

# **Aortic Anatomy, Pathology, and Procedures**

**MSTCVS-QC Cardiac Surgery Data Managers Meeting  
Grand Rapids, MI**

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# Disclosures

- None



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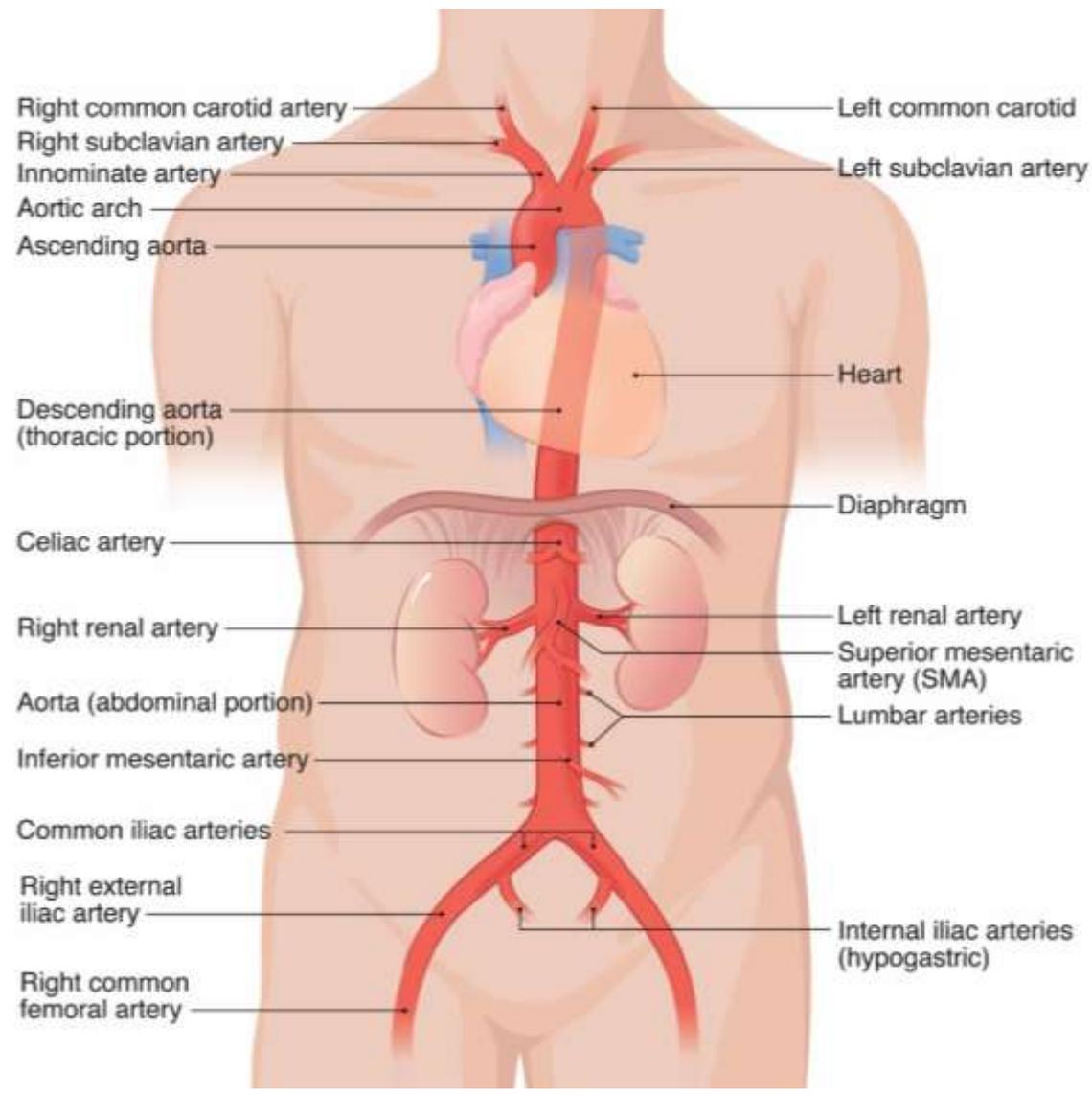
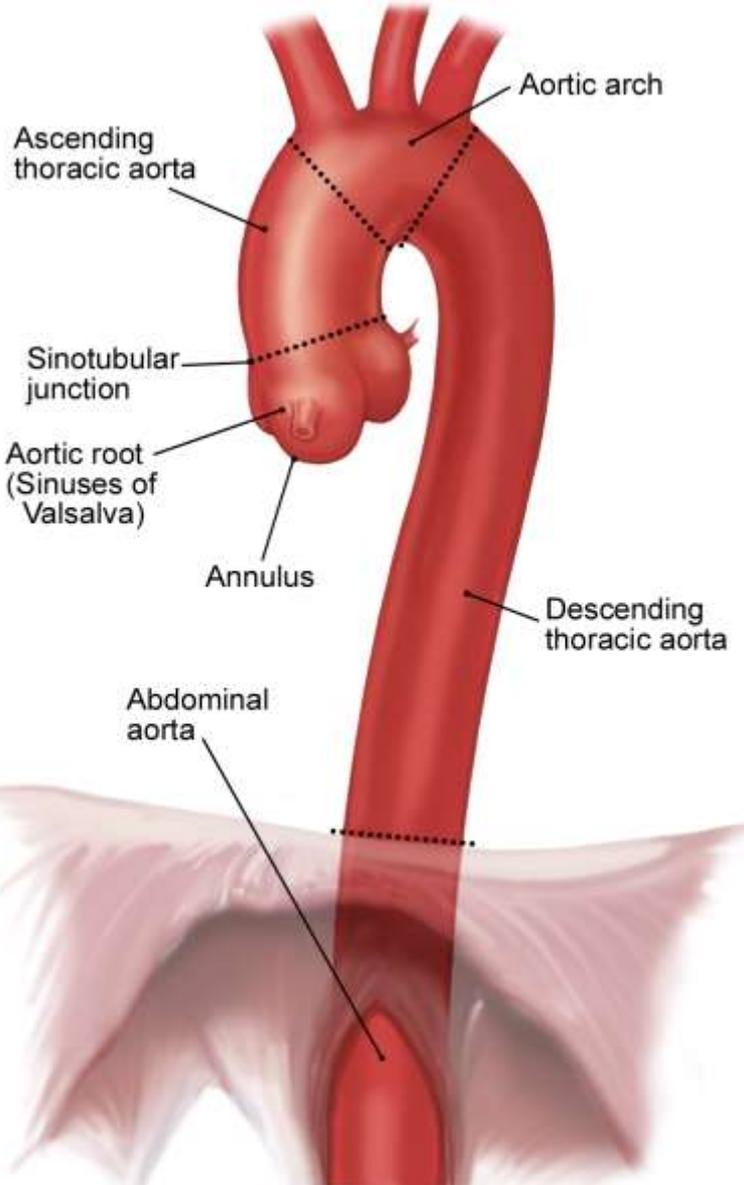


# Why do we care?

- Aortic disease happens in prime years of life
  - Gaining understanding regarding genetic factors
- Acute aortic syndromes are life-threatening
- More aortic disease is being diagnosed incidentally (CT scans)
- Surgical/endovascular therapies are improving, decreasing morbidity/mortality
- There is a lot we don't know!
  - Treatment (medical, open surgical, endovascular)
  - Outcomes
- STS Aortic Database is an important step
- YOU are important!



