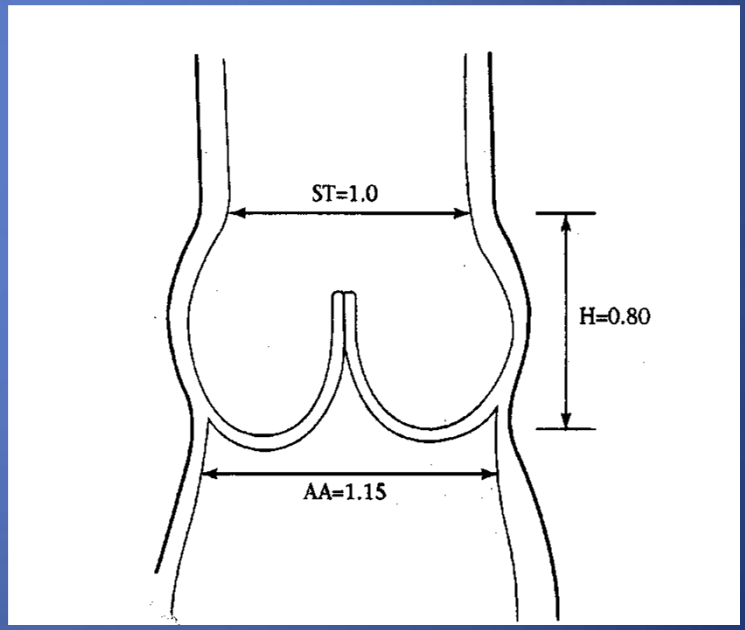
Takashi Kunihara, MD, PhD,[a] Diana Aicher, MD,[a] Svetlana Rodionycheva, MD,[a] Heinrich-Volker Groesdonk, MD,[a] Frank Langer, MD,[a] Fumihiro Sata, MD, PhD,[b] and Hans-Joachim Schäfers, MD, PhD[a]

1995-2009, 401 remodeling, 29 re-implantation (24 marfan pts)



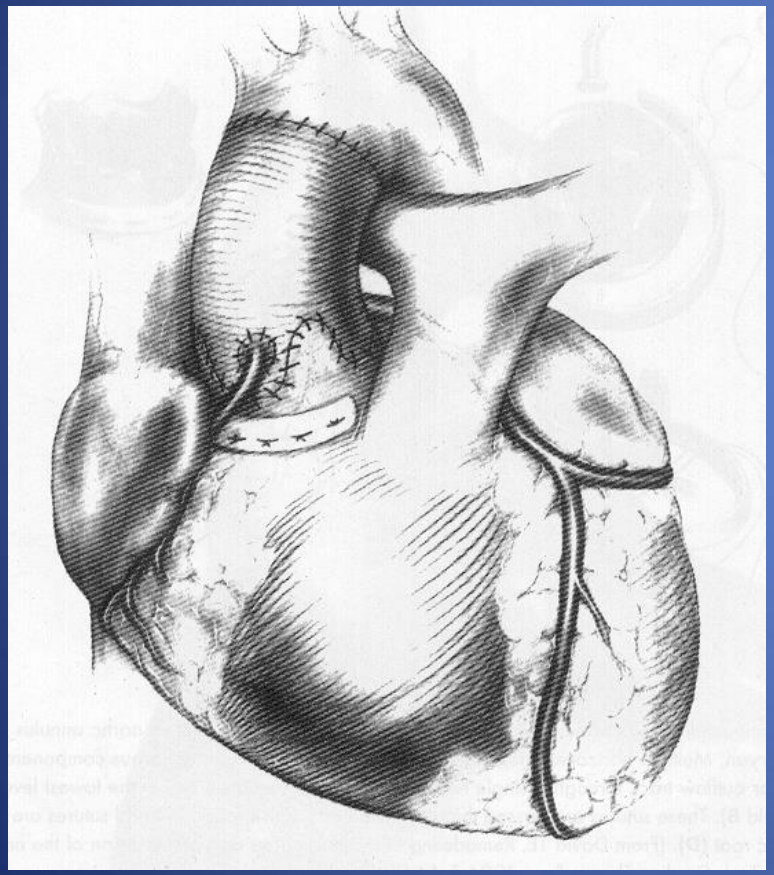
Restore Normal Root Geometry

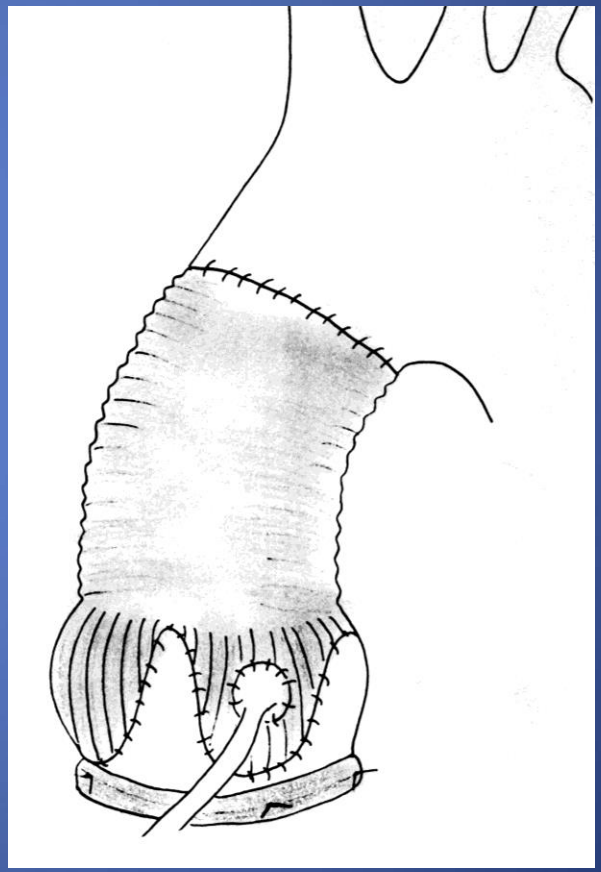




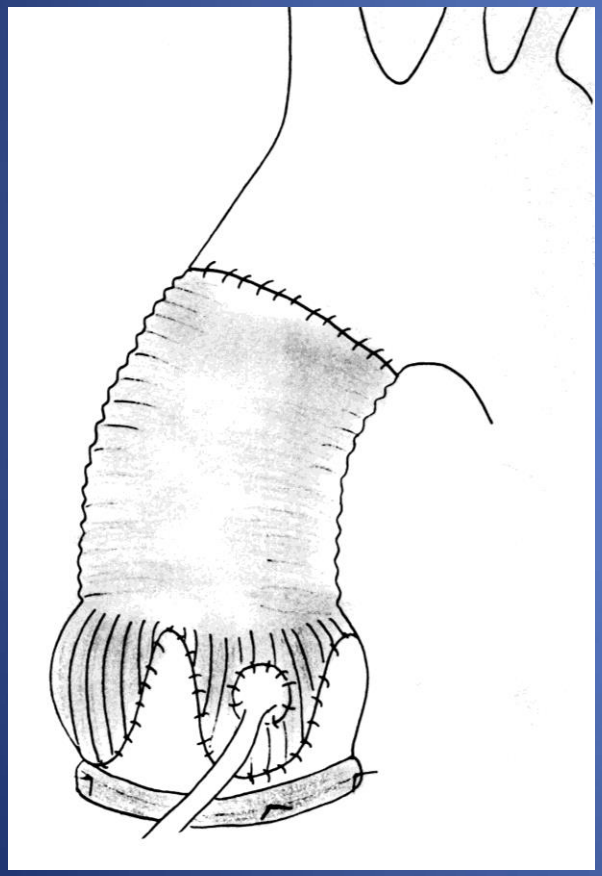
Kunzelman K, 1994

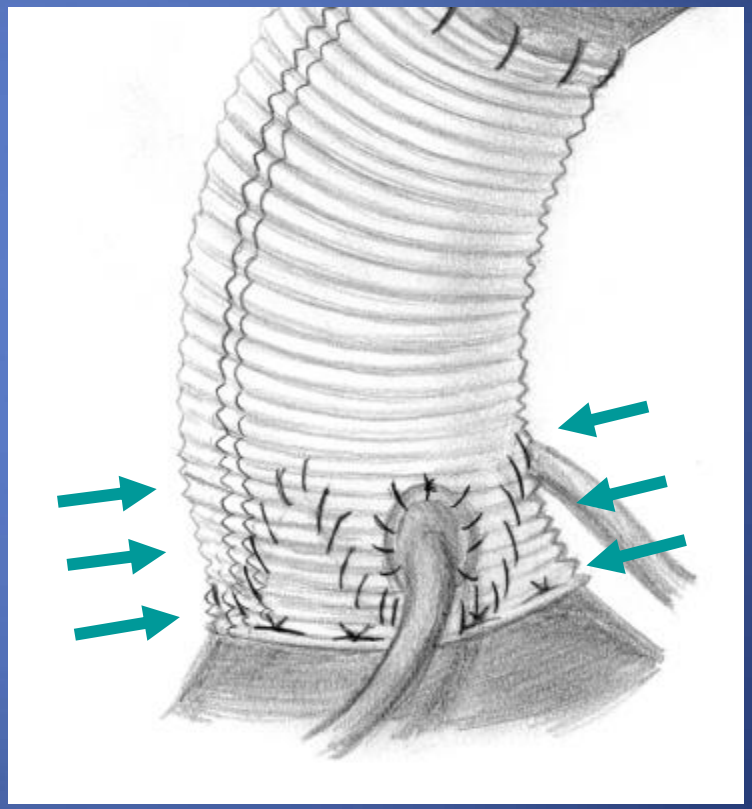
Remodeling +annuloplasty (D3, Lansac)



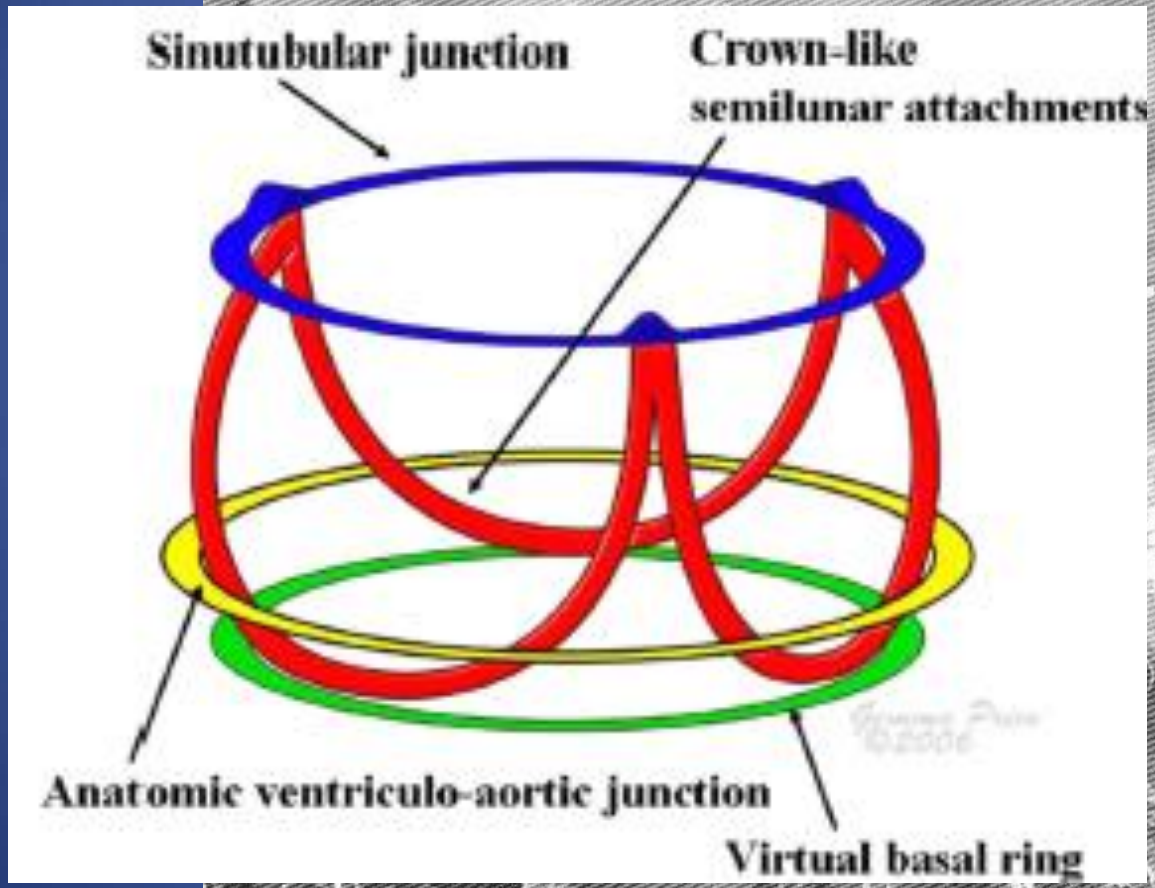


Compare

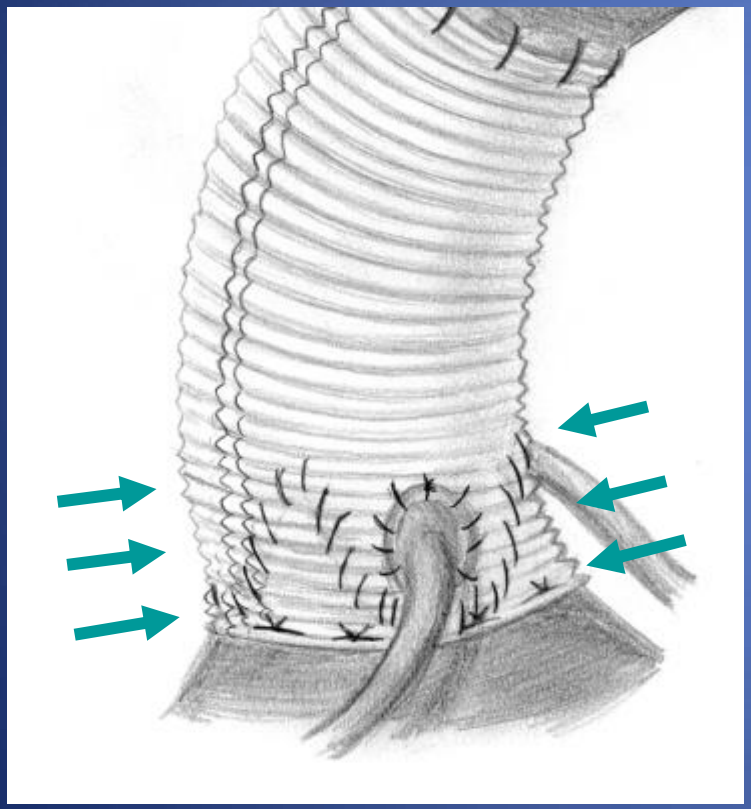


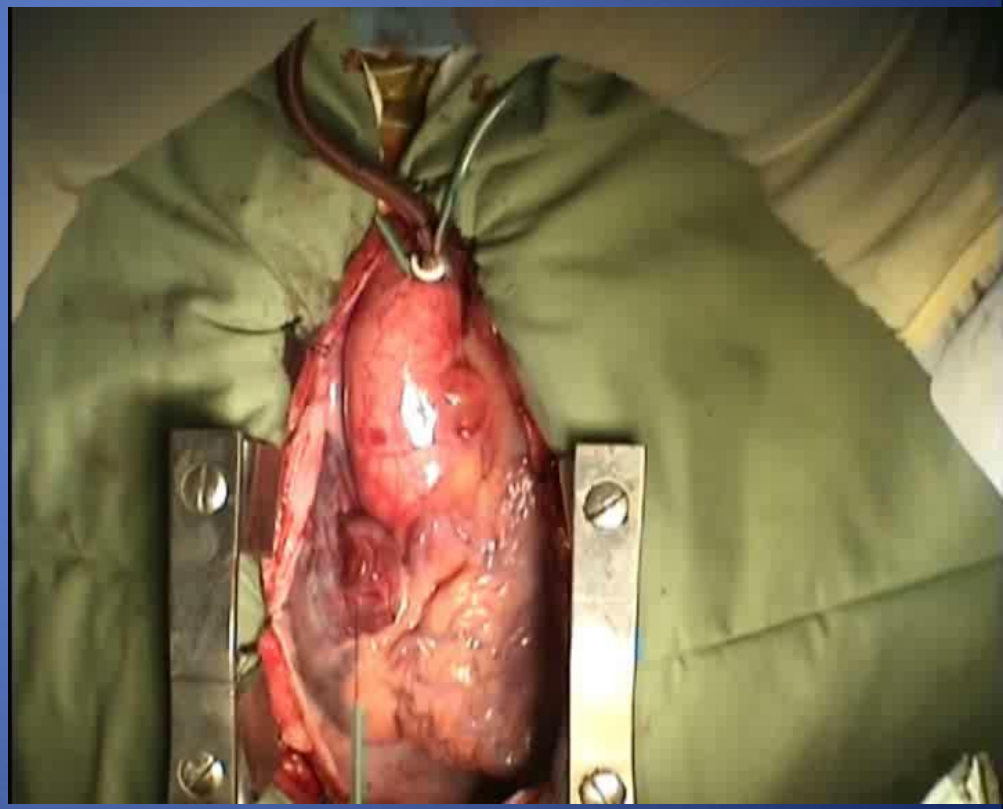


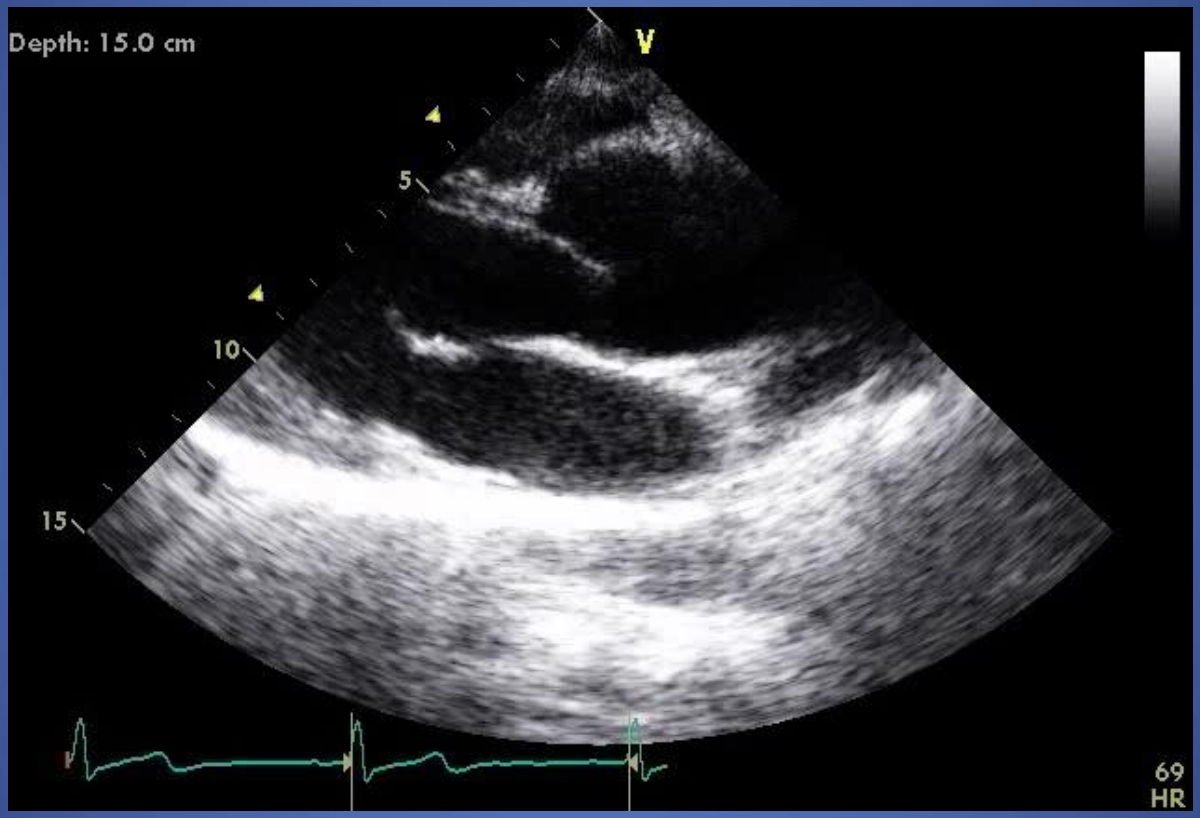
LVOT and Aortic Root Complex



RE-Implantation (David)