# Aortic Anatomy



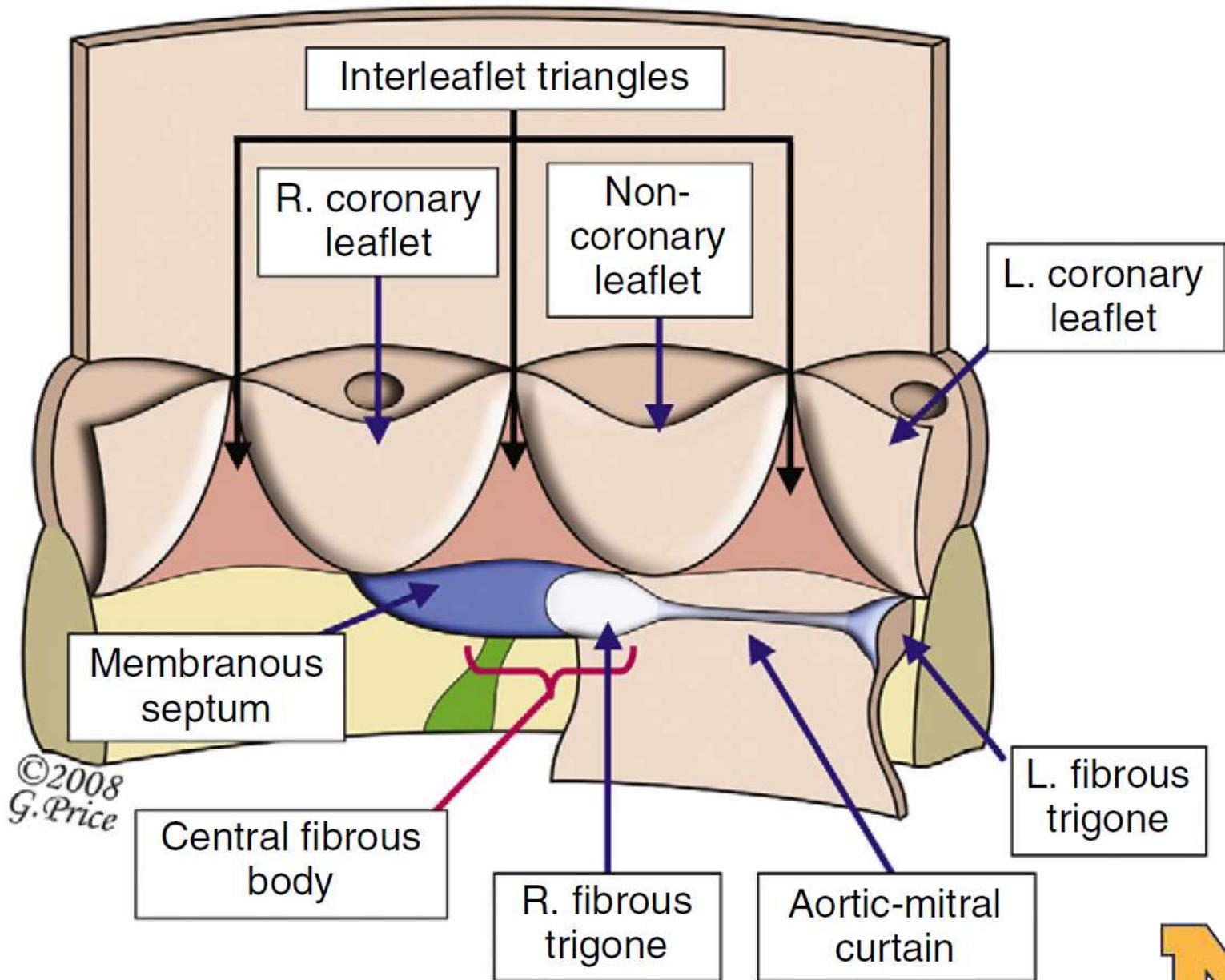
# Aortic Root

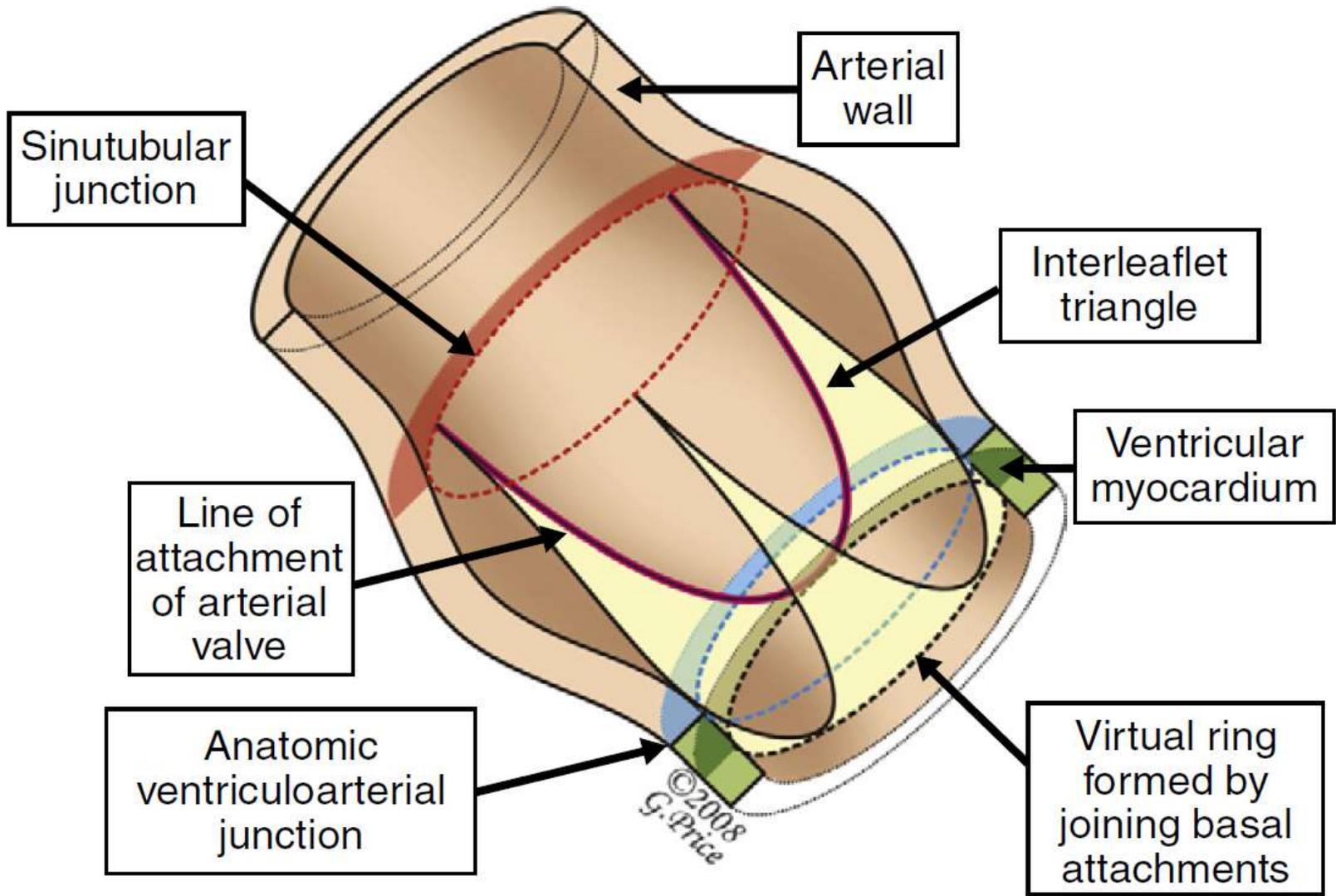


David TE. Aortic valve-sparing operations. In: Selke FW and Ruel M, eds., Atlas of Cardiac Surgical Techniques (1ed). Philadelphia: Elsevier Saunders;2010. p. 151.



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# Types of Aortic Aneurysms