Depth: 15.0 cm
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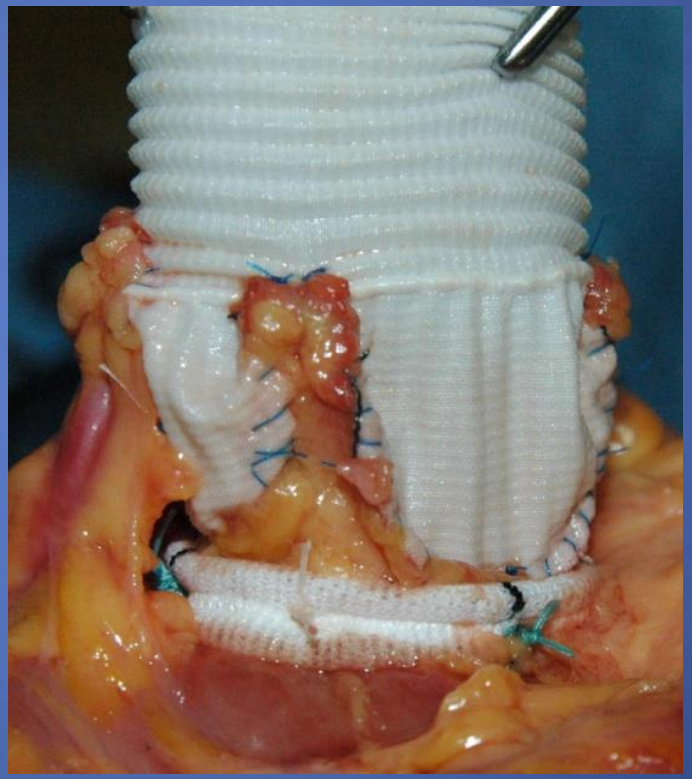
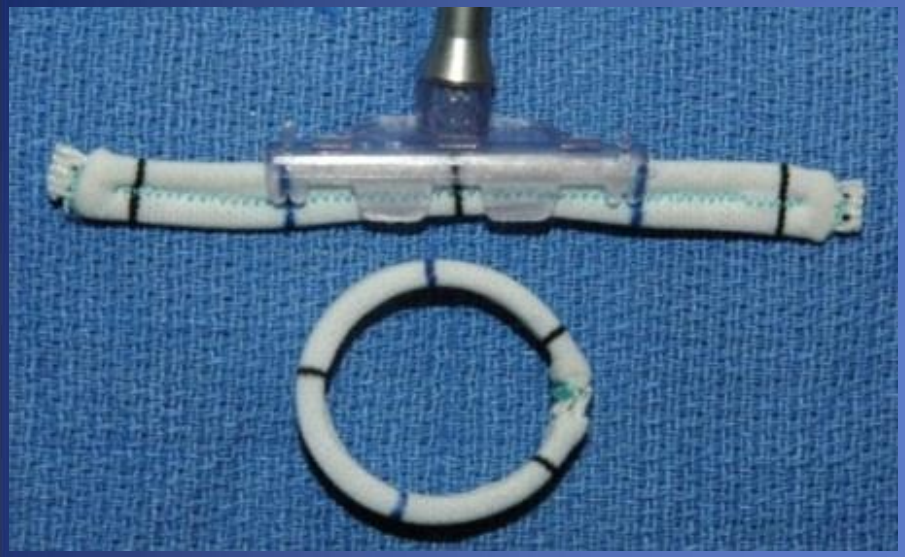


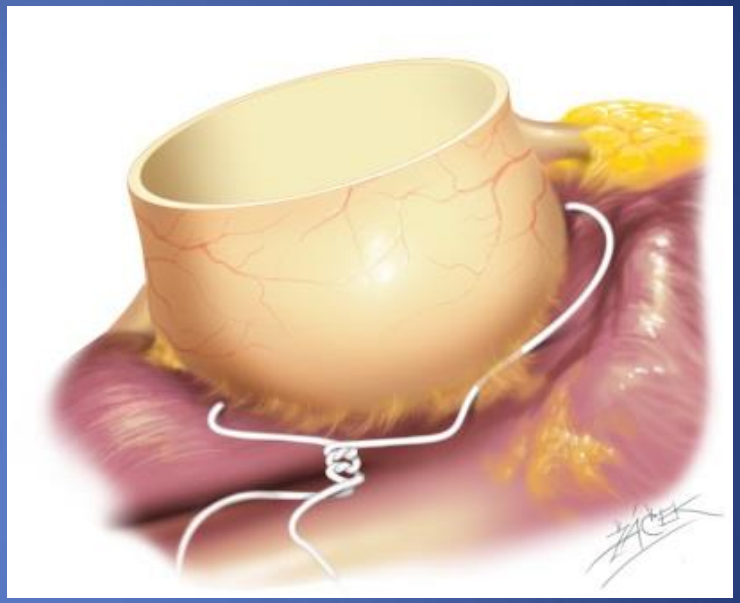
Courtesy E Lansac

Expansible Band



Lansac 2006

PTFE annuloplasty



Kazui, Svensson, Schäfers 2007

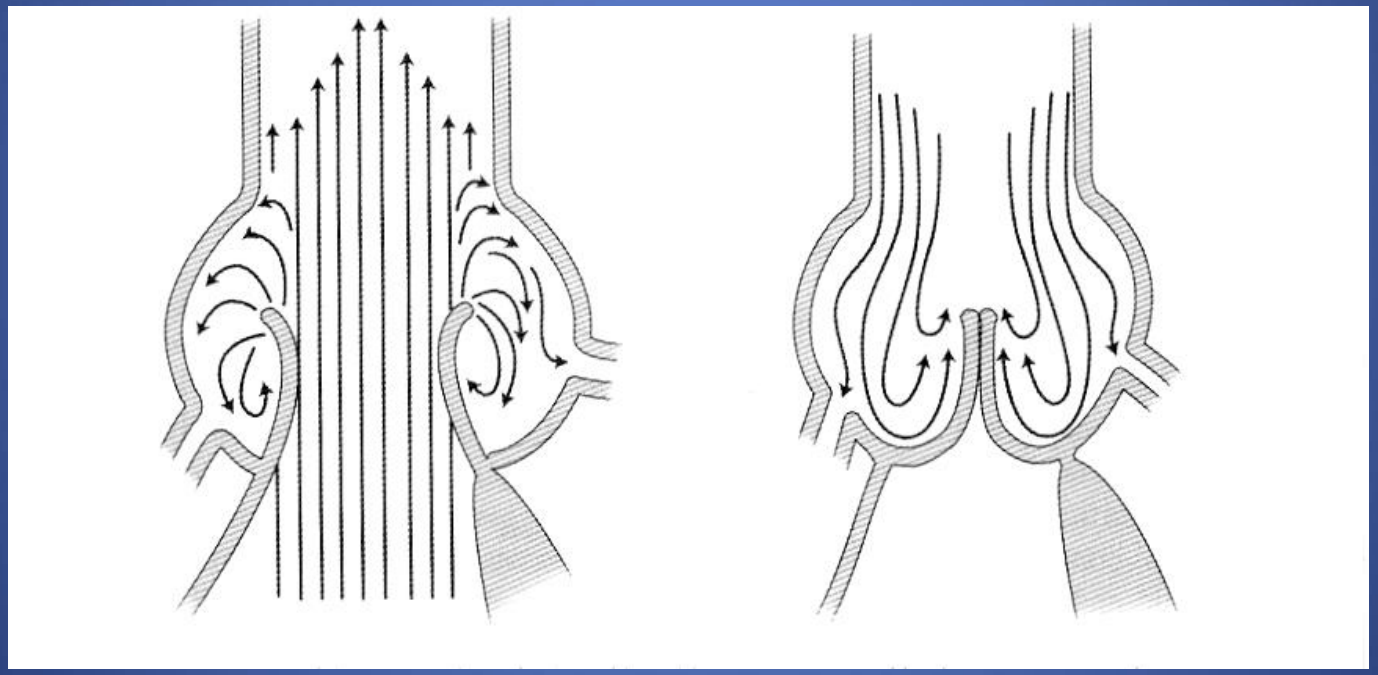
Standardized approach to valve repair using an expansible aortic ring versus mechanical Bentall: Early outcomes of the CAVIAAR multicentric prospective cohort study

Emmanuel Lansac, MD, PhD,[a] Olivier Bouchot, MD, PhD,[b] Eric Arnaud Crozat, MD,[c] Rachid Hacini, MD,[c] Fabien Doguet, MD, PhD,[d] Roland Demaria, MD, PhD,[e] Alain Leguerrier, MD,[f]

ECC time (min) mean ± SD (range)	156.1 ± 49.2 (65-315)	183.1 ± 38.7 (114-315)	129.1 ± 43.5 (65-314)	<.0001†
AC time (min) mean ± SD (range)	123.8 ± 38.1 (50-137)	147.7 ± 30.1 (103-237)	99.8 ± 29.2 (50-180)	<.0001†
Second CPB run	12 (4.6%)	11 (8.5%)	1 (0.8%)	.003*
Second CPB AC time (min)	32.0 ± 14.2 (20-65)	28.3 ± 8.7 (20-45)	65.0 (.)	.004†