normal



ascending  
aorta  
aneurysm



aortic  
arch  
aneurysm

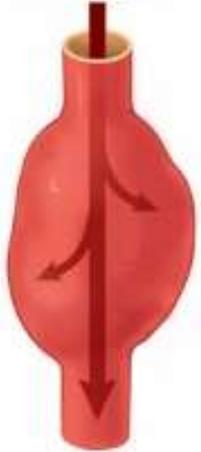


descending  
aorta  
aneurysm

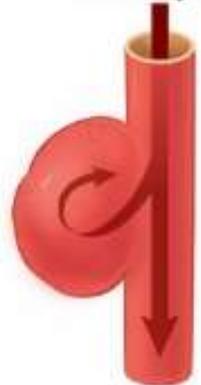


abdominal  
aorta  
aneurysm

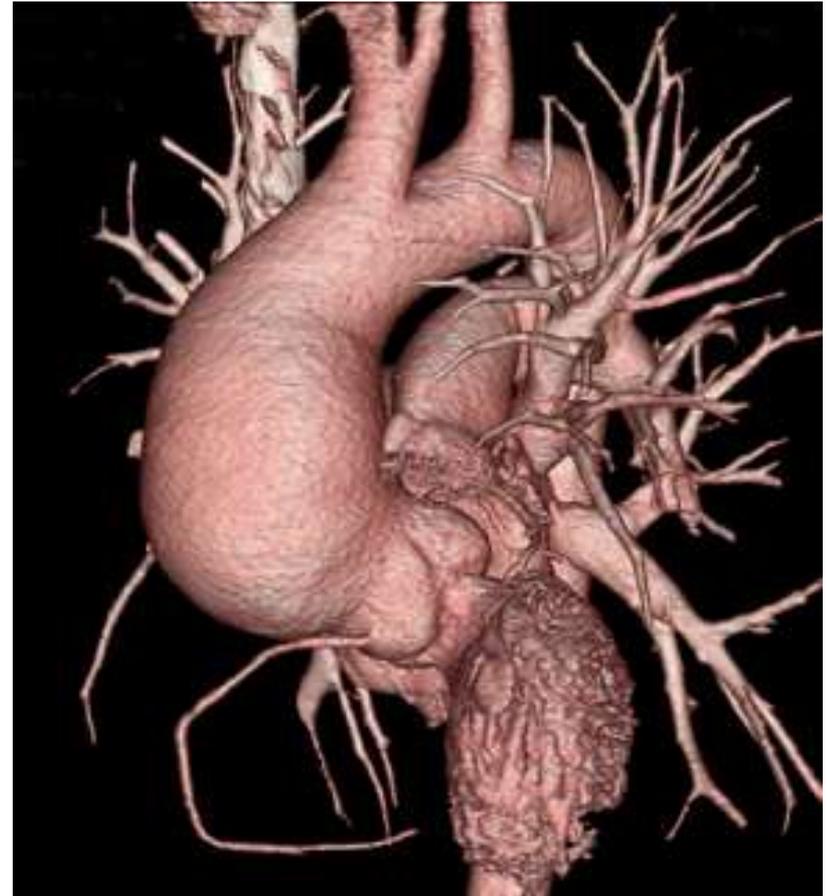
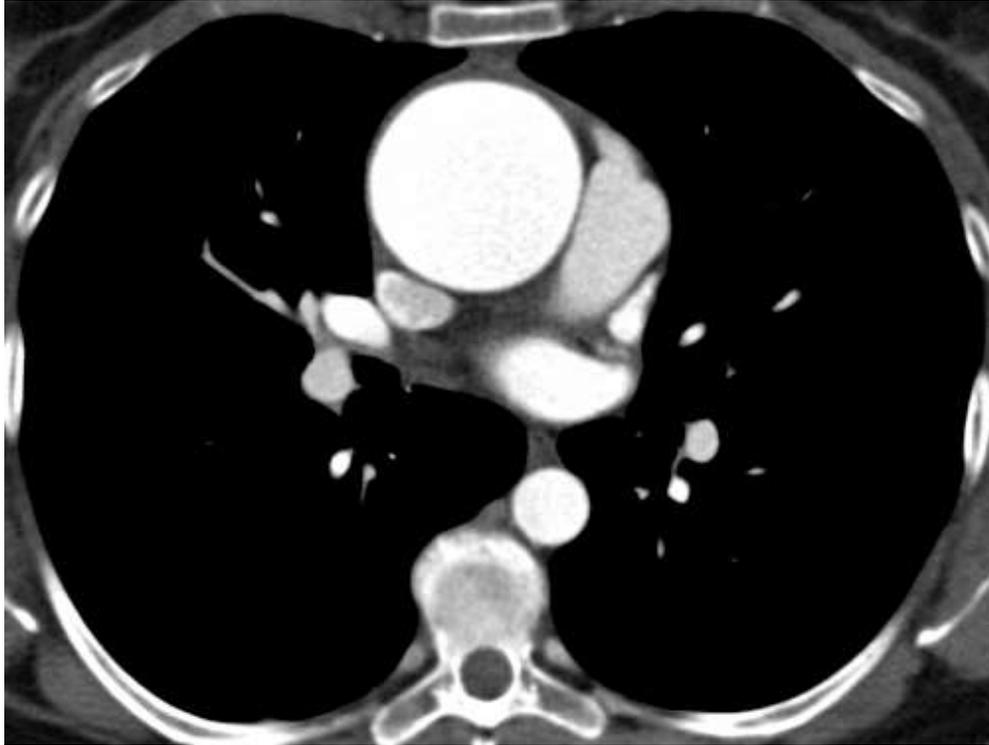
Fusiform  
Aneurysm