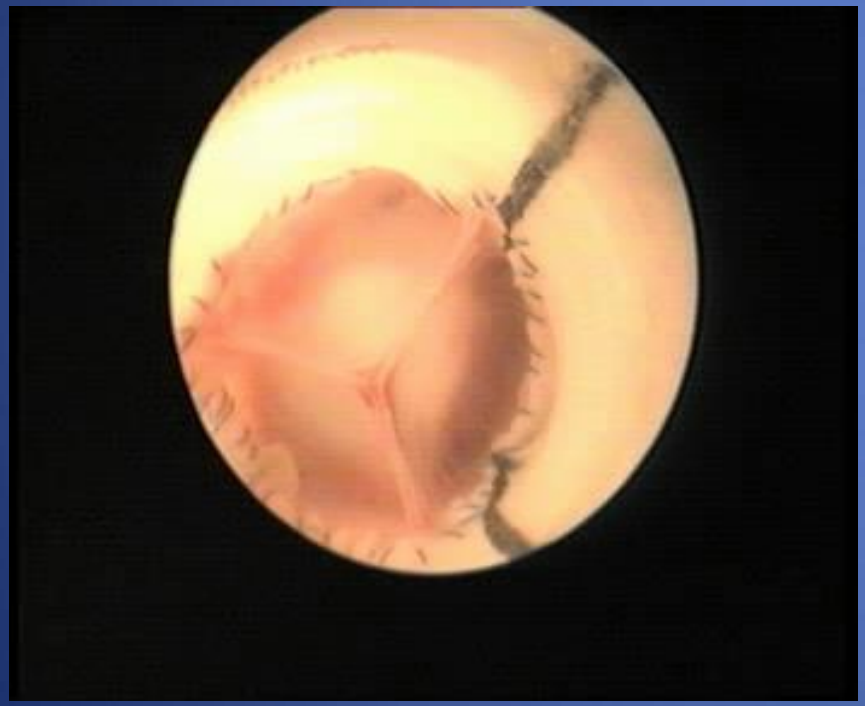
Lansac E, JTCVS 2015

Function of Aortic Sinuses

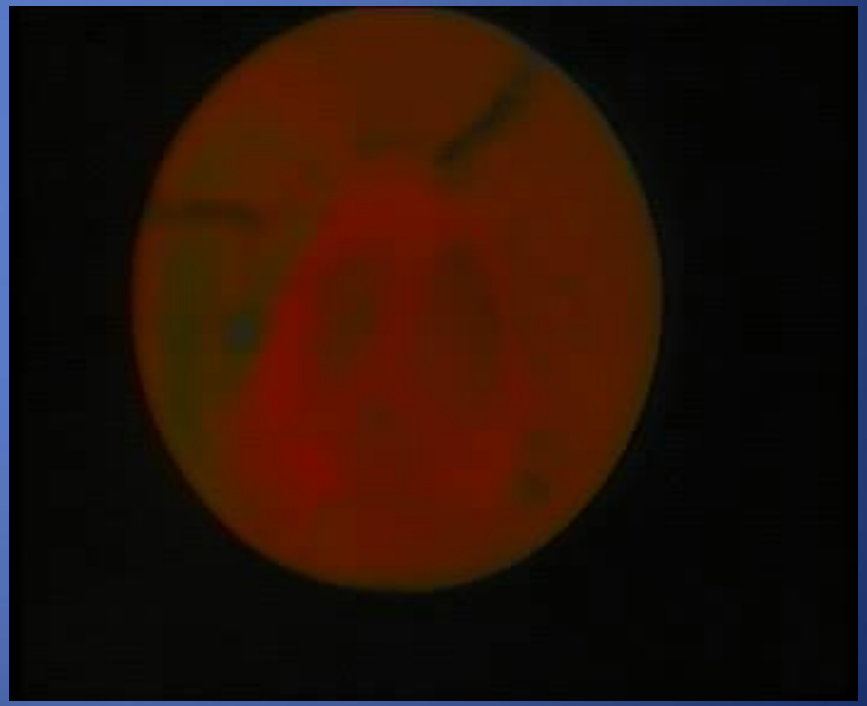


The effect of the sinuses of valsalva on cusp closure

With Sinuses

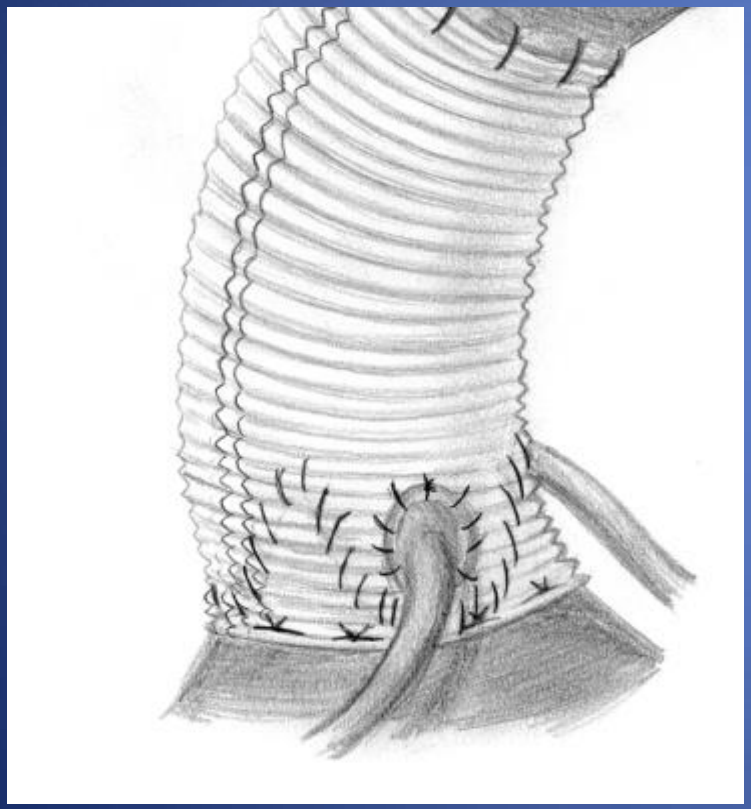


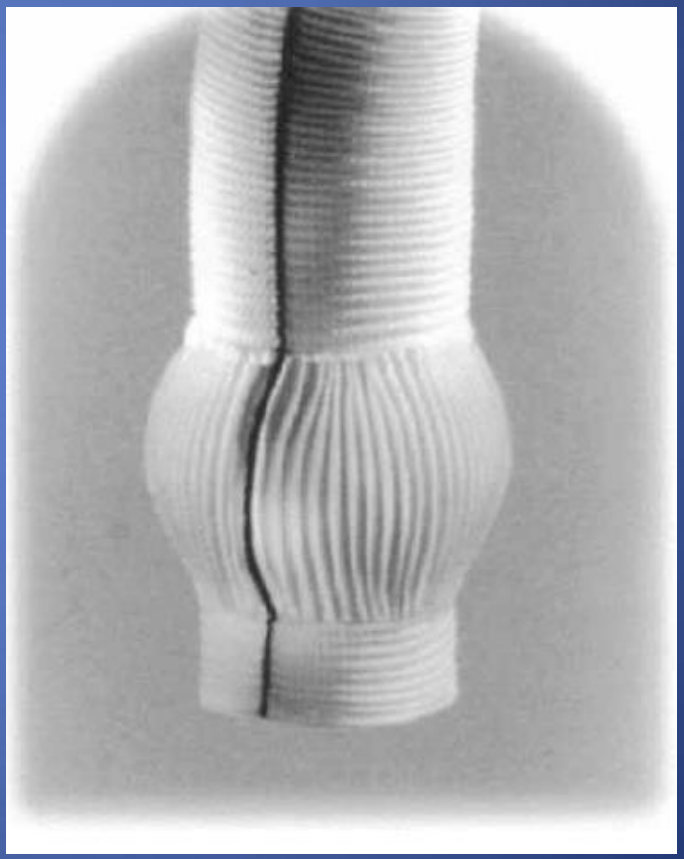
No Sinuses



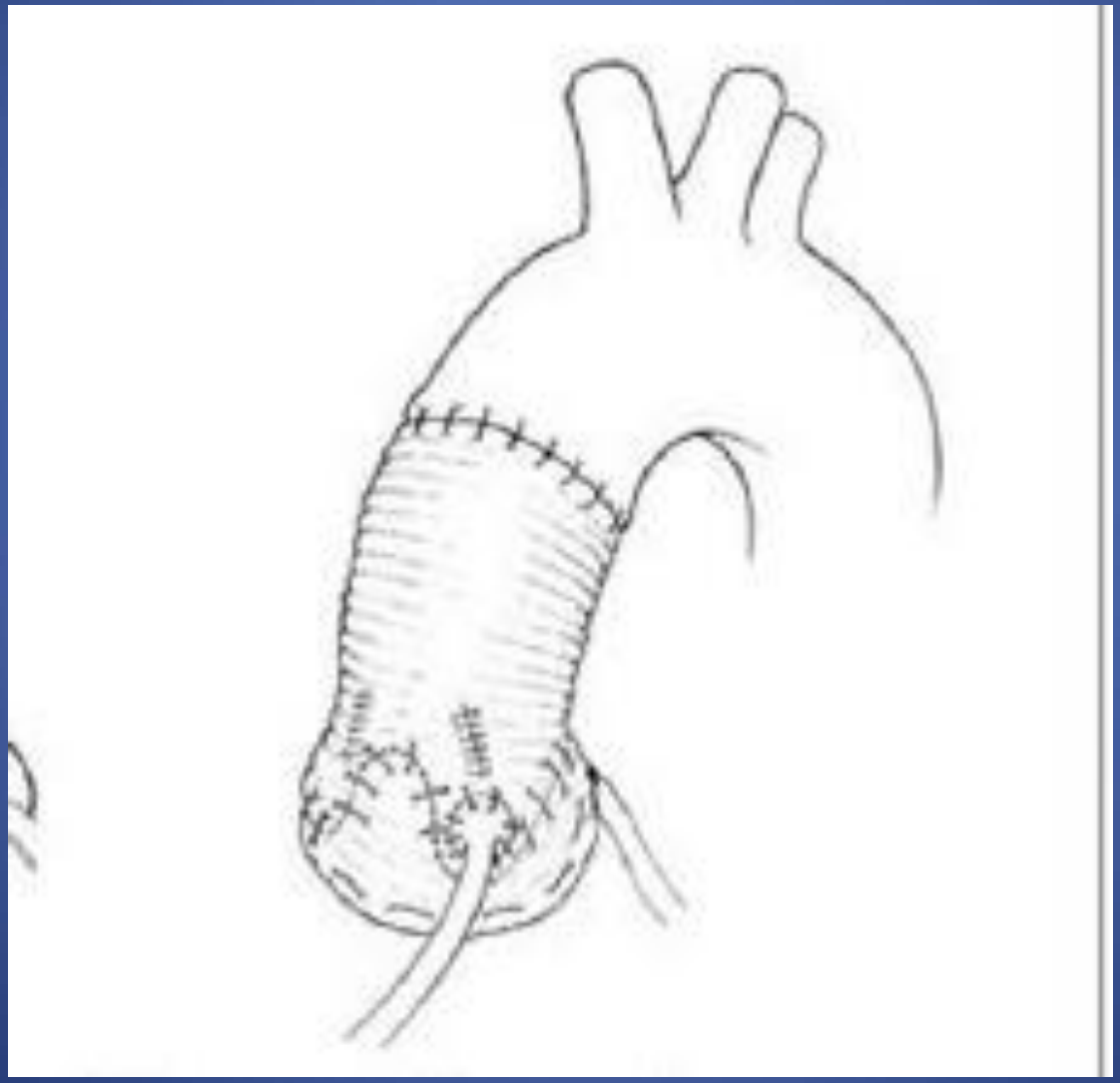
Courtesy Schafers H

Valsalva graft





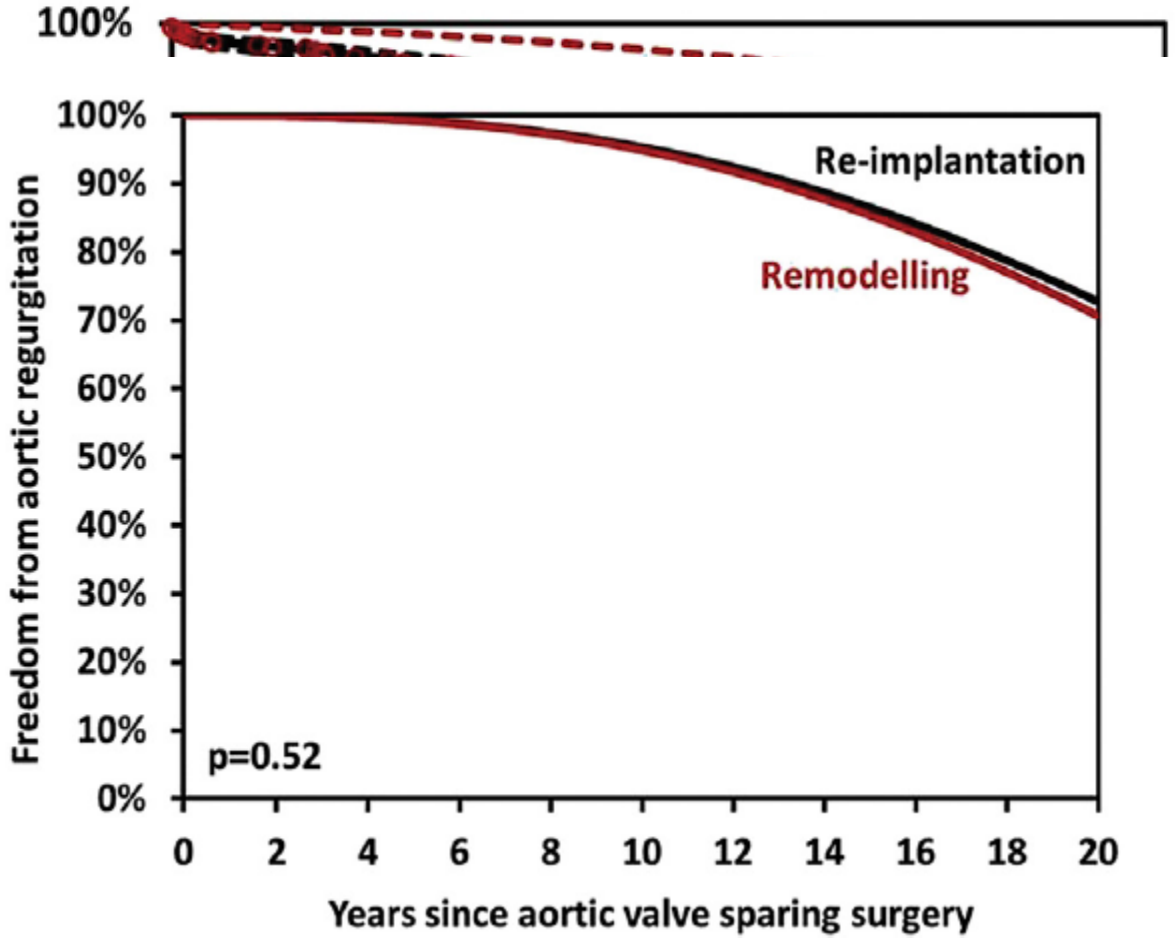
Neo-Aortic Sinuses



A quarter of a century of experience with aortic valve-sparing operations

Tirone E. D , BSc

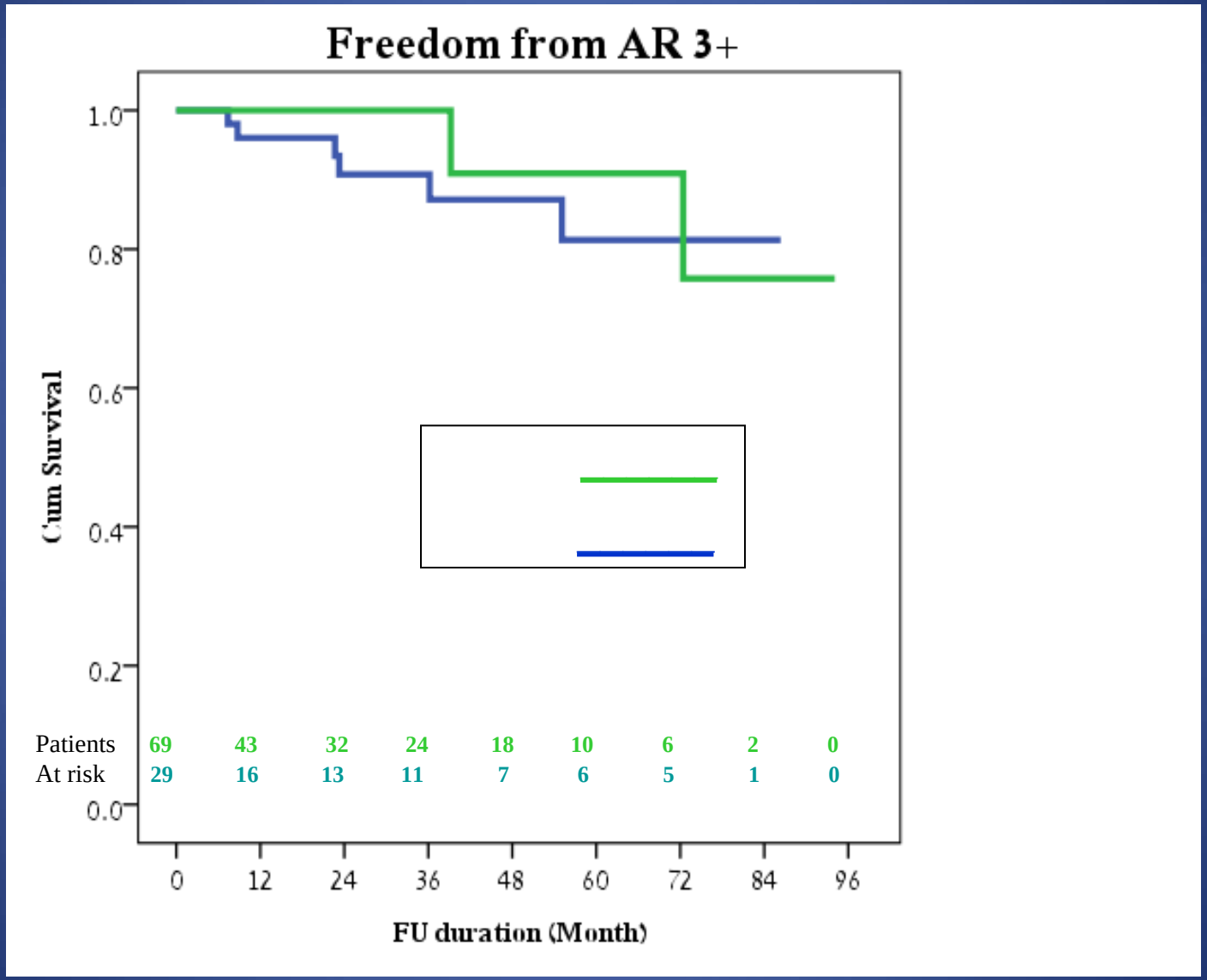
- 19
- 29
- M



matched for age and gender.

The Journal of Thoracic and Cardiovascular Surgery • September 2014

Marfan (38) compared to non- Marfan (133) Patients Late Echo



Preoperative aortic root geometry and postoperative cusp configuration primarily determine long-term outcome after valve-preserving aortic root repair

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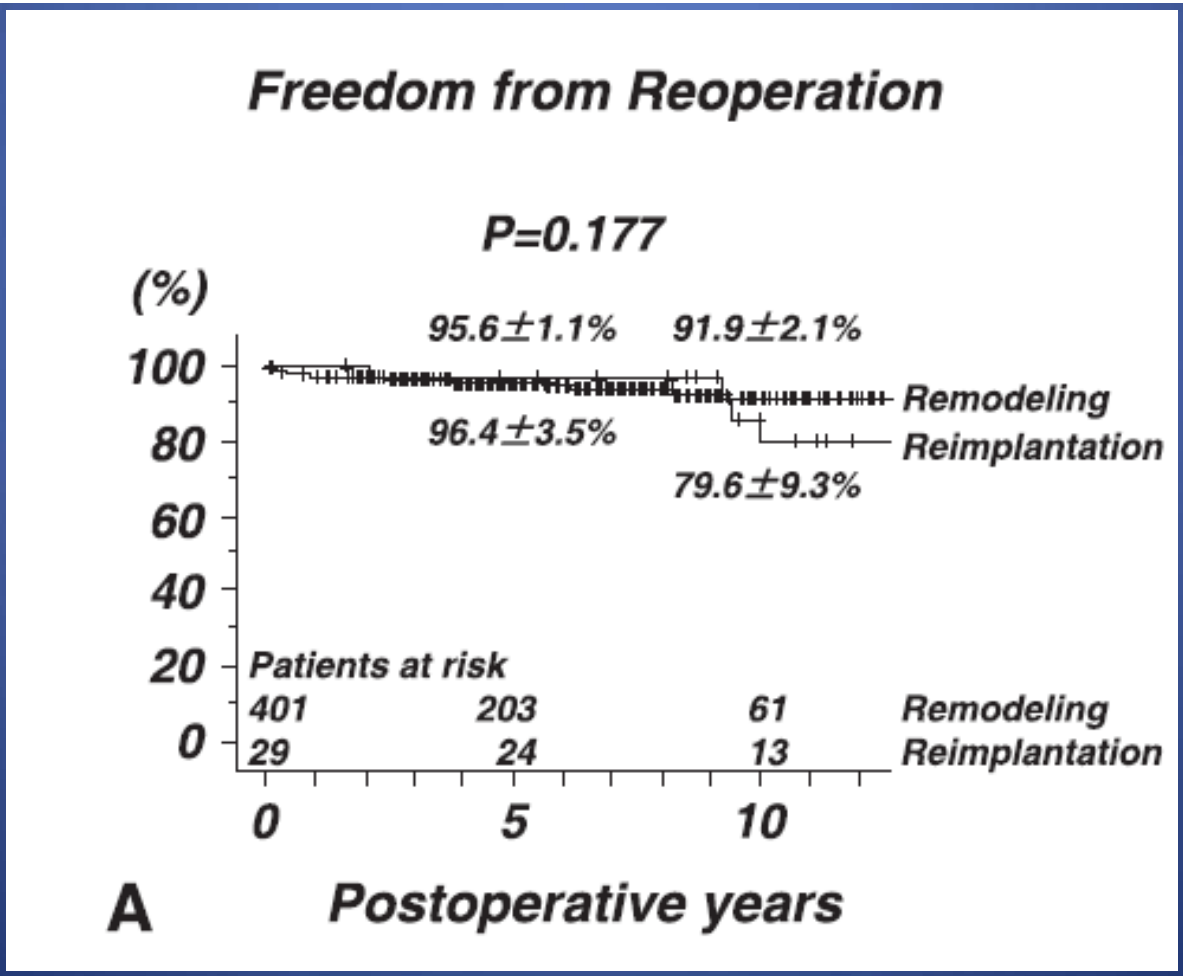
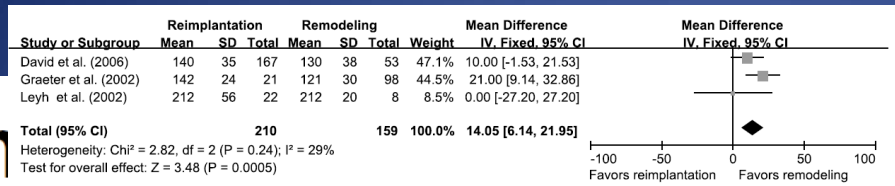


Rein … emodeling: A M…

Lei Liu, M… …ian, M.D., Yan-Hai Meng, M.D., and Qian…

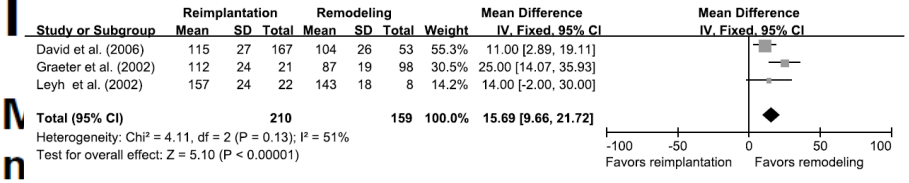


Study or Subgroup	Reimplantation Mean	SD	Total	Remodeling Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
David et al. (2006)	140	35	167	130	38	53	47.1%	10.00 [-1.53, 21.53]
Graeter et al. (2002)	142	24	21	121	30	98	44.5%	21.00 [9.14, 32.86]
Leyh et al. (2002)	212	56	22	212	20	8	8.5%	0.00 [-27.20, 27.20]
Total (95% CI)			**210**			**159**	**100.0%**	**14.05 [6.14, 21.95]**

Heterogeneity: Chi² = 2.82, df = 2 (P = 0.24); I² = 29%
Test for overall effect: Z = 3.48 (P = 0.0005)

Mean Difference IV, Fixed, 95% CI
-100 -50 0 50 100
Favors reimplantation Favors remodeling

Figure 2. *CPB time for reimplantation versus remodeling.*

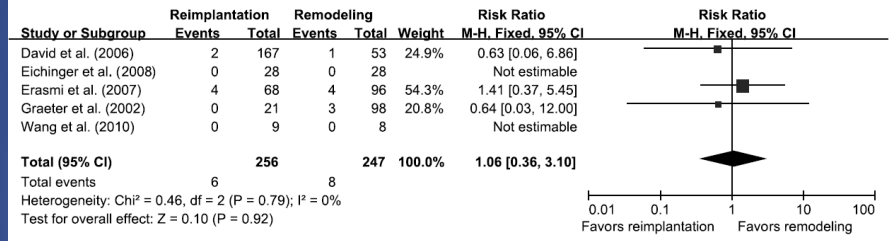


Study or Subgroup	Reimplantation Mean	SD	Total	Remodeling Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
David et al. (2006)	115	27	167	104	26	53	55.3%	11.00 [2.89, 19.11]
Graeter et al. (2002)	112	24	21	87	19	98	30.5%	25.00 [14.07, 35.93]
Leyh et al. (2002)	157	24	22	143	18	8	14.2%	14.00 [-2.00, 30.00]
Total (95% CI)			**210**			**159**	**100.0%**	**15.69 [9.66, 21.72]**

Heterogeneity: Chi² = 4.11, df = 2 (P = 0.13); I² = 51%
Test for overall effect: Z = 5.10 (P < 0.00001)

Mean Difference IV, Fixed, 95% CI
-100 -50 0 50 100
Favors reimplantation Favors remodeling

Figure 3. *Aortic clamping time for reimplantation versus remodeling.*

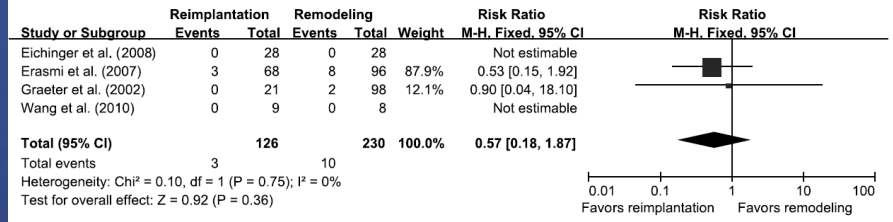


Study or Subgroup	Reimplantation Events	Total	Remodeling Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI
David et al. (2006)	2	167	1	53	24.9%	0.63 [0.06, 6.86]
Eichinger et al. (2008)	0	28	0	28		Not estimable
Erasmi et al. (2007)	4	68	4	96	54.3%	1.41 [0.37, 5.45]
Graeter et al. (2002)	0	21	3	98	20.8%	0.64 [0.03, 12.00]
Wang et al. (2010)	0	9	0	8		Not estimable
Total (95% CI)		**256**		**247**	**100.0%**	**1.06 [0.36, 3.10]**
Total events	6		8			

Heterogeneity: Chi² = 0.46, df = 2 (P = 0.79); I² = 0%
Test for overall effect: Z = 0.10 (P = 0.92)

Risk Ratio M-H, Fixed, 95% CI
0.01 0.1 1 10 100
Favors reimplantation Favors remodeling

Figure 4. *Early (30-day) deaths for reimplantation versus remodeling.*

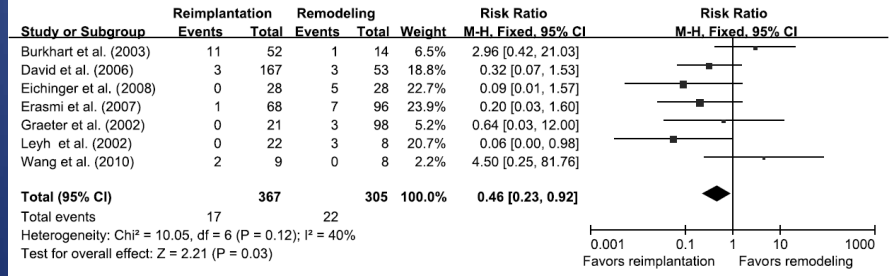


Study or Subgroup	Reimplantation Events	Total	Remodeling Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Eichinger et al. (2008)	0	28	0	28		Not estimable
Erasmi et al. (2007)	3	68	8	96	87.9%	0.53 [0.15, 1.92]
Graeter et al. (2002)	0	21	2	98	12.1%	0.90 [0.04, 18.10]
Wang et al. (2010)	0	9	0	8		Not estimable
Total (95% CI)		**126**		**230**	**100.0%**	**0.57 [0.18, 1.87]**
Total events	3		10			

Heterogeneity: Chi² = 0.10, df = 1 (P = 0.75); I² = 0%
Test for overall effect: Z = 0.92 (P = 0.36)

Risk Ratio M-H, Fixed, 95% CI
0.01 0.1 1 10 100
Favors reimplantation Favors remodeling

Figure 5. *Late deaths for reimplantation versus remodeling.*



Study or Subgroup	Reimplantation Events	Total	Remodeling Events	Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Burkhart et al. (2003)	11	52	1	14	6.5%	2.96 [0.42, 21.03]
David et al. (2006)	3	167	3	53	18.8%	0.32 [0.07, 1.53]
Eichinger et al. (2008)	0	28	5	28	22.7%	0.09 [0.01, 1.57]
Erasmi et al. (2007)	1	68	7	96	23.9%	0.20 [0.03, 1.60]
Graeter et al. (2002)	0	21	3	98	5.2%	0.64 [0.03, 12.00]
Leyh et al. (2002)	0	22	3	8	20.7%	0.06 [0.00, 0.98]
Wang et al. (2010)	2	9	0	8	2.2%	4.50 [0.25, 81.76]
Total (95% CI)		**367**		**305**	**100.0%**	**0.46 [0.23, 0.92]**
Total events	17		22			

Heterogeneity: Chi² = 10.05, df = 6 (P = 0.12); I² = 40%
Test for overall effect: Z = 2.21 (P = 0.03)

Risk Ratio M-H, Fixed, 95% CI
0.001 0.1 1 10 1000
Favors reimplantation Favors remodeling

Figure 6. *Reoperation related to moderate or severe AI for reimplantation versus remodeling.*

Liu Lei. J Card Surg 2011

Factors associated with the development of aortic valve regurgitation over time after two different techniques of valve-sparing aortic root surgery

Thorsten Hanke, MD,[a,*] Efstratios I. Charitos, MD,[a,*] Ulrich Stierle, MD,[a,*] Derek Robinson, MA, MSc, DPhil, CStat,[b] Armin Gorski, MD,[c] Hans-H. Sievers, MD,[a] and Martin Misfeld, MD, PhD[a]

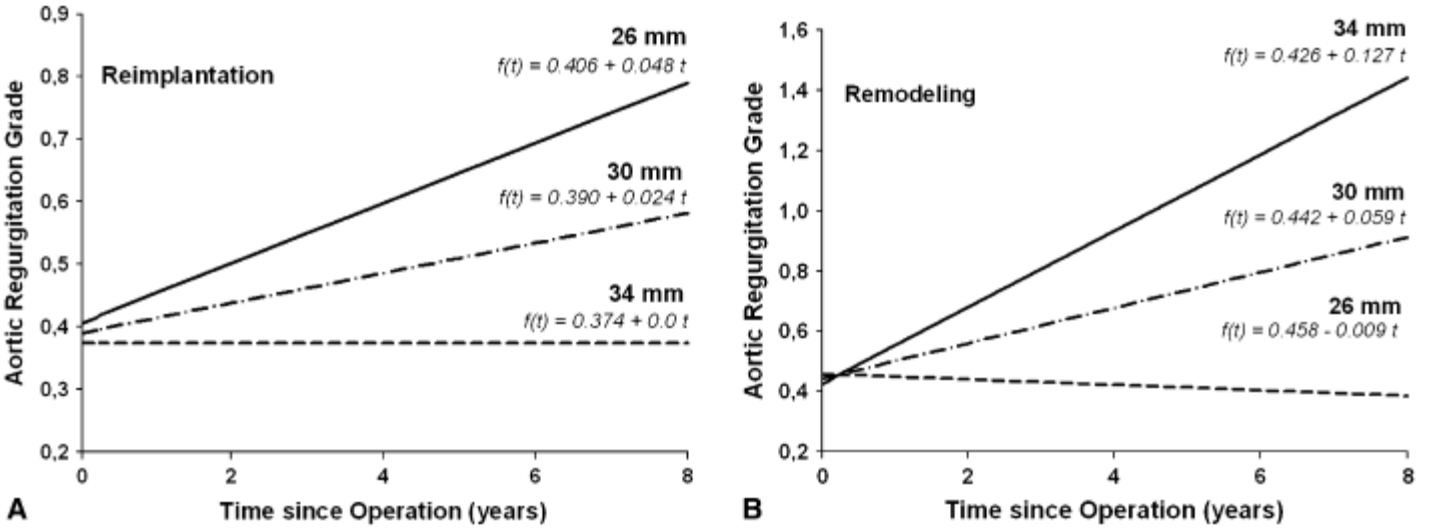


FIGURE 4. Multilevel modeling of the association of preoperative aortic annulus diameter and AR grade with time in patients treated with the reimplantation (A) and remodeling (B) techniques. With increasing diameters of the aortic annulus, aortic valve incompetence is pronounced in patients treated with the

Hanke T JTCVS 2009

VALVE-PRESERVING REPLACEMENT OF THE ASCENDING AORTA: REMODELING VERSUS REIMPLANTATION

H.-J. Schäfers, MD, PhD[a]
R. Fries, MD[b]
E. Langer, MD[a]

Objective: Aortic valve regurgitation in combination with dilatation of the ascending aorta and root requires a combined procedure to restore

Conclusions: Depending on individual root pathologic condition, both the remodeling and the reimplantation techniques appeared to have their individual merits. Both result in adequate restoration of aortic valve function and elimination of pathologic aortic dilatation. (J Thorac Cardiovasc Surg 1998;116:990-6)

Schafers HJ, JTCVS 1998

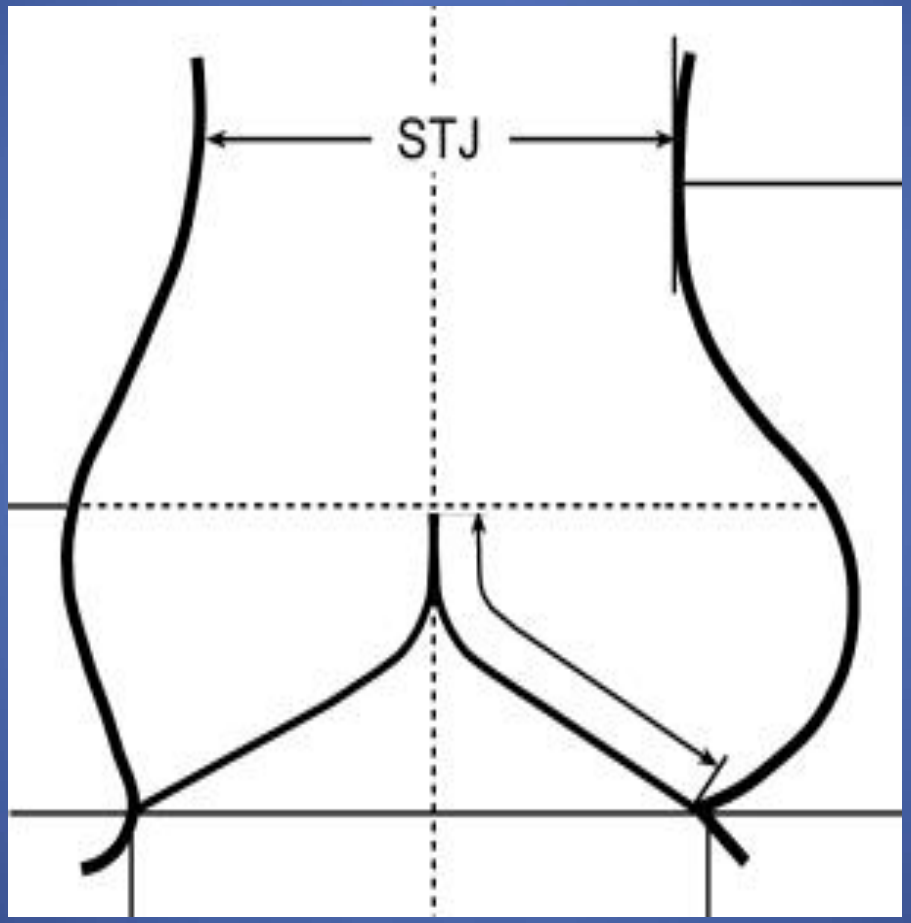
Summary I

- Re-implantation is a more complex procedure with longer operative times
- This has not seemed to affect early M&M
- Long-term outcomes are comparable mainly due to stratification of type I root to the re-implantation

Summary II

- Procedures are not competitive to each other:
  - For type 2 root aneurysm, the remodeling should be the preferred approach
  - For younger pts with type 1 root aneurysm and genetic syndromes, re-implantation has proven to be effective with excellent long term outcomes.
- D3 or the remodeling + annuloplasty (Lansac/Schafers), may also provide good outcomes, long-term FU is needed

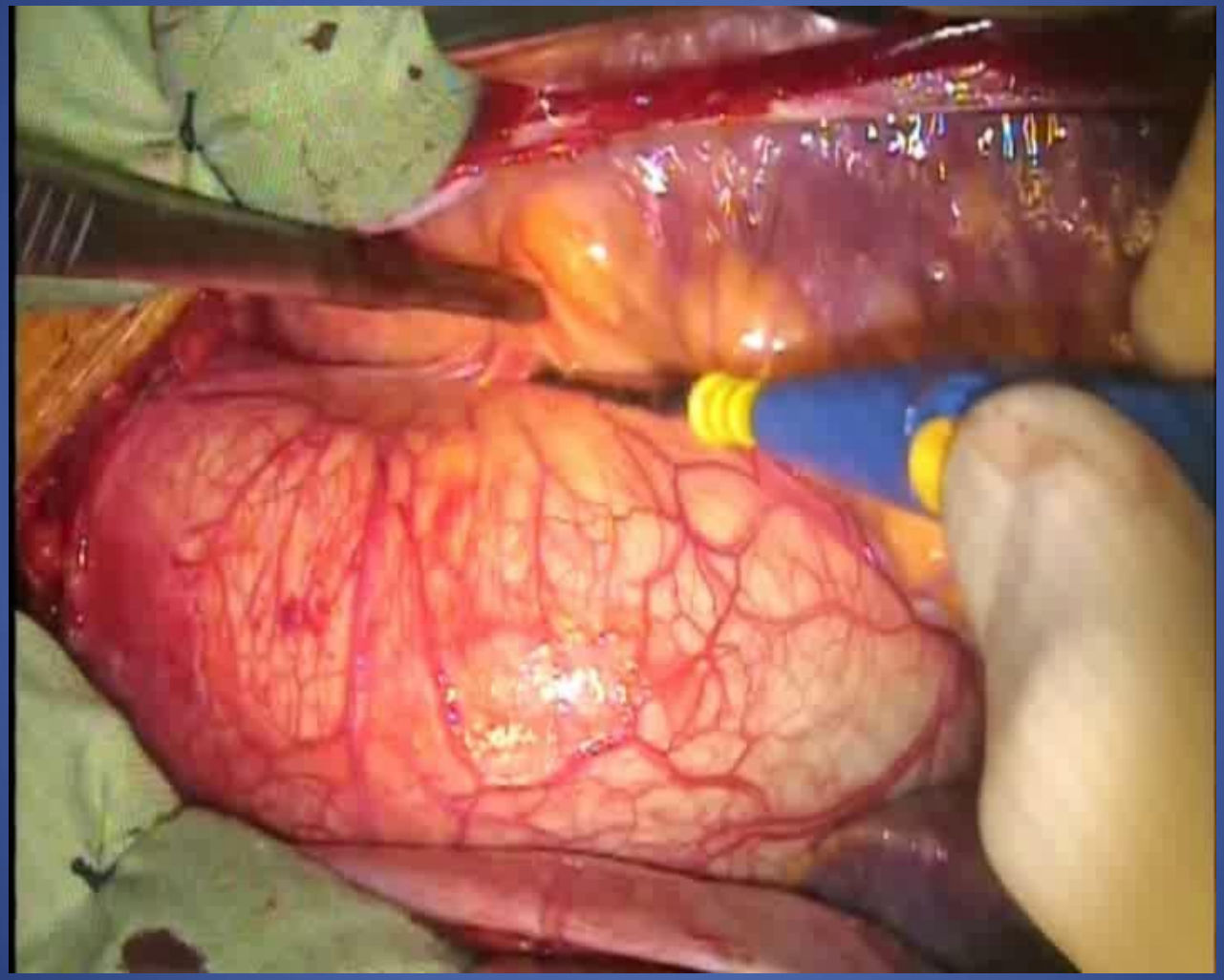
Restore Normal Geometry



The wolf also shall dwell with the lamb, and Tiger with the kid

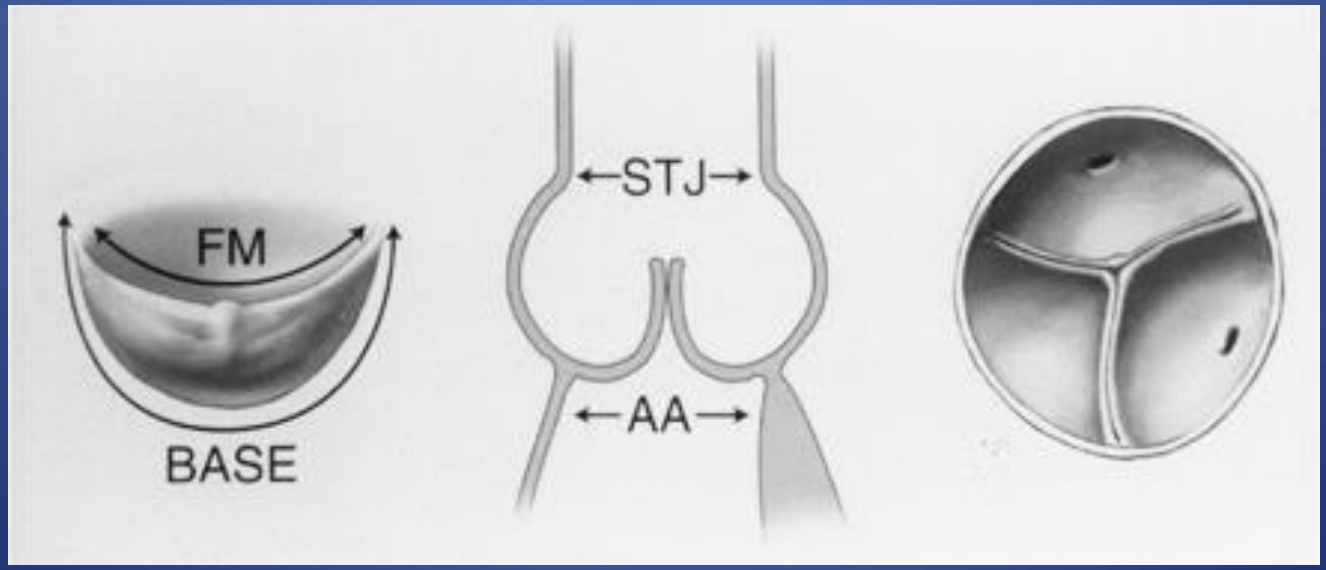
Thank you

The Leviev Heart Center



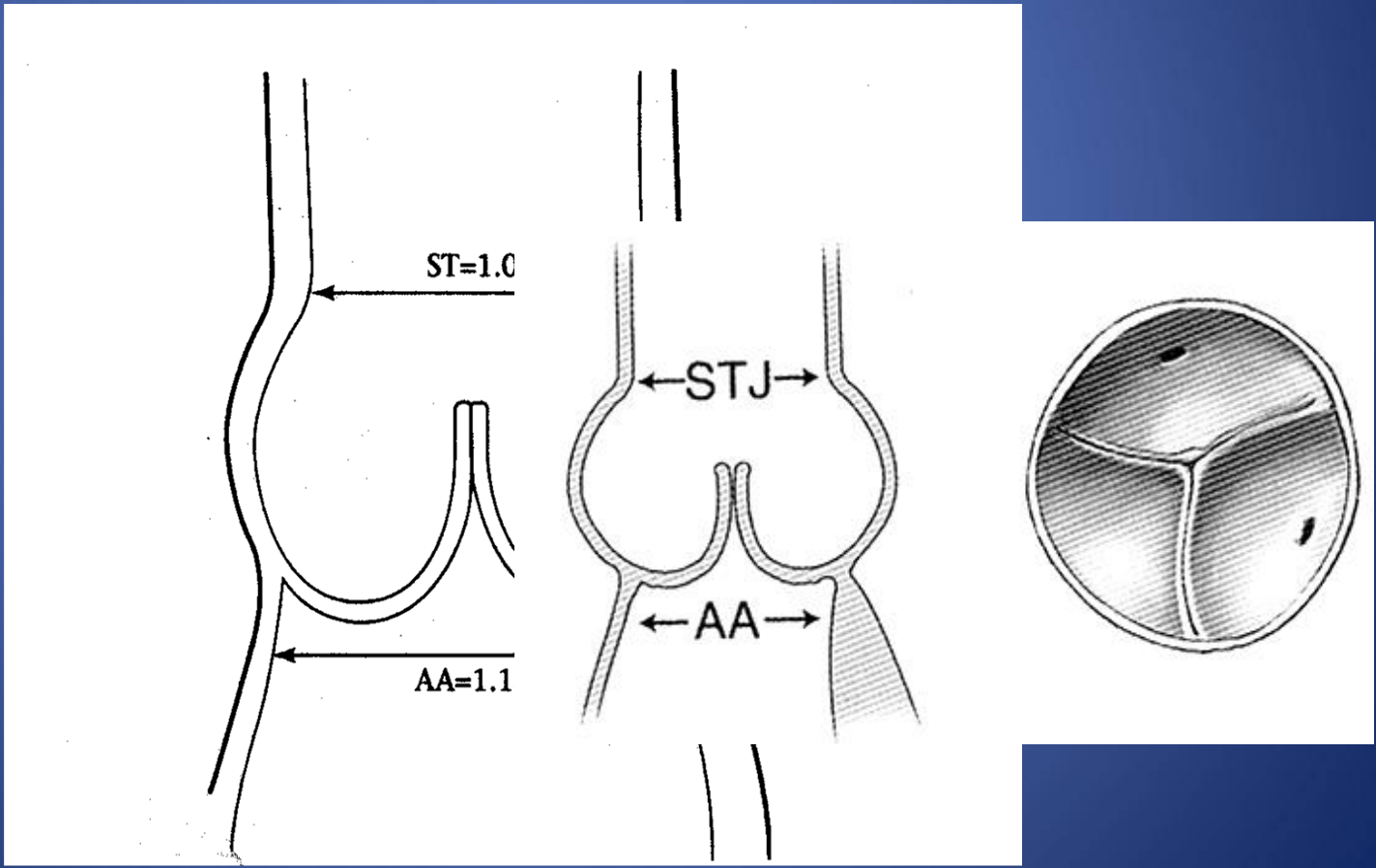
Aortic Cusps

- Consist of collagen, elastin, glycosaminoglycans
- Semilunar shape - base 1.5 x free margin
- Cusps meet at commisures - immediately below sinotubular junction
- Non-coronary cusp tends to be slightly larger