Saccular  
Aneurysm



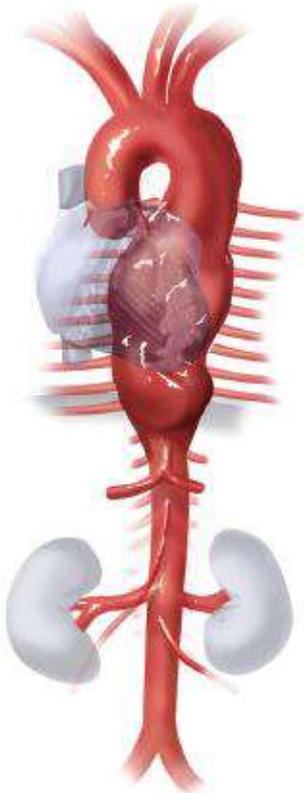
# Ascending Aortic Aneurysm



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# Thoracoabdominal Aneurysms

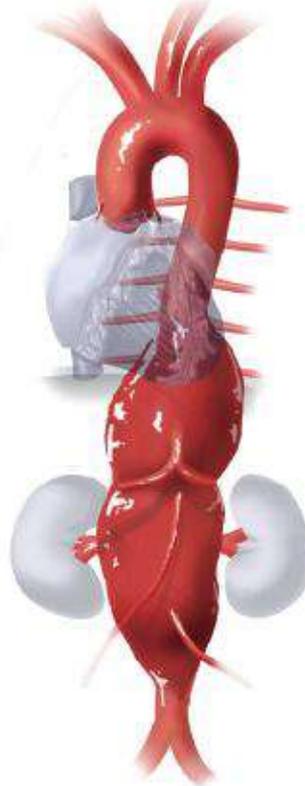
Extent I



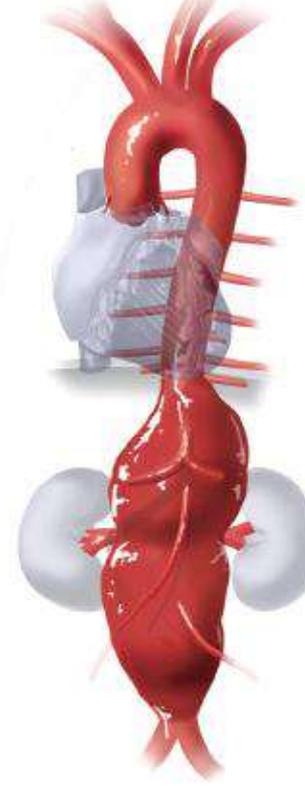
Extent II



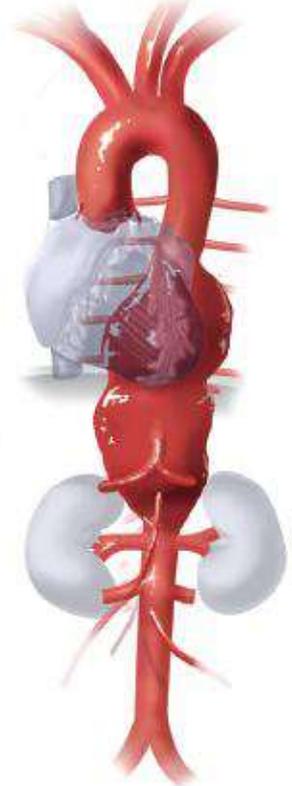
Extent III



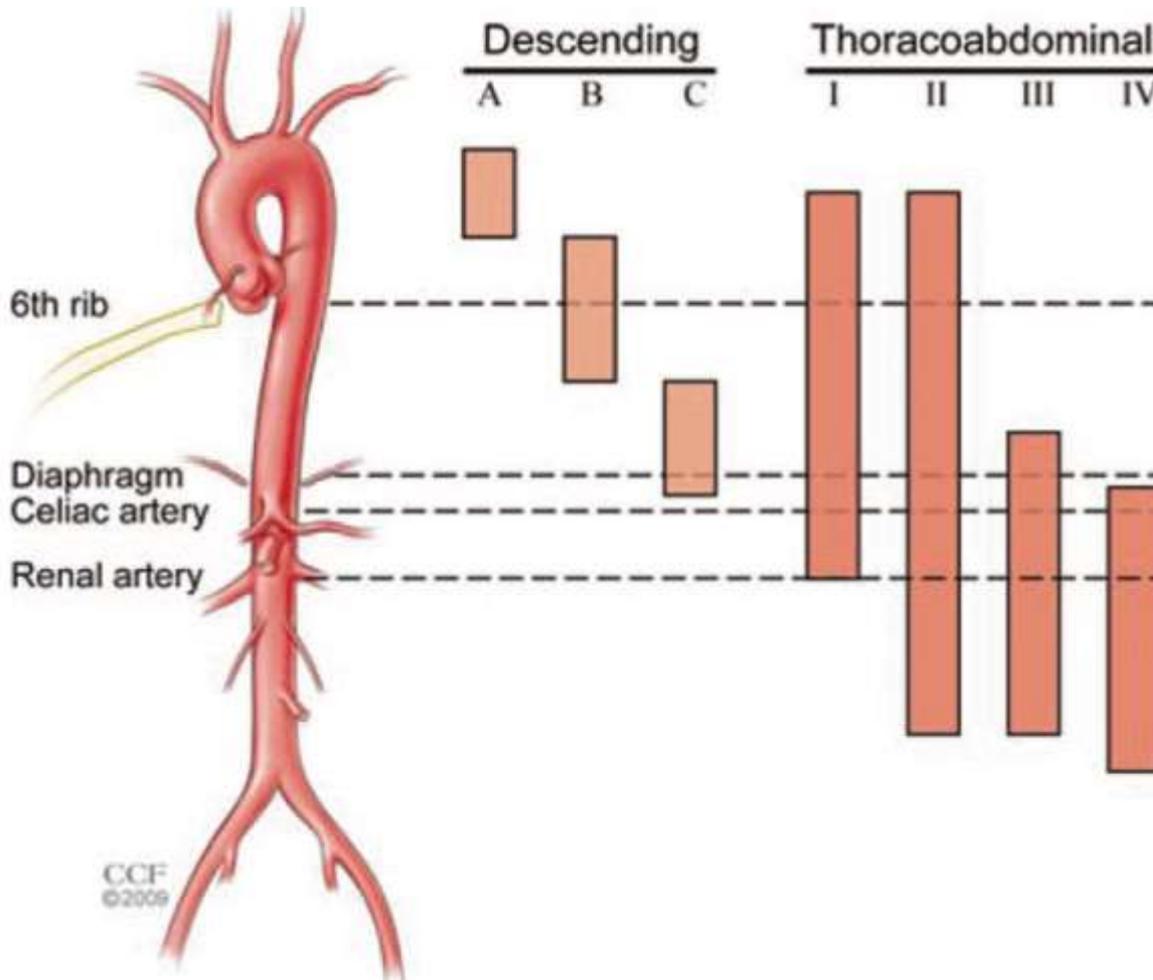
Extent IV



Extent V



# Classification of Descending and Thoracoabdominal Aneurysms

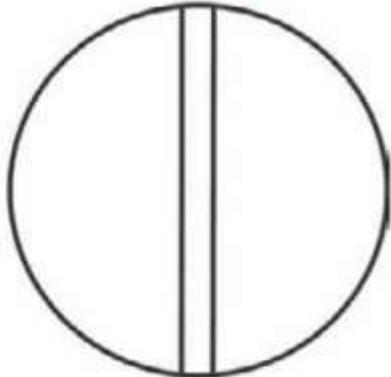
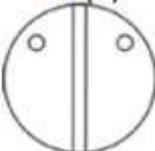
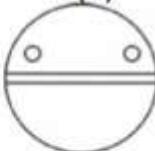