Geometric Relationships of the Aortic Root

Kunzelman et. al. 1994

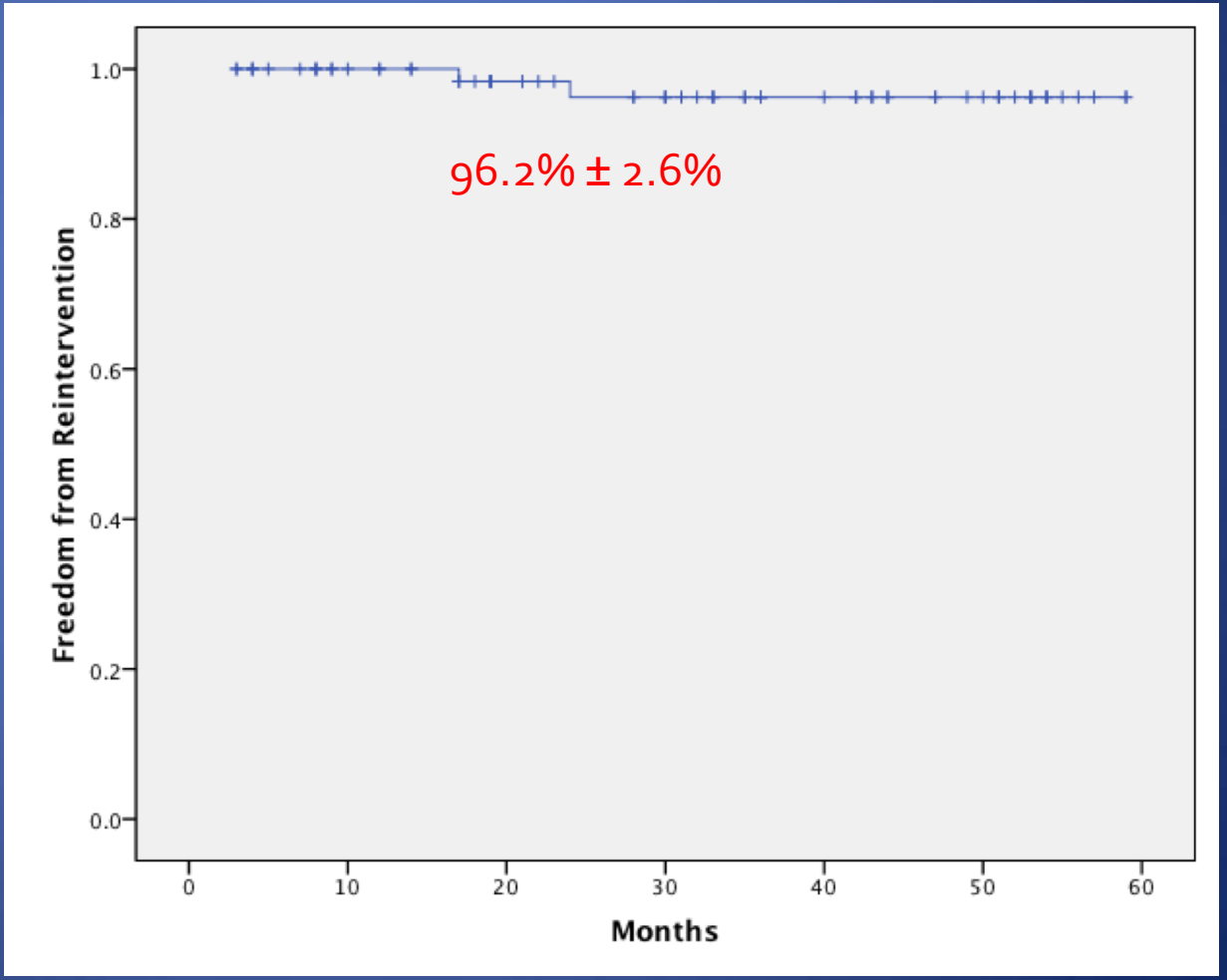


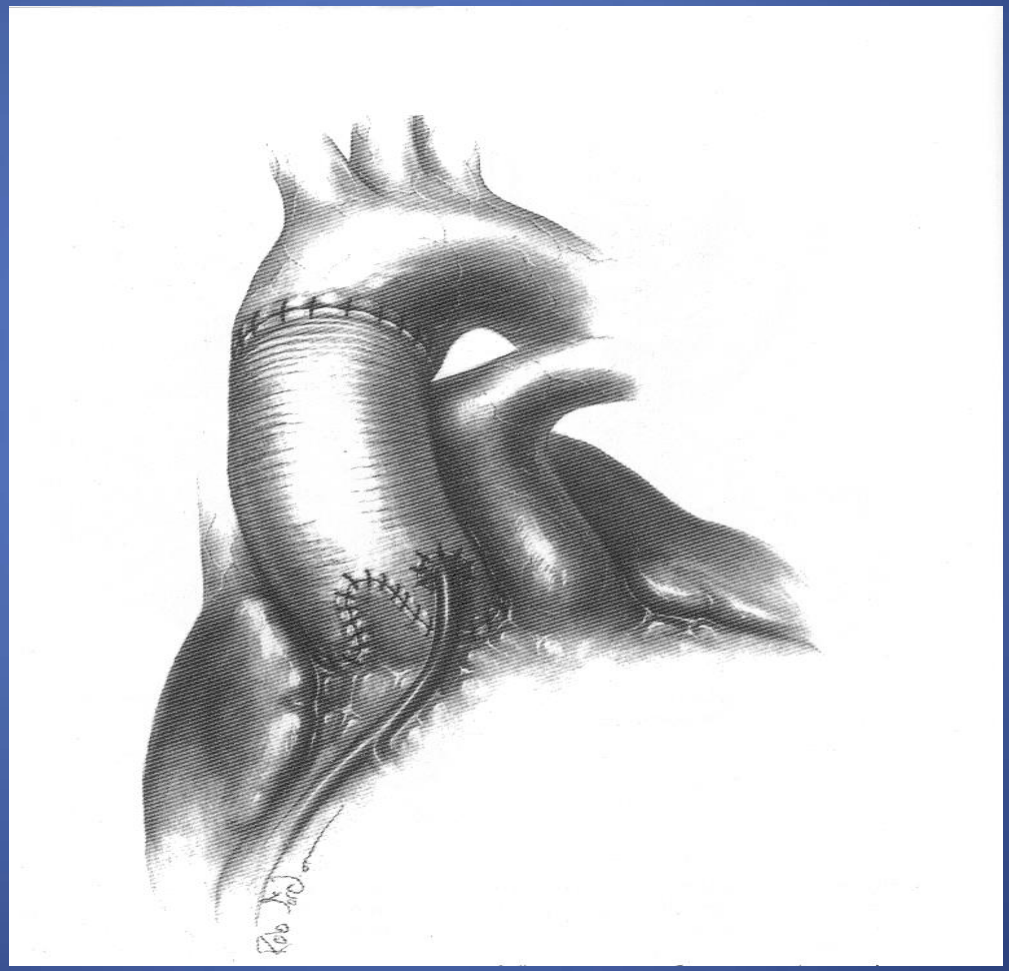
Patients and methods

- From January 1996 to November 2008
- 305 patients underwent aortic valve preservation surgery (include dissections)
- 100 elective pts with AI greater than 2+ were included

Freedom from re-operation after 5 years

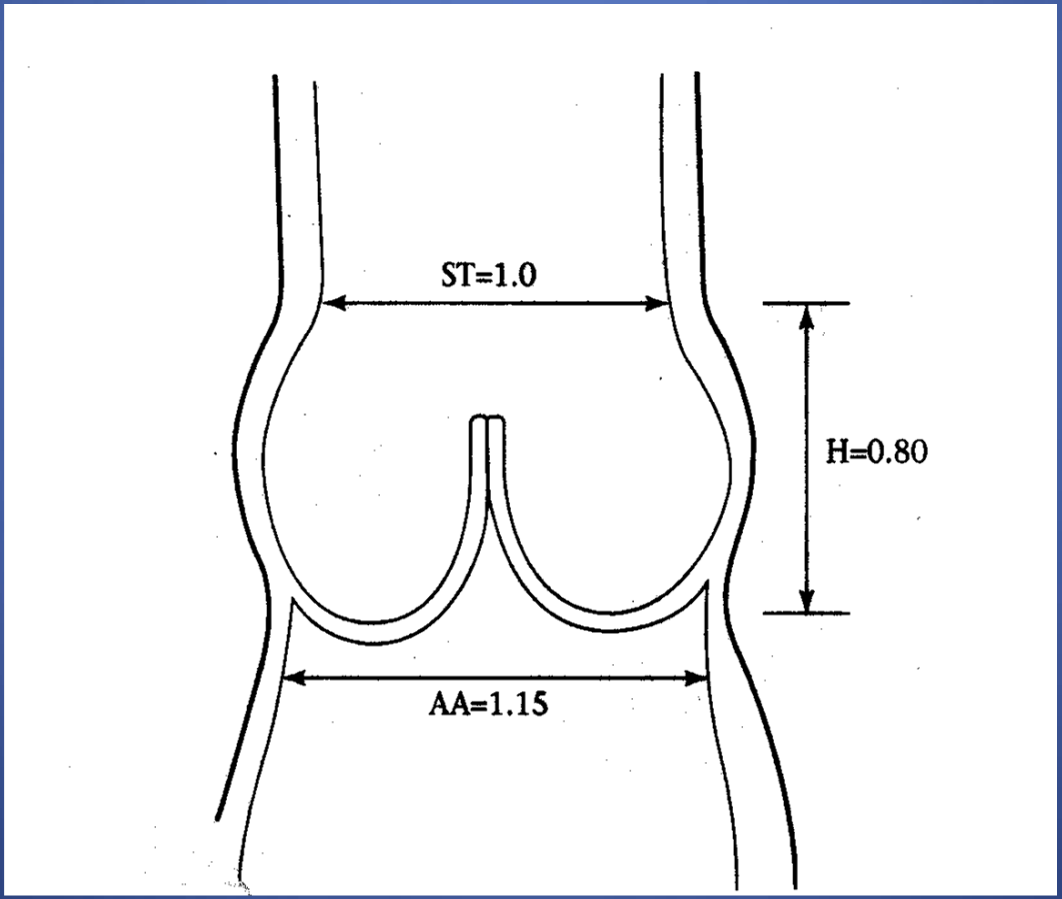
Three patients needed re-operation because of severe AI.(Two of them underwent the remodeling technique)



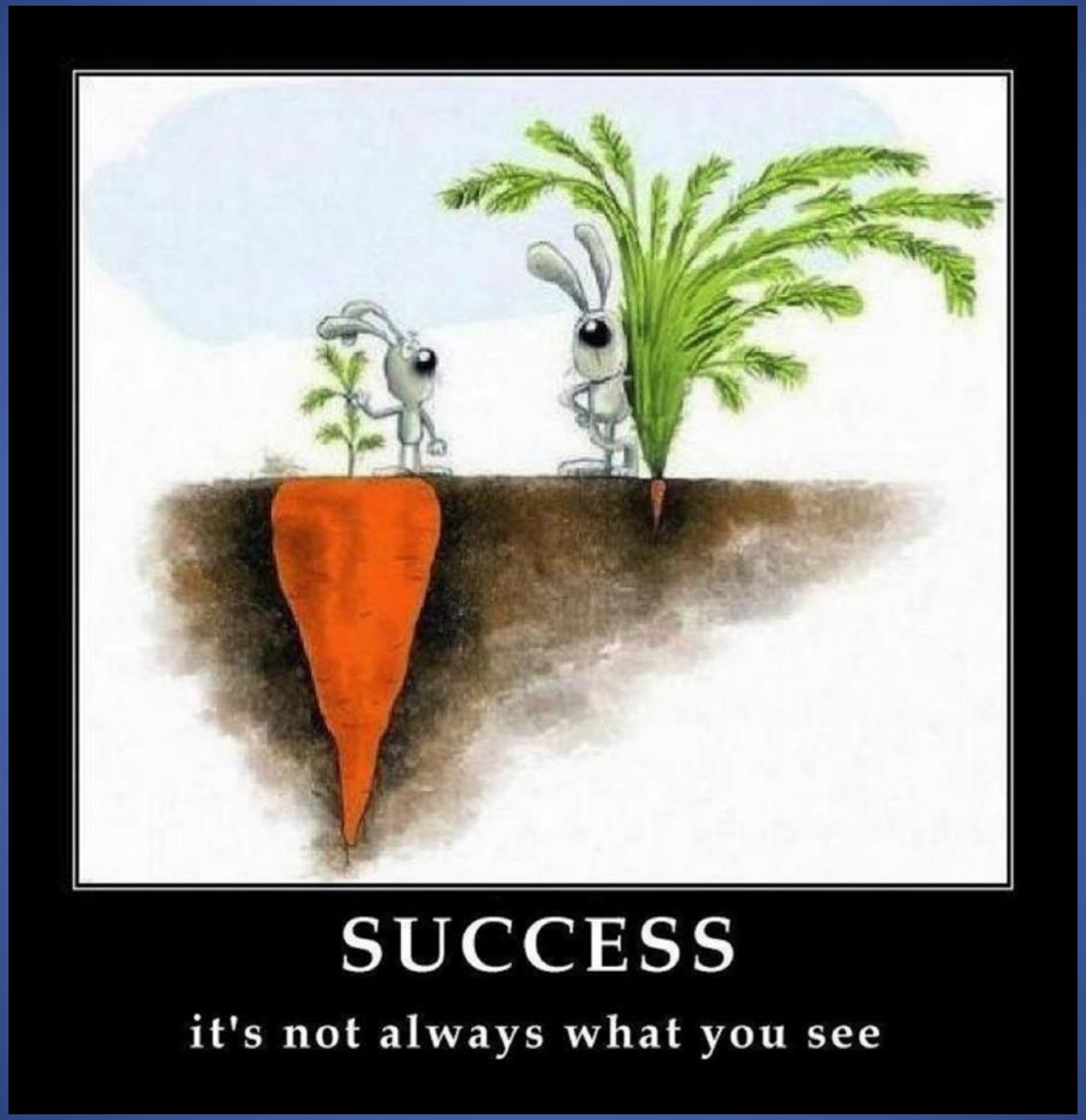


Geometric Relationships of the Aortic Root

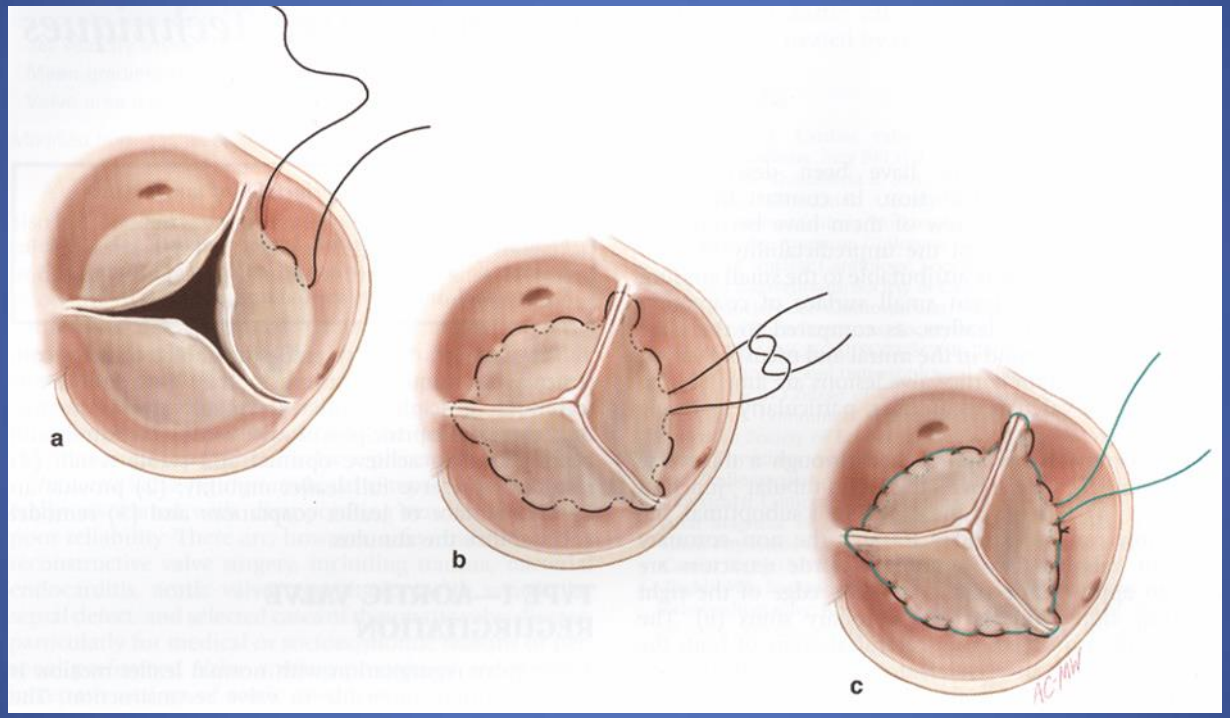
Kunzelman et. al. 1994



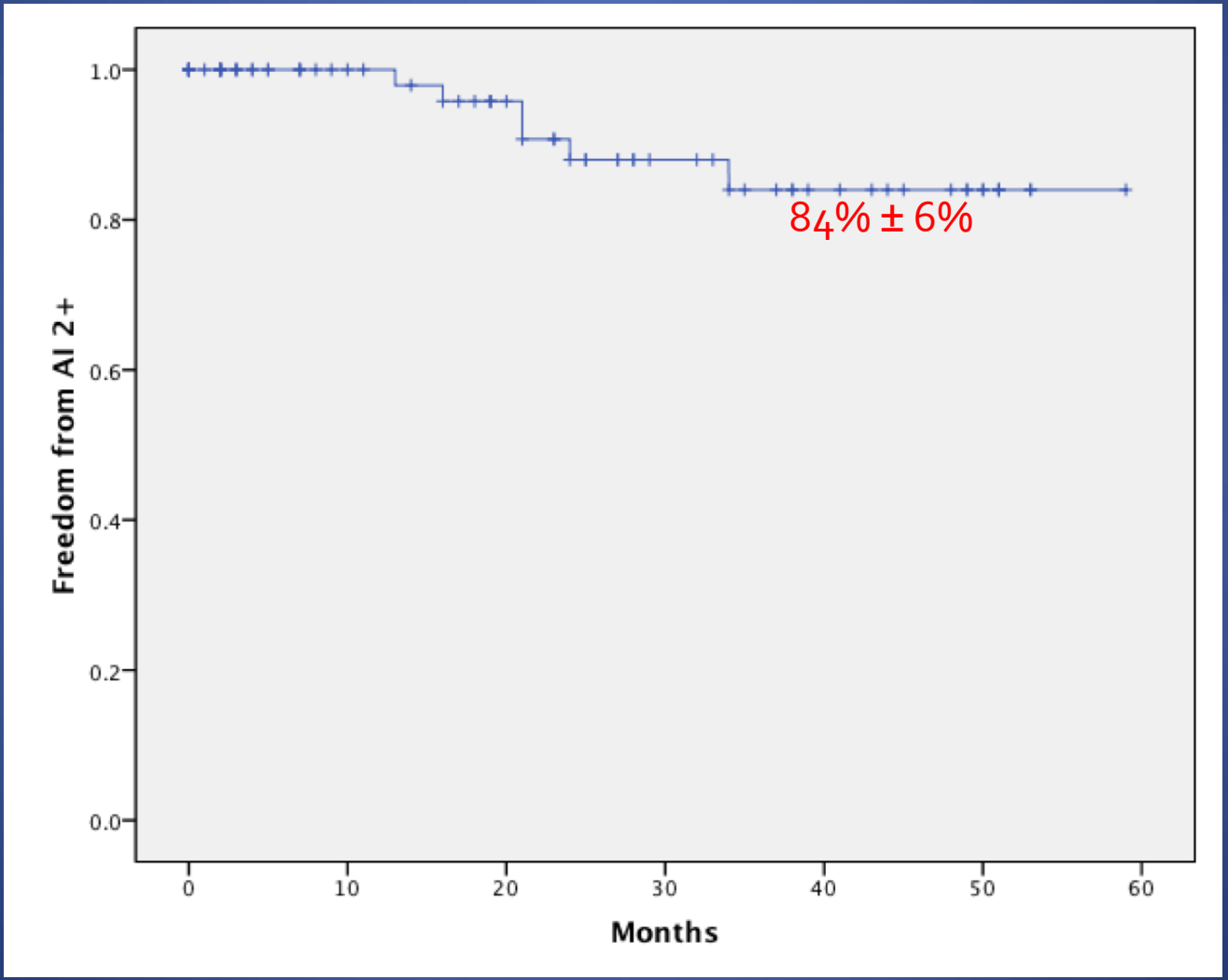
Selection of Pts for Aortic Valve Preserving


SUCCESS
it's not always what you see

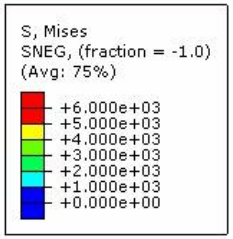
Aortic Annuloplasty

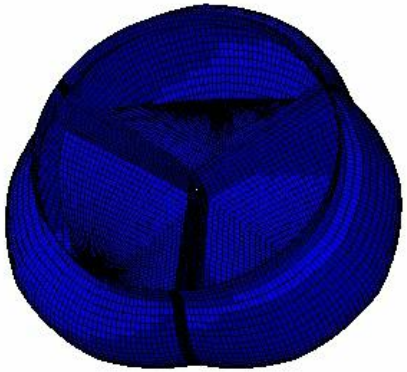


Freedom from AI 2+ after 5 years



Computer Finite Element Model, FSI





Parametric Aortic Valve Study: Effect of Annulus Diameter on Coaptation Height

Rami Haj-Ali, Ehud Raanani, Hans-Joachim Schafers
Tel-Aviv, University, Israel
Sheba Medical Center and Tel-Aviv University, Israel
University Hospitals Homburg, Homburg/Saar, Germany

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A general three-dimensional parametric geometry of the native aortic valve and root for biomechanical modeling

Rami Haj-Ali [a,b,*,1], Gil Marom [a,1], Sagit Ben Zekry [c], Moshe Rosenfeld [a], Ehud Raanani [d]

[a] School of Mechanical Engineering, Faculty of Engineering, Tel Aviv University, Tel Aviv, Israel
[b] College of Engineering, Georgia Institute of Technology, Atlanta, GA, USA

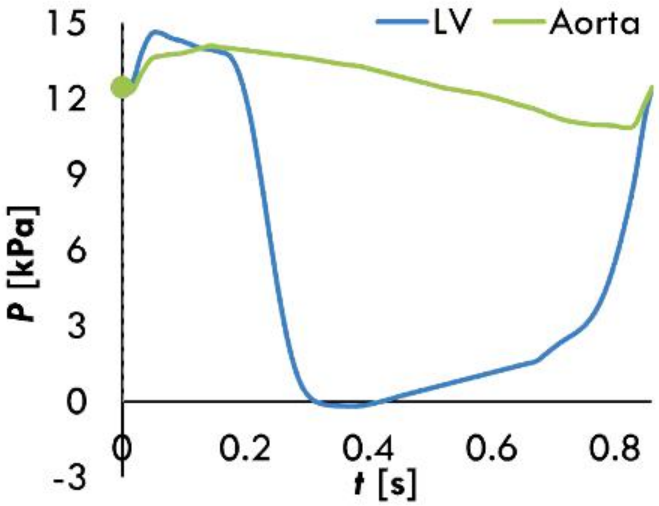
Med Biol Eng Comput (2012) 50:173–182
DOI 10.1007/s11517-011-0849-5