**Figure 29.** Descending aneurysm classification. Descending aneurysms are classified as involving thirds of the descending thoracic aorta and various combinations. A involves the proximal third, B the middle third, and C as the distal third. Thus, an aneurysm involving the proximal two thirds is an AB extent aneurysm. Practically, these groupings can be combined into proximal or distal aneurysm, because these extents influence the risk of paralysis after either open or endovascular repairs. Thoracoabdominal aneurysms are classified according to the Crawford classification: Type I extends from proximal to the sixth rib and extends down to the renal arteries. Type II extends from proximal to the sixth rib and extends to below the renal arteries. Type III extends from distal to the sixth rib but from above the diaphragm into the abdominal aorta. Type IV extends from below the diaphragm and involves the entire visceral aortic segment and most of the abdominal aorta. Juxtarenal and supraaortic aneurysms are excluded.<sup>379-382</sup> Image reprinted with permission from the Cleveland Clinic Foundation.

# Risk Factors for Aortic Dissection and Aneurysm

- Hypertension
- Atherosclerosis
- Bicuspid aortic valve
- Genetic syndromes
  - Marfan
  - Loeys-Dietz
  - Ehlers-Danlos
  - Familial Thoracic Aortic Aneurysm
  - Turner
- Arteritis
  - Takayasu
  - Giant Cell
  - Behcet
  - Ankylosing spondylitis
  - Syphilis



<u>main category:</u> number of raphes	0 raphe - <b>Type 0</b>		1 raphe - <b>Type 1</b>			2 raphes - <b>Type 2</b>
	 21 (7)		 269 (88)			 14 (5)
<u>1. subcategory:</u> spatial position of cusps in Type 0 and raphes in Types 1 and 2	lat 13 (4) 	ap 7 (2) 	L - R 216 (71) 	R - N 45 (15) 	N - L 8 (3) 	L - R / R - N 14 (5) 
<u>2. subcategory:</u> VALUATION						
I	6 (2)	1 (0.3)	79 (26)	22 (7)	3 (1)	6 (2)
S	7 (2)	5 (2)	119 (39)	15 (5)	3 (1)	6 (2)
B (I + S)		1 (0.3)	15 (5)	7 (2)	2 (1)	2 (1)
No			3 (1)	1 (0.3)		



**Table 1** TAAD with their corresponding genes and clinical features

Disorder	Gene(s)	Main cardiovascular features	Additional clinical features
<b>Syndromic TAAD</b>			
Marfan (1,7,8)	<i>FBN1</i>	Aortic root aneurysm, aortic dissection, mitral valve prolapse, main pulmonary artery dilatation, left ventricular dysfunction	Lens luxation, skeletal features (arachnodactyilia, pectus deformity, scoliosis, flat feet, increased armspan, dolichocephalia)
Ehlers-Danlos (9-11) (vascular, valvular)	<i>COL3A1</i> , <i>COL1A2</i>	Arterial rupture and dissection without preceding dilatation/aneurysm, severe valvular insufficiency	Translucent skin, dystrophic scars, facial characteristics (Madonna face, thin lips, deep set eyes)
<b>TGFβ-related vasculopathies</b>			
Loeys-Dietz (2,12)	<i>TGFBR1/2</i>	Aortic root aneurysm, aortic dissection, arterial aneurysms and dissections, arterial tortuosity, mitral valve prolapse, congenital cardiac malformations*	Bifid uvula/cleft palate, hypertelorism, pectus abnormalities, scoliosis, club feet
Aneurysm-Osteoarthritis (13-15)	<i>SMAD3</i>	Aortic root aneurysm, aortic dissection, arterial aneurysms and dissections, arterial tortuosity, mitral valve prolapse, congenital cardiac malformations*	Osteoarthritis, soft skin, flat feet, scoliosis, recurrent hernia's, hypertelorism, pectus abnormalities
<i>TGF<sub>β</sub>2</i> (16,17)	<i>TGF<sub>β</sub>2</i>	Aortic root aneurysm, aortic dissection, arterial aneurysms and dissections, arterial tortuosity, mitral valve prolapse, congenital cardiac malformations*	Club feet, soft translucent skin
Arterial tortuosity syndrome (18)	<i>SLC2A10</i>	Arterial tortuosity, arterial stenoses and aneurysms	Hyperlax skin and joints
Cutis laxa syndromes (19)	<i>FBLN4</i>	Aortic root aneurysm, arterial tortuosity	Hyperlax skin and joints, mild emphysema
<b>Non syndromic TAAD</b>			
Familial thoracic aortic aneurysm syndrome (FTAA) (20-22)	<i>TGFBR1/2</i> (3-5%)	Thoracic aortic aneurysm/dissection	Lack of syndromal features
	<i>ACTA2</i> (10-14%)	Thoracic aortic aneurysm/dissection, cerebrovascular disease, coronary artery disease	Lack of Marfanoid skeletal features, livedo reticularis, iris flocculi, coronary artery/cerebrovascular disease)
	<i>MLCK</i>	Thoracic aortic aneurysm/dissection	Gastro-intestinal abnormalities
	<i>SMAD3</i> (2%)	Intracranial and other arterial aneurysms	
	<i>TGF<sub>β</sub>2</i>	Mitral valve prolapse	
FTAA with bicuspid aortic valve (BAV) (23,24)	<i>ACTA2</i>		Lack of Marfanoid skeletal features, livedo reticularis, iris flocculi
	<i>NOTCH1</i>	Highly calcified valve	
FTAA with patent ductus arteriosus (PDA) (6)	<i>MYH11</i>	Patent ductus arteriosus	

# Ascending Aortic Aneurysm: Size Matters

## Indications and imaging for aortic surgery: Size and other matters

John A. Elefteriades, MD,<sup>a</sup> Bulat A. Ziganshin, MD,<sup>a,b</sup> John A. Rizzo, PhD,<sup>a,c</sup> Hai Fang, PhD,<sup>d</sup> Maryann Tranquilli, RN,<sup>a</sup> Vijayapraveena Paruchuri, MD,<sup>c</sup> Gregory Kuzmik, MD,<sup>a</sup> George Gubernikoff, MD,<sup>c</sup> Julia Dumfarth, MD,<sup>a</sup> Paris Charilaou, MD,<sup>a</sup> and Panagiotis Theodoropoulos, MD<sup>a</sup>

**Objectives:** To review the current general concepts and understanding of the natural history of thoracic aortic aneurysm and their clinical implications.

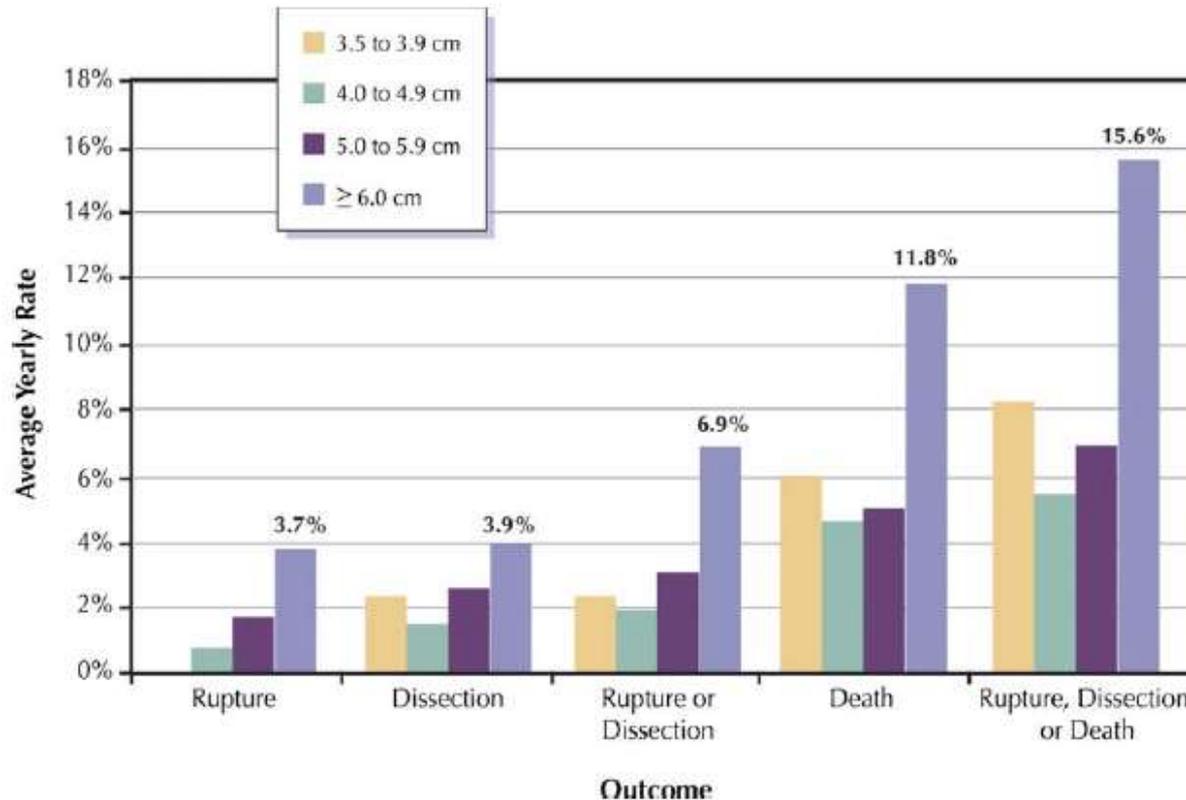
**Methods:** Data on the the normal thoracic aortas were derived from the database of the Multi-Ethnic Study of Atherosclerosis (n = 3573), representative of the general population. Data on diseased thoracic aorta were derived from the database of the Aortic Institute at Yale-New Haven Hospital (n = 3263), representative of patients with thoracic aortic aneurysm and dissection.

**Results:** Our studies have shown that the normal aorta in the general population is small (3.2 cm for the ascending aorta). Aortas larger than 5 cm are rare in the real world. The aneurysmal aorta grows at a mean of 0.2 cm/y, and larger aneurysms grow faster than do smaller ones. The dissection size paradox (which shows some aortic dissections occurring at small aneurysm sizes) is explained by the huge number of patients with small aortas in the general population. Genetic testing of patients with thoracic aortic disease helps identify genes responsible for aortic aneurysm and dissection. New imaging techniques such as 4-dimensional magnetic resonance imaging may add engineering data to our decision making.

**Conclusions:** Size continues to be a strong predictor of natural complications and a suitable parameter for intervention. As we enter the era of personalized aneurysm care, it is likely that specific genetic mutations will facilitate the determination of the appropriate size criterion for surgical intervention in individual cases. (J Thorac Cardiovasc Surg 2015;149:S10-3)



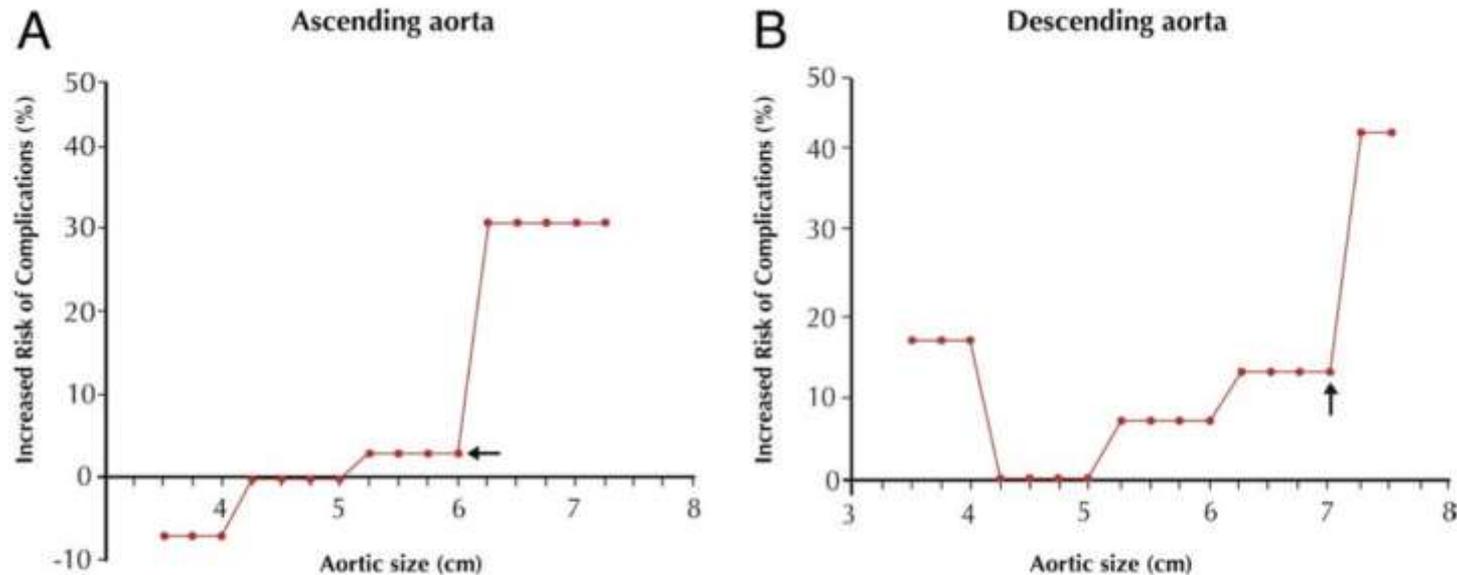
# Ascending Aortic Aneurysm: Size Matters



**Figure 11** Yearly Rates of Rupture, Dissection, or Death Related to Aortic Size

Note that the likelihood of rupture, dissection, or death within the coming year also jumps sharply for aneurysms that reach 6 cm or larger. (The rates indicated for rupture or dissection and for rupture, dissection, or death are lower than the sum of the rates in individual categories because patients with multiple complications were counted only once in the combined categories.) These data underlie the conclusion that aneurysms in the ascending aorta need corrective surgery when the artery balloons to 5.5 cm. Adapted, with permission, from Elefteriades (14). Figure illustration by Rob Flewell.