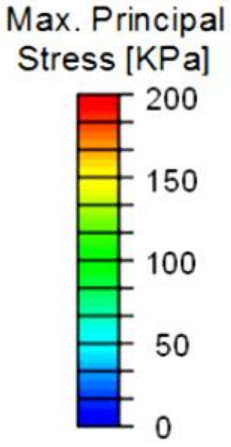
ORIGINAL ARTICLE

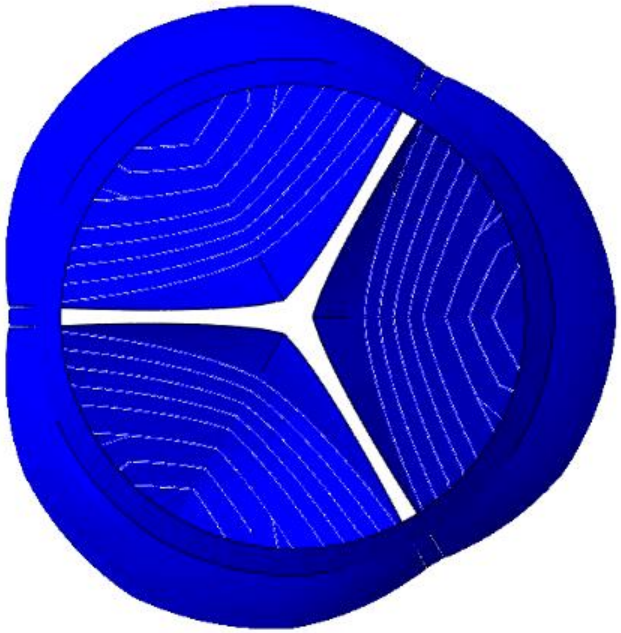
A fluid–structure interaction model of the aortic valve with coaptation and compliant aortic root

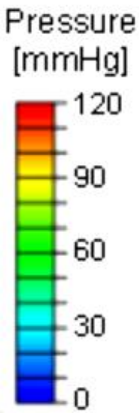
Gil Marom · Rami Haj-Ali · Ehud Raanani · Hans-Joachim Schäfers · Moshe Rosenfeld

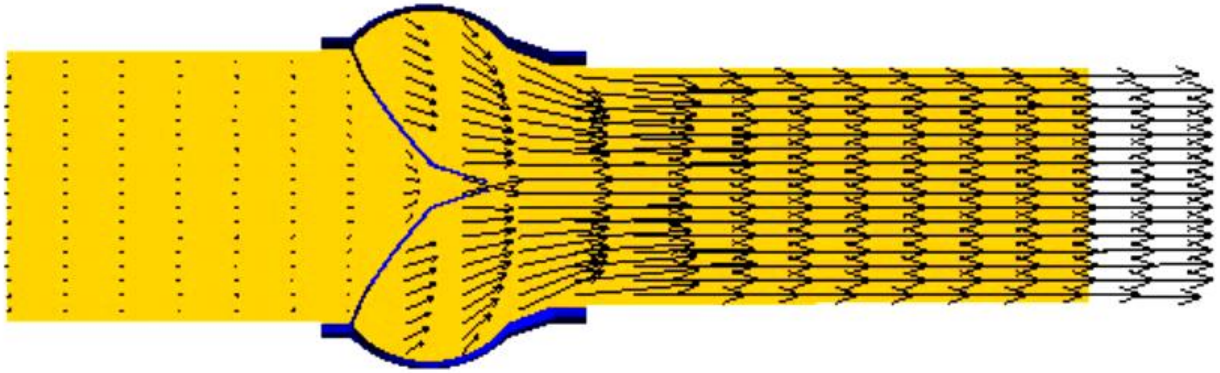
Non Pathological FSI Model







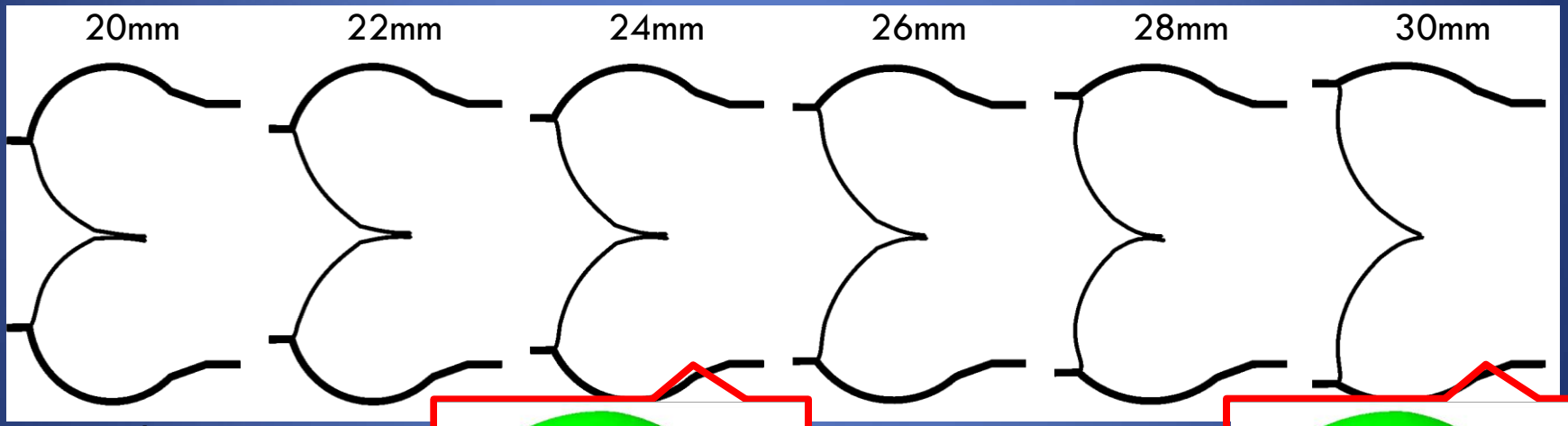




Effect of annulus diameter

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

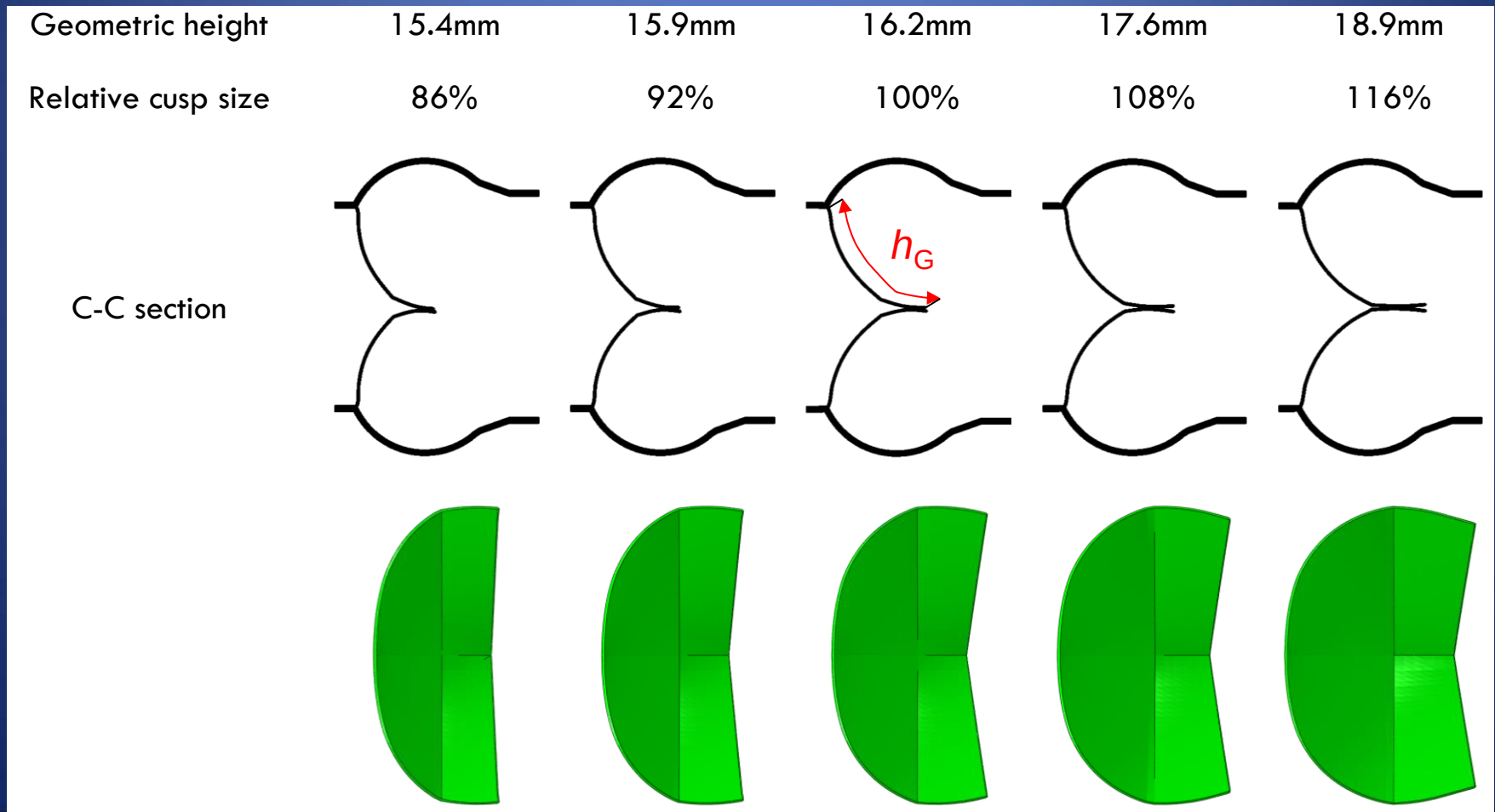
Gil Marom, MSc,[a] Rami Haj-Ali, PhD,[a] Moshe Rosenfeld, DSc,[a] Hans Joachim Schäfers, MD,[b] and Ehud Raanani, MD[c]



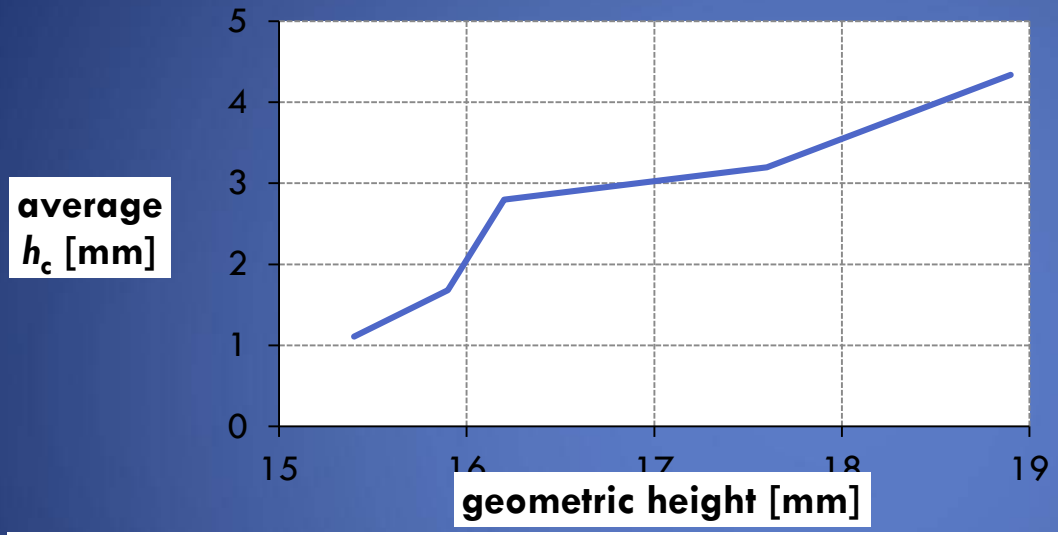
C-C section

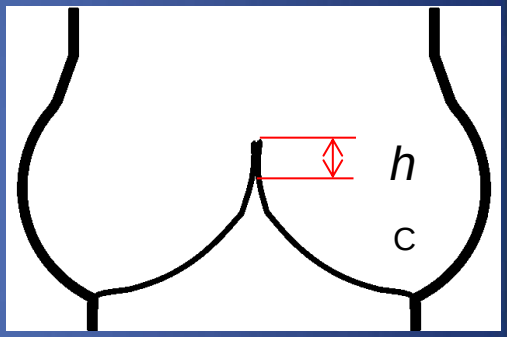
Effect of cusp size

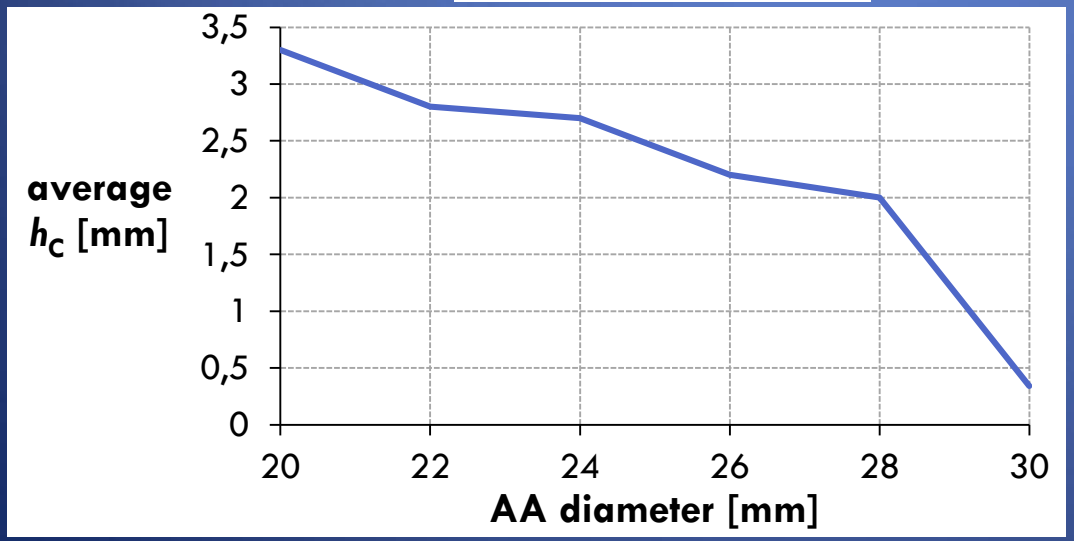
- Five cases with different cusp size
  - The root dimensions are identical to the 24mm case

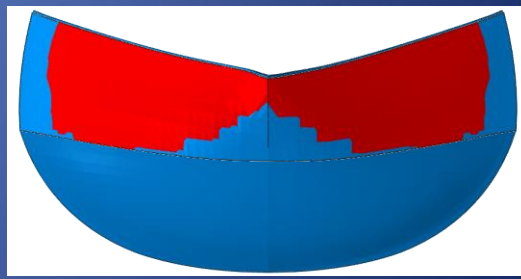


Influence of the geometry on coaptation



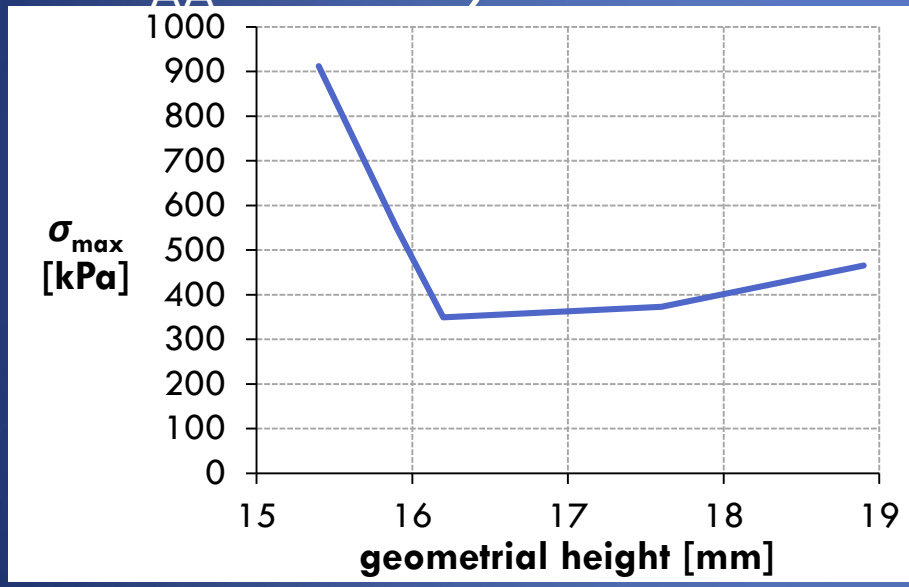


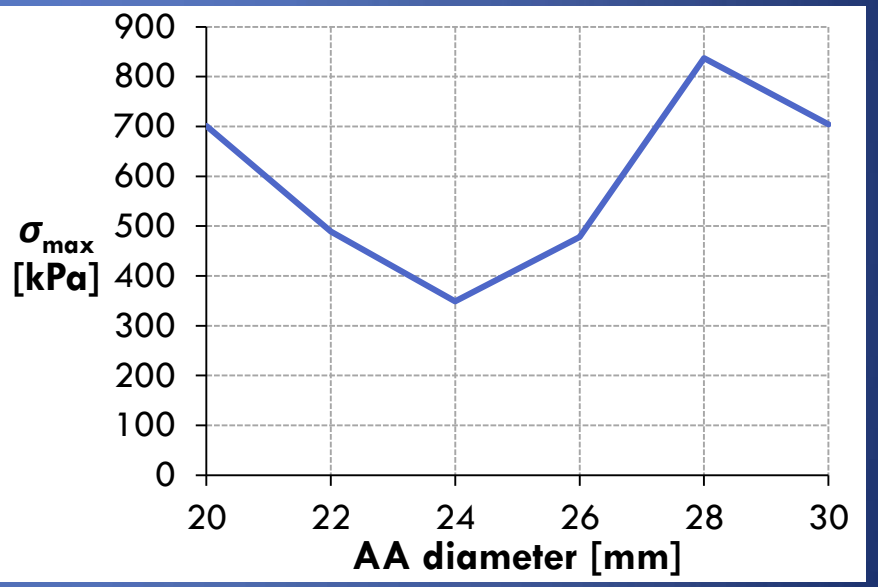


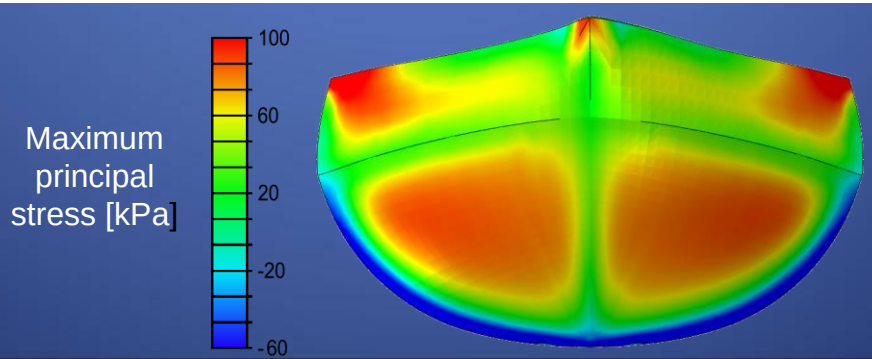


Influence of the geometry on the max. principal stress

- The average dimensions case (gh=16.2mm, d_{AA}=24mm) has the lowest mechanical stress