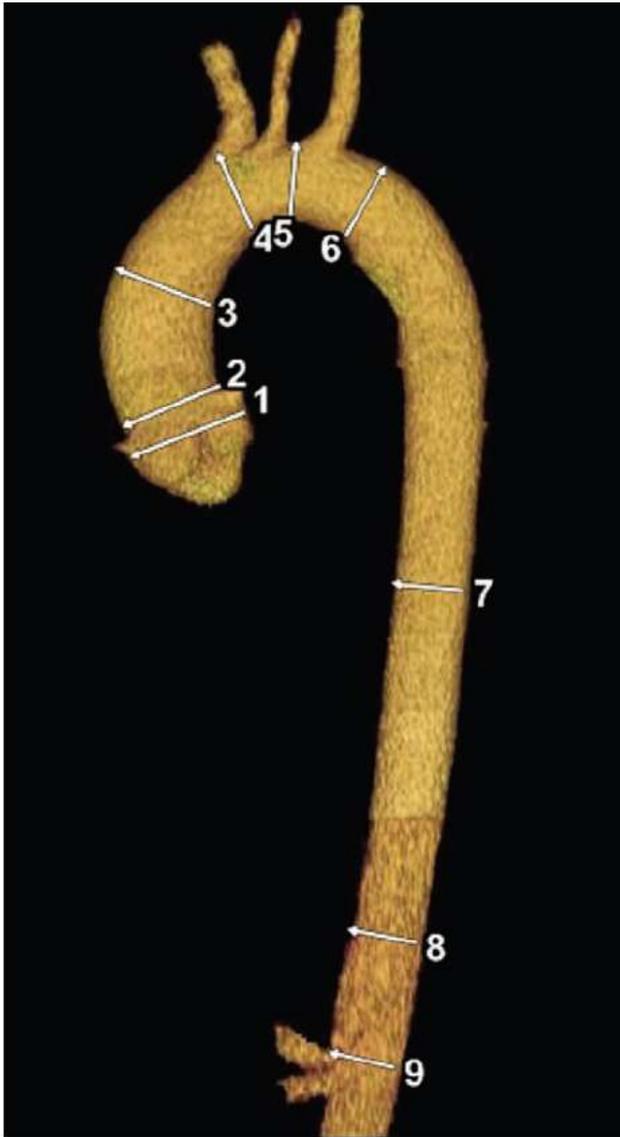
# Ascending Aortic Aneurysm: Size Matters



**Figure 10** Depiction of “Hinge Points” for Lifetime Natural History Complications at Various Sizes of the Aorta

The y-axis lists the probability of complication; complication refers to rupture or dissection. The x-axis shows aneurysm size. **(A)** The ascending aorta. **(B)** The descending aorta. **Arrows** indicate discrepant diameter. Adapted, with permission, from Coady MA, Rizzo JA, Hammond GL, et al. What is the appropriate size criterion for resection of thoracic aortic aneurysm? *J Thorac Cardiovasc Surg* 1997;113:476–91. Figure illustration by Rob Flewell.

# Measuring Aortic Diameter



**Figure 12.** Normal anatomy of the thoracoabdominal aorta with standard anatomic landmarks for reporting aortic diameter as illustrated on a volume-rendered CT image of the thoracic aorta. CT indicates computed tomographic imaging. Anatomic locations: 1, Aortic sinuses of Valsalva; 2, Sinotubular junction; 3, Mid ascending aorta (midpoint in length between Nos. 2 and 4); 4, Proximal aortic arch (aorta at the origin of the innominate artery); 5, Mid aortic arch (between left common carotid and subclavian arteries); 6, Proximal descending thoracic aorta (begins at the isthmus, approximately 2 cm distal to left subclavian artery); 7, Mid descending aorta (midpoint in length between Nos. 6 and 8); 8, Aorta at diaphragm (2 cm above the celiac axis origin); 9, Abdominal aorta at the celiac axis origin. CT indicates computed tomographic imaging.

# **2010 ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM Guidelines for the Diagnosis and Management of Patients With Thoracic Aortic Disease**

**A Report of the American College of Cardiology Foundation/American Heart Association  
Task Force on Practice Guidelines, American Association for Thoracic Surgery, American  
College of Radiology, American Stroke Association, Society of Cardiovascular  
Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of  
Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine**

*Endorsed by the North American Society for Cardiovascular Imaging*

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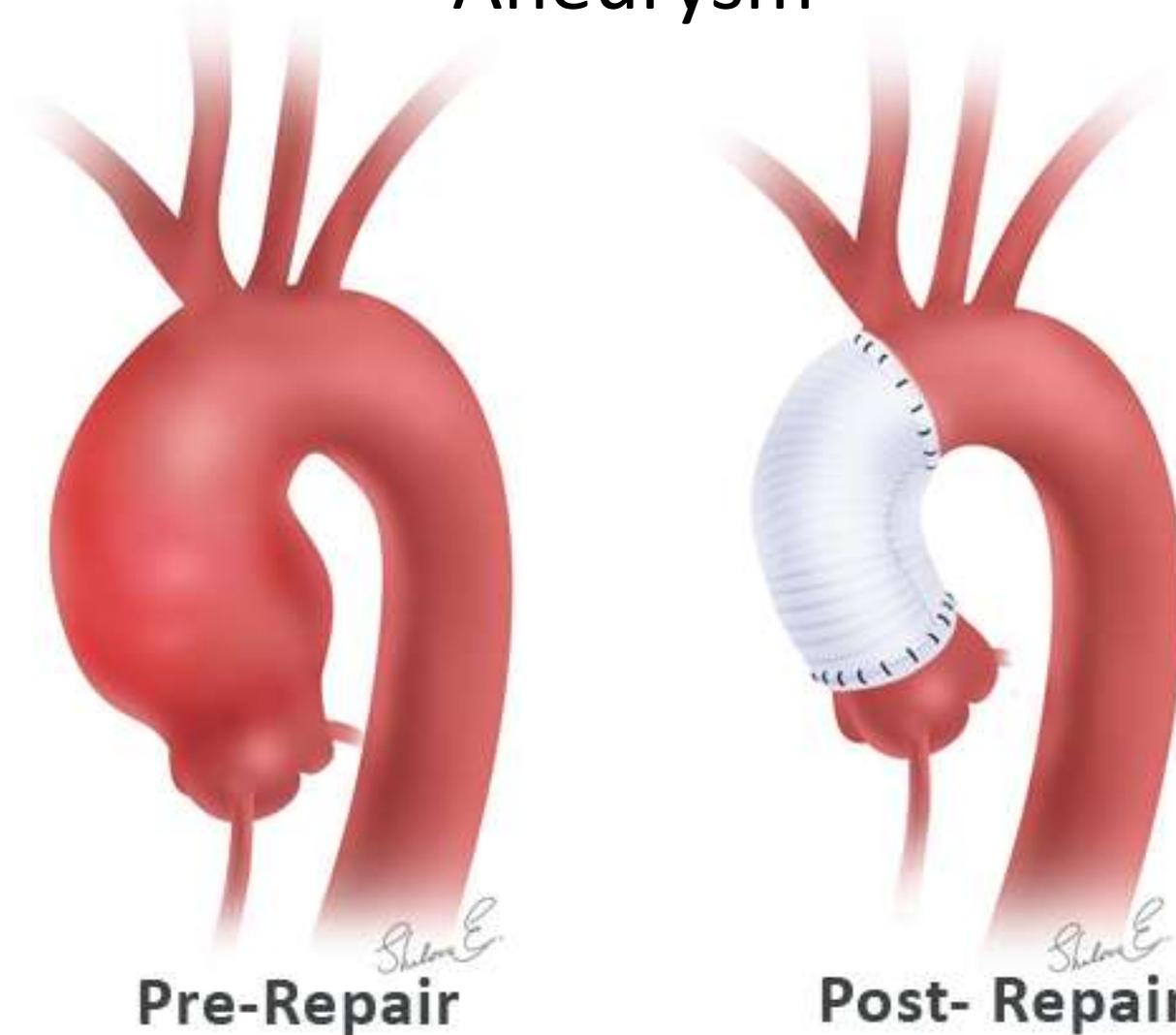
# Indications for Surgical Intervention: Ascending Aorta