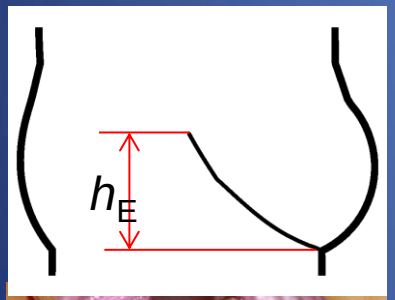


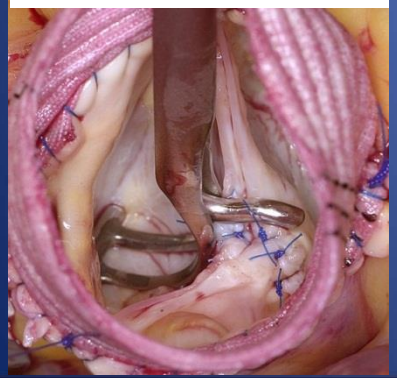


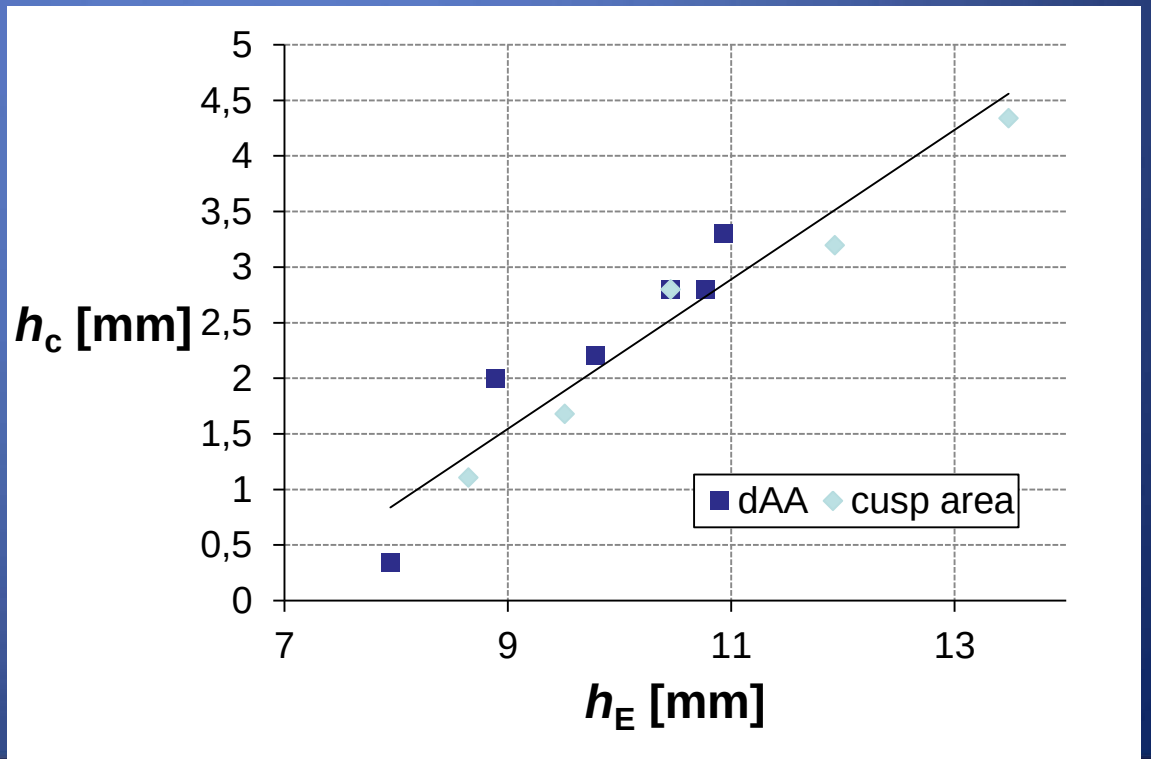
Aortic root numeric model: Correlation between intraoperative effective height and diastolic coaptation

Gil Marom, MSc,[a] Rami Haj-Ali, PhD,[a] Moshe Rosenfeld, DSc,[a] Hans Joachim Schäfers, MD,[b] and Ehud Raanani, MD,[c] Tel Aviv and Tel Hashomer, Israel; and Homburg, Germany

- The effective height correlates well with valve coaptation
- The cusp in all the cases with h_E<9mm prolapsed during diastole



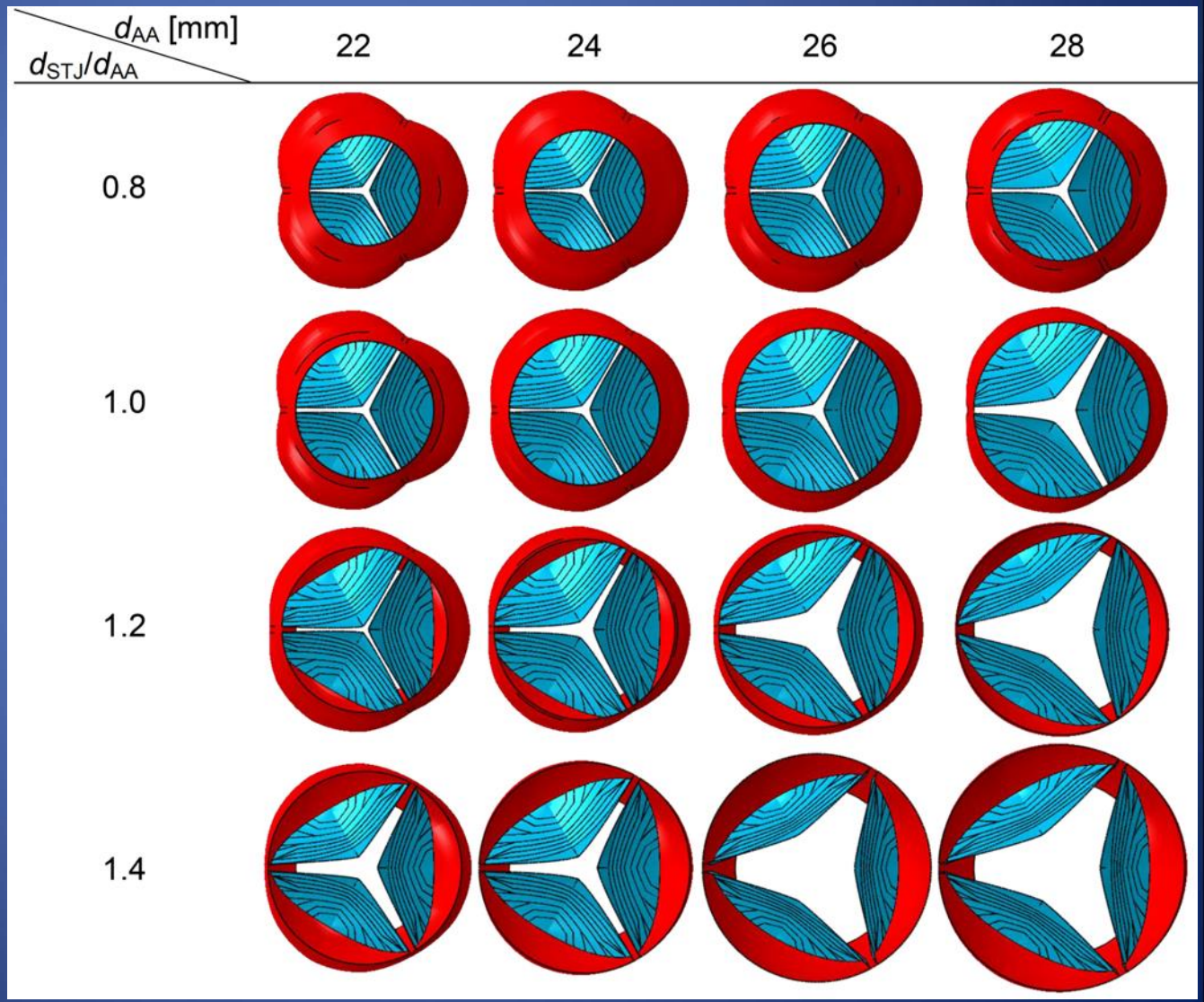




Numerical model of the aortic root and valve: Optimization of graft size and sinotubular junction to annulus ratio

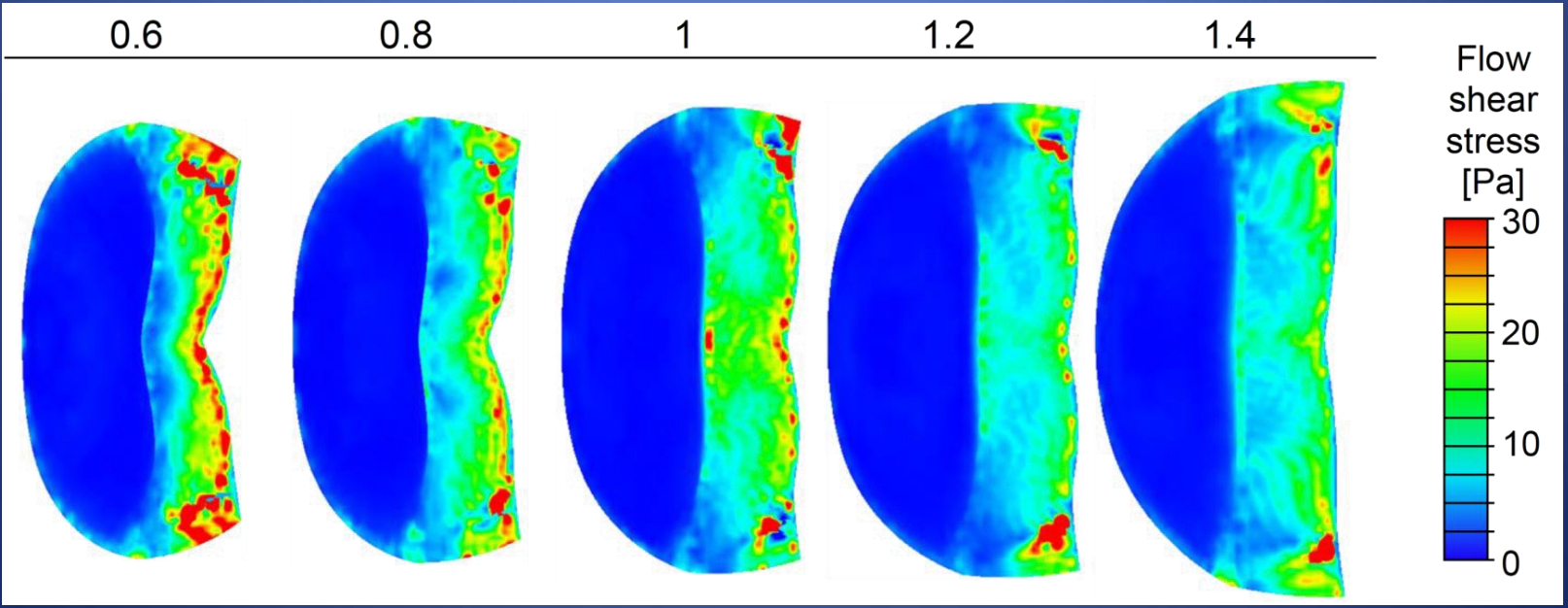
Gil Marom, MSc,[a] Rotem Halevi, MSc,[a] Rami Haj-Ali, PhD,[a] Moshe Rosenfeld, DSc,[a] Hans-Joachim Schäfers, MD,[b] and Ehud Raanani, MD[c]

- Sixteen cases of aortic roots
- Were calculated from the base geometry with an applied outer pressure that expanded or shrank the initial AA and STJ



Influence of d_{STJ}/d_{AA} on flow shear stress

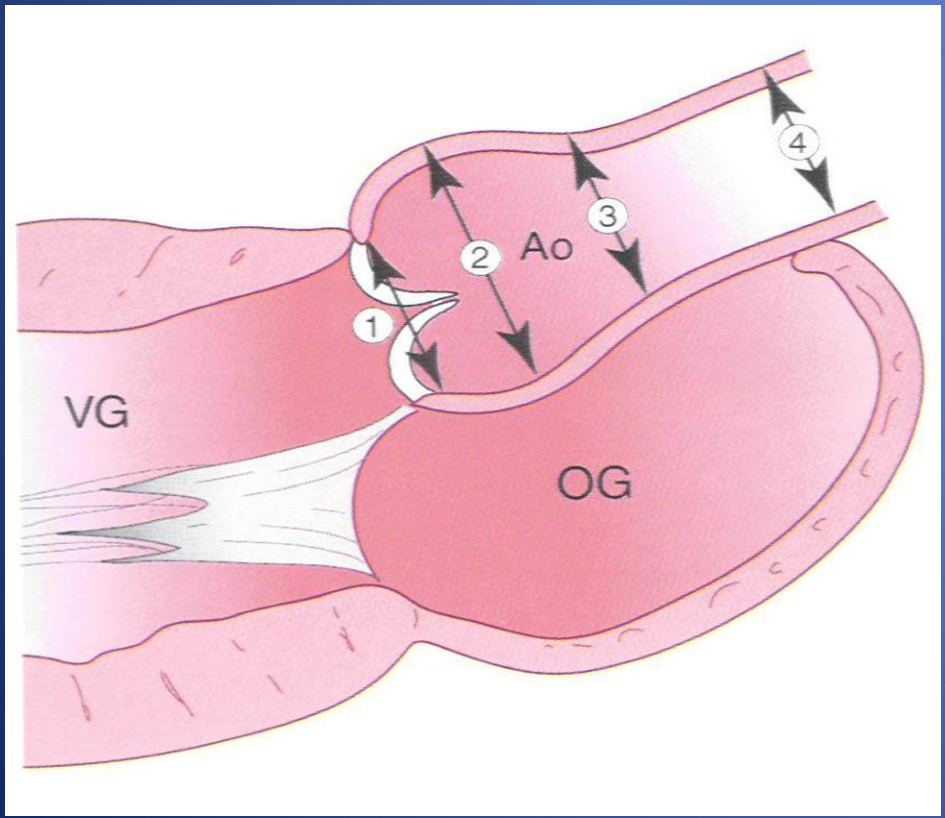
- FSI parametric study with five cases of aortic roots
- Reducing dSTJ/dAA increases the shear stress values
- To prevent AA expansion - valve-sparing with annuloplasty is preferable

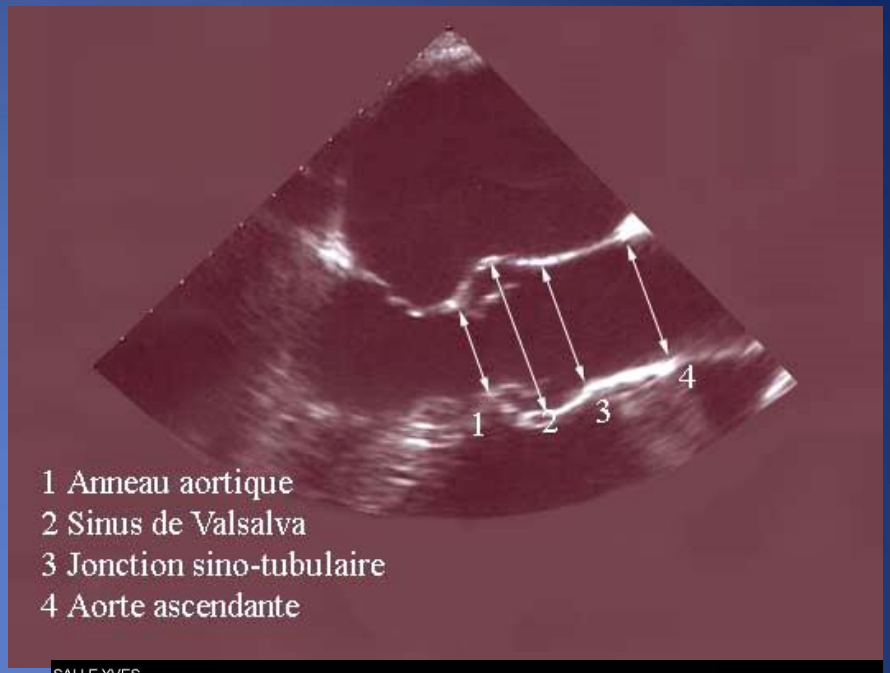


Acknowledgments

- Gil Marom,Phd
  - Prof. Ehud Raanani
  - Prof. Moshe Rosenfeld
  - Prof. Rami Haj-Ali
- Collaborators:
  - Prof. Hans-Joachim Schäfers
  - Dr. Sagit Ben Zekry (Echo)
  - Prof. Hee-Sun Kim
  - Dr. Ashraf Hamdan (Cardiac CT)
- Mechanics of composite materials lab members:
  - Rotem Halevi
  - Mor Peleg

Near Future:

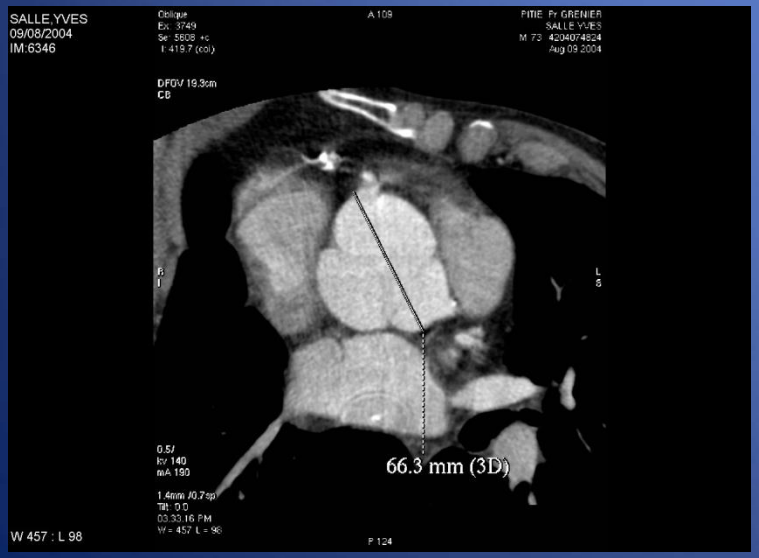

VG
OG
Ao
1
2
3
4

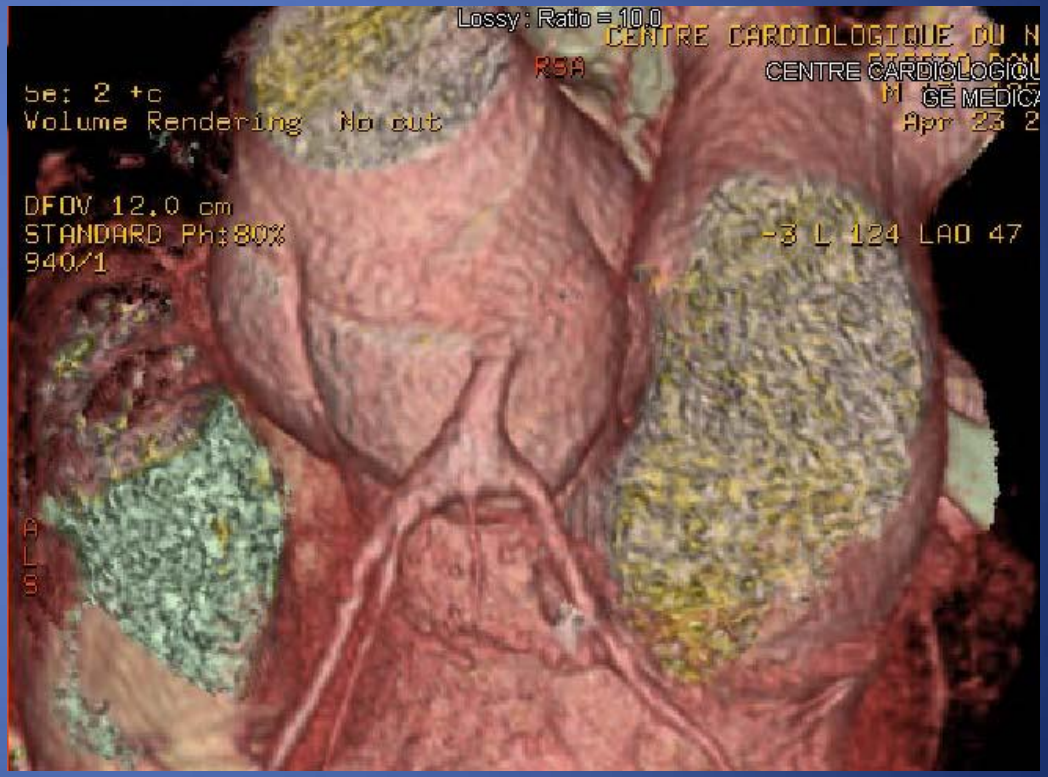

1
2
3
4
1 Anneau aortique
2 Sinus de Valsalva
3 Jonction sino-tubulaire
4 Aorte ascendante


SALLE,YVES
09/08/2004
IM:6335
W 539 : L 177

CT Scan


SALLE.YVES
09/08/2004
IM:6335
W 539 : L 177


SALLE.YVES
09/08/2004
IM:6346
Oblique
A 109
PITIE Pr GRENIER
SALLE.YVES
Aug 09 2004
DFOV 19.3cm
CB
66.3 mm (3D)
W 457 : L 98


Lossy : Ratio = 10.0
CENTRE CARDIOLOGIQUE DU N
RSA
Se: 2 +c
Volume Rendering No cut
DFOV 12.0 cm
STANDARD Ph:80%
940/1
-3 L 124 LAO 47
Apr 23 2

Summary

- The aortic root structure is complex
- Pathology is diverse and mixed in many cases
- In many cases, in order to preserve the AV, multiple surgical techniques have to be used
- Pre-operative computer analysis and planning may improve durability of valve

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

Gil Marom, MSc,[a] Rami Haj-Ali, PhD,[a] Moshe Rosenfeld, DSc,[a] Hans Joachim Schäfers, MD,[b] and Ehud Raanani, MD[c]

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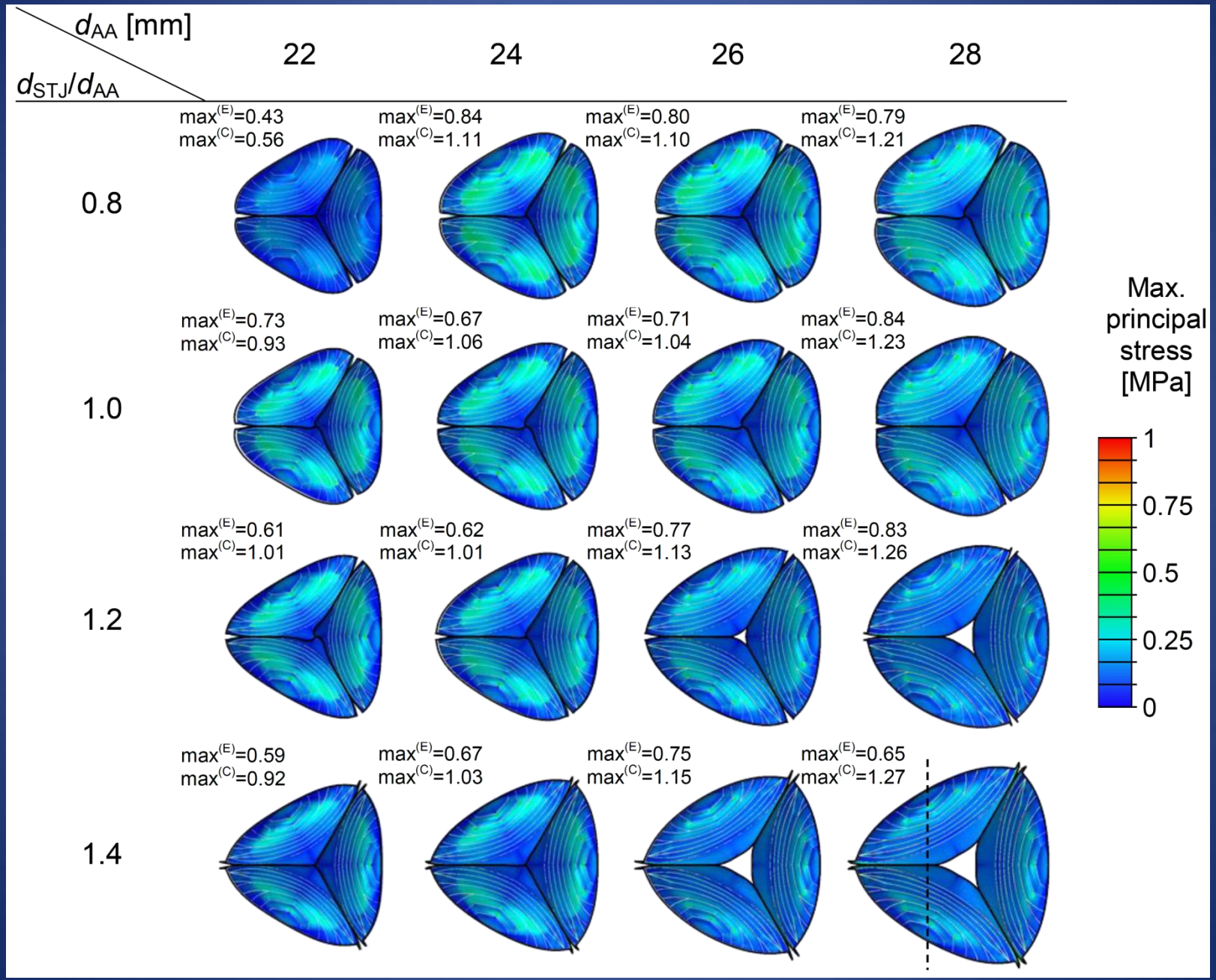
Stress distribution during diastole



THE INFLUENCE OF GRAFT SIZE AND STJ TO AA RATIO

- CFN model and hyperelastic material in the sinuses
- Time dependent and physiological BC

Remarks

- Lower aortic annulus (AA) diameter increases coaptation area
  - Small difference (3.5%) between 22mm and 24mm cases
- The 24mm case has the highest durability
- The coaptation increases with the size of the cusp
- The case with average dimensions has the best combination of coaptation and low mechanical stress

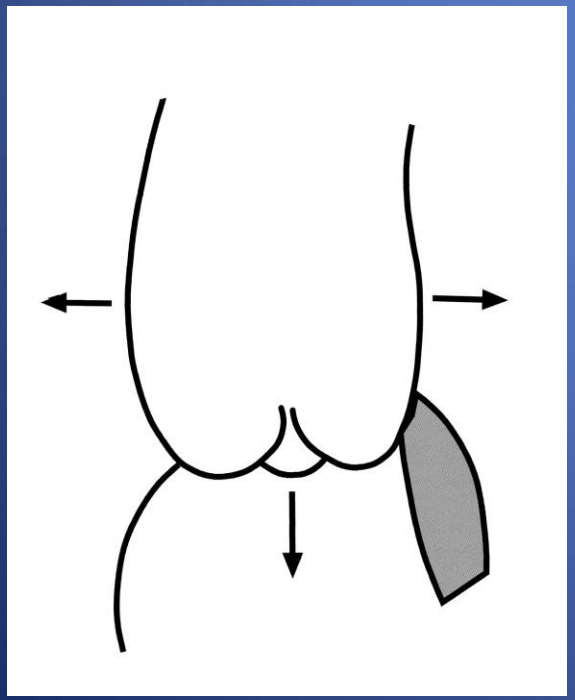
INFLUENCE OF CUSP SIZE AND AORTIC ANNULUS DIAMETER

- Simplified linear elastic and isotropic model
- Solution duration of 10ms - constant BC

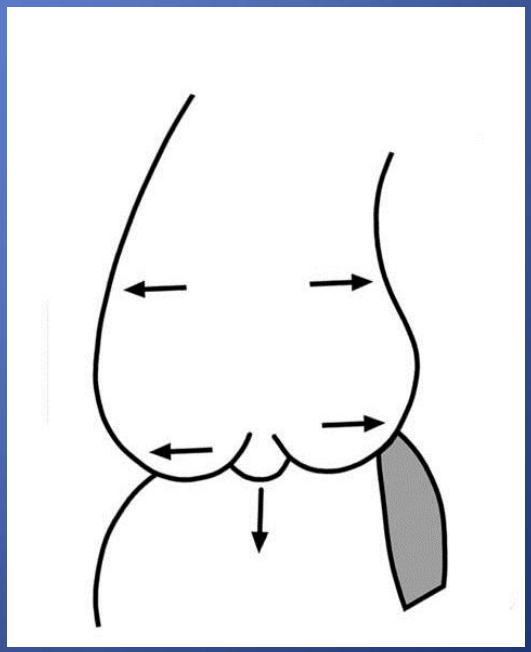
Marom, Raanani et al. (2012) *J. Thorac. Cardiovasc. Surg.* doi: 10.1016/j.jtcvs.2012.01.080
Marom Raanani et al. (2012) *J. Thorac. Cardiovasc. Surg.* doi: 10.1016/j.jtcvs.2012.08.043

Dysfunction of Aortic Root

Sinu-tubular Dilatation



Sinu-tubular + Annular Dilatation



Patients with AI 2+ and above (n=100)

- Mean age – 60 ± 17 years (range 21-81 years)
- 69% – males
- 73 elective pts and 27 emergent
- NYHA class
  - I – 67%
  - II – 14%
  - III – 4%
  - IV – 5%
- Mean EF% - 55.5 % ± 7.8%
- Rre-do – 15 pts
- Mean logistic EuroSCORE – 11.2% ± 12%

Dimensions

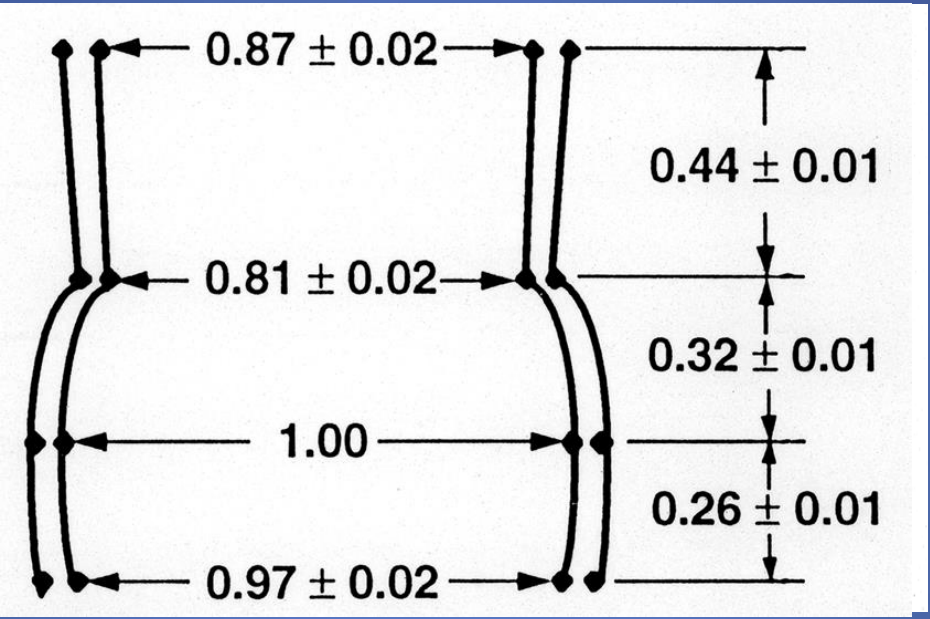
Aortic root and valve relationships

Impact on surgical repair

A surgical procedure has recently been described for patients with aortic incompetence caused by annular dilation, but with normal aortic leaflets. The dilated aortic root is replaced with a Dacron graft, and the native aortic valve is resuspended within the graft. Matching the size and shape of the graft to the size of the leaflets may have significant effects on valve closure and leaflet stress and thus on the longevity of the repair. To define the relationship of native aortic root structure to leaflet size, we morphologically examined normal human aortic roots ($n = 10$) and valve leaflets and applied mathematic analyses to the results. Our data show that the root has a consistent shape with varying size and that there is a definable mathematic relationship between root diameter and clinically measurable leaflet dimensions. We derived an equation that allows calculation of the appropriate diameter of the root at the sinus of Valsalva level from leaflet heights and perimeters. The diameter of the graft at the sinotubular junction and base should follow the relationship of the normalized root dimensions, either by tailoring of the graft or by new graft design. The current data imply that the graft should incorporate sinuses for proper valve closure and for sharing stress with the leaflets. Application of these results will allow prosthetic graft design to more closely resemble the native aorta. These new grafts should improve physiologic function of the valve, reduce leaflet stress, and increase the durability of the repair. (J THORAC CARDIOVASC SURG 1994;107:162-70)

Karyn S. Kunzelman, PhD, K. Jane Grande, BA, Tirone E. David, MD,* R. P. Cochran, MD, and Edward D. Verrier, MD, *Seattle, Wash.*

Dimensions

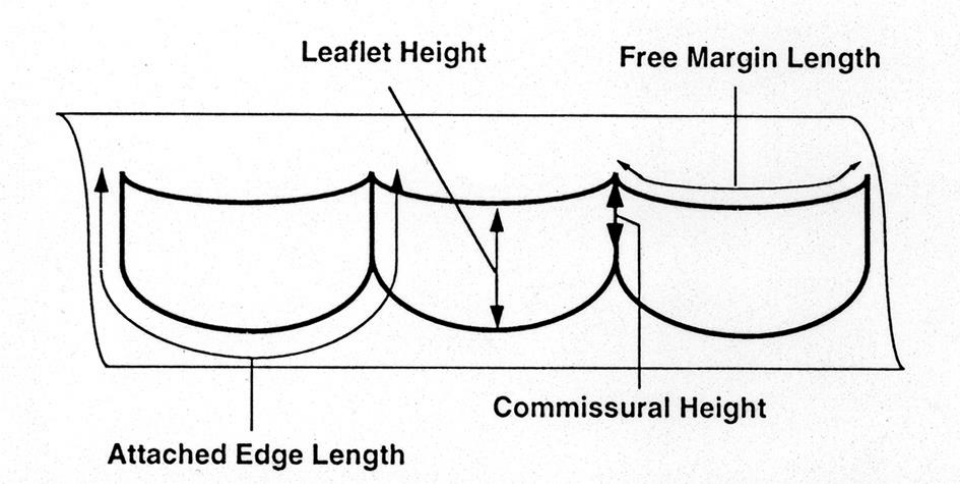


Human aortic root measurements

Level	*Orifice area (cm^2)*	*Diameter (mm)**	*Diameter (mm)†*	*Thickness (mm)*	*Interlevel distance (mm)*
STJ_1	3.40 ± 0.38	21.1 ± 1.0	20.6 ± 1.0	1.9 ± 0.2	10.0 ± 0.0
STJ_0	2.98 ± 0.32‡	18.9 ± 0.9‡	19.3 ± 0.9‡	1.8 ± 0.2	7.3 ± 0.4
SINUS	4.49 ± 0.40§	22.4 ± 1.7§	23.7 ± 1.0§	1.3 ± 0.1	62.4 ± 0.4
BASE	4.24 ± 0.44	23.4 ± 1.2	23.0 ± 1.1	0.8 ± 0.1	

Valves given as mean plus or minus standard error of the mean.

Dimensions



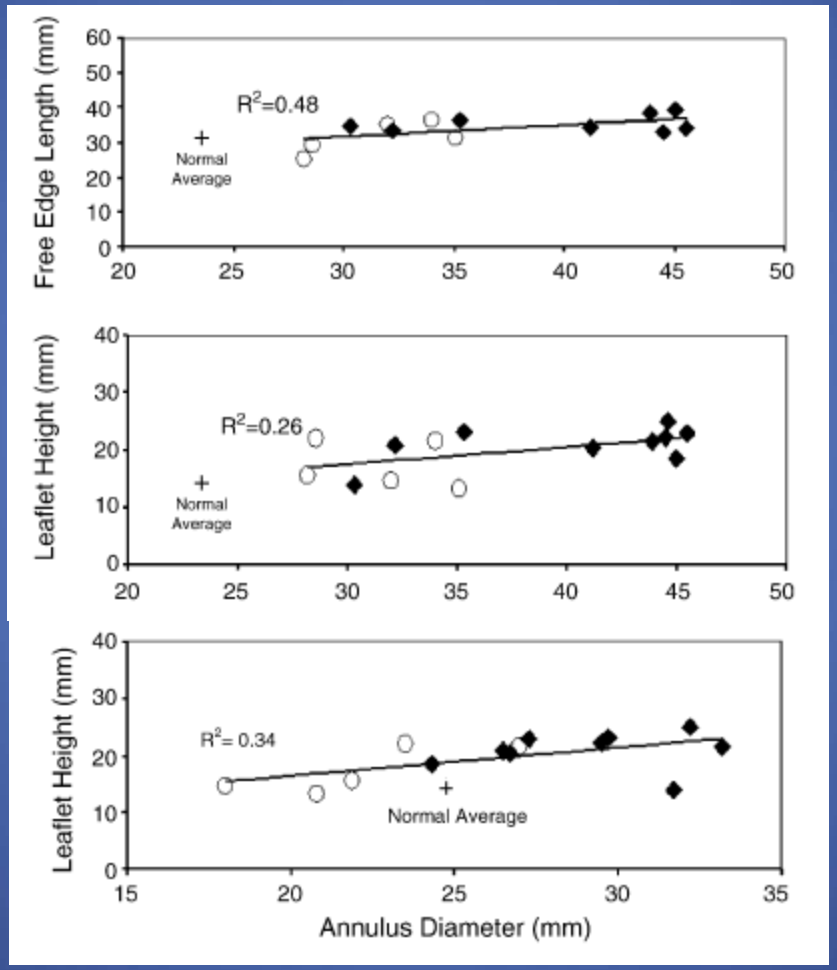
Human aortic leaflet dimensions

	Right	*Left*	*Noncoronary*	*Average*
Height (cm)	1.33 ± 0.06	1.39 ± 0.08	1.37 ± 0.04	1.36 ± 0.06
Free margin length (cm)	3.30 ± 0.14	3.15 ± 0.14*	3.27 ± 0.13	3.24 ± 0.13
Attached edge length (cm)	4.64 ± 0.20	4.76 ± 0.22	4.81 ± 0.16	4.74 ± 0.19
Perimeter (cm)	7.94 ± 0.33	7.91 ± 0.35	8.08 ± 0.28	7.98 ± 0.31
Area (cm^2)	2.97 ± 0.17	3.09 ± 0.27	3.17 ± 0.18	3.07 ± 0.21

Values given as mean plus or minus standard error of the mean.

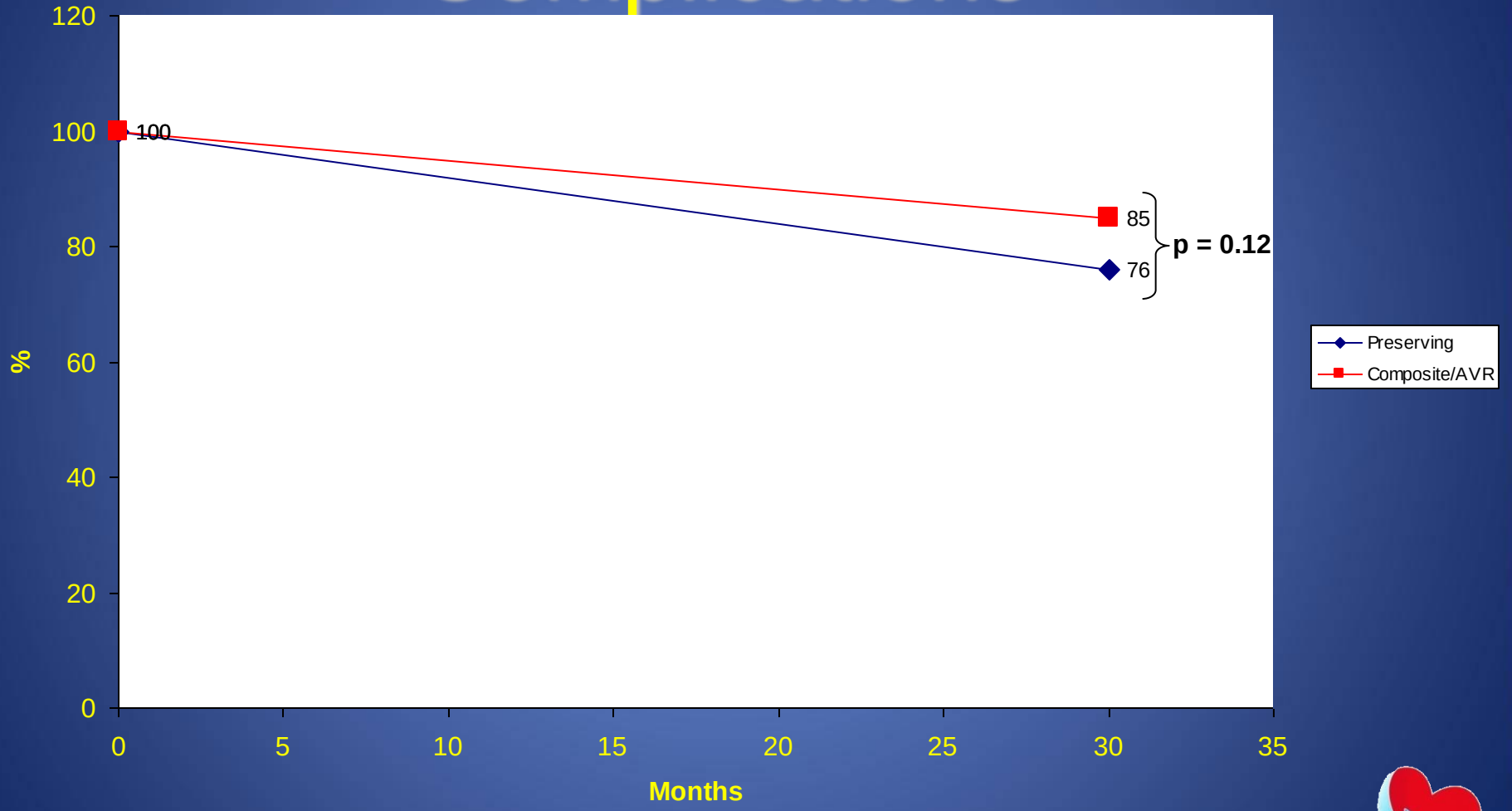
*$p < 0.05$, left < right, left < noncoronary, one-way ANOVA.

Dysfunction of Aortic Root



Thubrikar Eu JCTS 2005

Freedom from Valve Related Complications



Valve related complication – all cause death, structural valve deteriotation, thrombotic or embolic events, bleeding, reintervention, permanent pacemaker (Akins et al, JTCS, April 2008)

Re-Implantation (TE. David)