## Class I

1. Asymptomatic patients with degenerative thoracic aneurysm, chronic aortic dissection, intramural hematoma, penetrating atherosclerotic ulcer, mycotic aneurysm, or pseudoaneurysm, who are otherwise suitable candidates and for whom the ascending aorta or aortic sinus diameter is 5.5 cm or greater, should be evaluated for surgical repair.<sup>371</sup> (*Level of Evidence: C*)
2. Patients with Marfan syndrome or other genetically mediated disorders (vascular Ehlers-Danlos syndrome, Turner syndrome, bicuspid aortic valve, or familial thoracic aortic aneurysm and dissection) should undergo elective operation at smaller diameters (4.0 to 5.0 cm depending on the condition; see Section 5) to avoid acute dissection or rupture.<sup>81,114,143,371,436–439</sup> (*Level of Evidence: C*)
3. Patients with a growth rate of more than 0.5 cm/y in an aorta that is less than 5.5 cm in diameter should be considered for operation. (*Level of Evidence: C*)
4. Patients undergoing aortic valve repair or replacement and who have an ascending aorta or aortic root of greater than 4.5 cm should be considered for concomitant repair of the aortic root or replacement of the ascending aorta. (*Level of Evidence: C*)



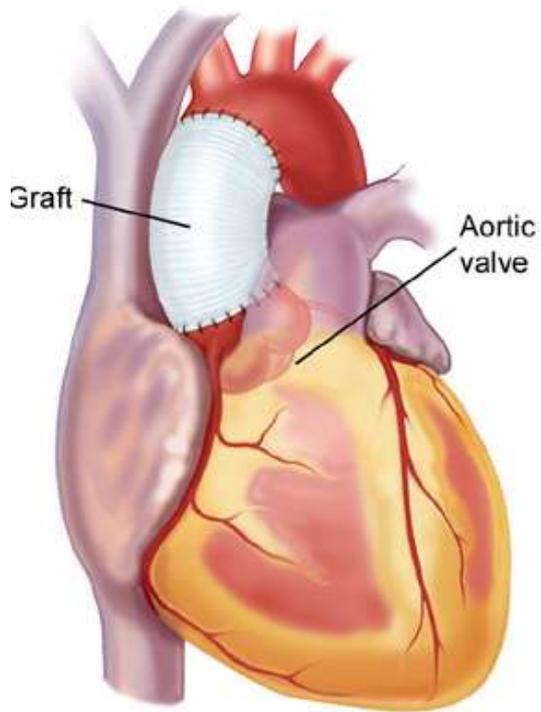
# Surgical Management of Ascending Aortic Aneurysm



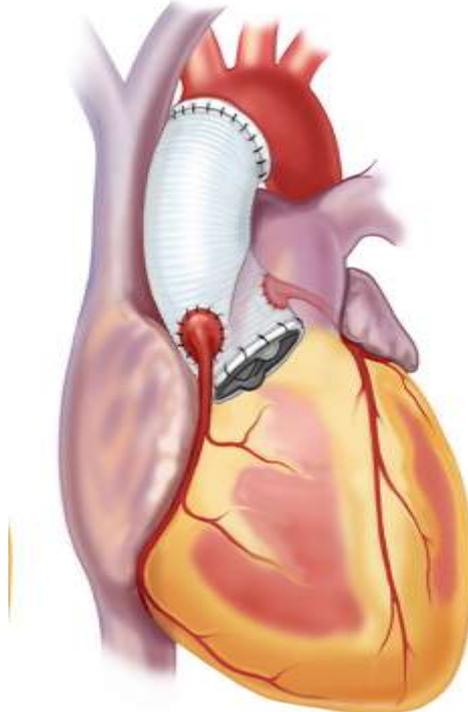
**Pre-Repair**

**Post- Repair**

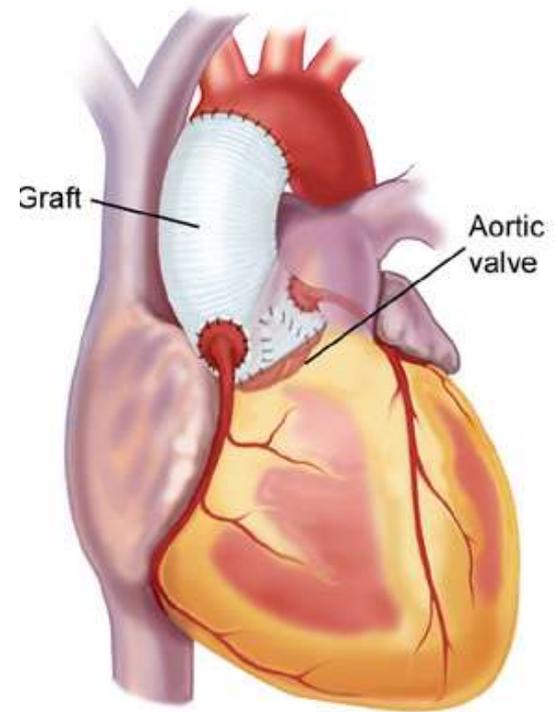
# Surgical Management of Ascending Aortic and Root Aneurysms



Supra Coronary Graft

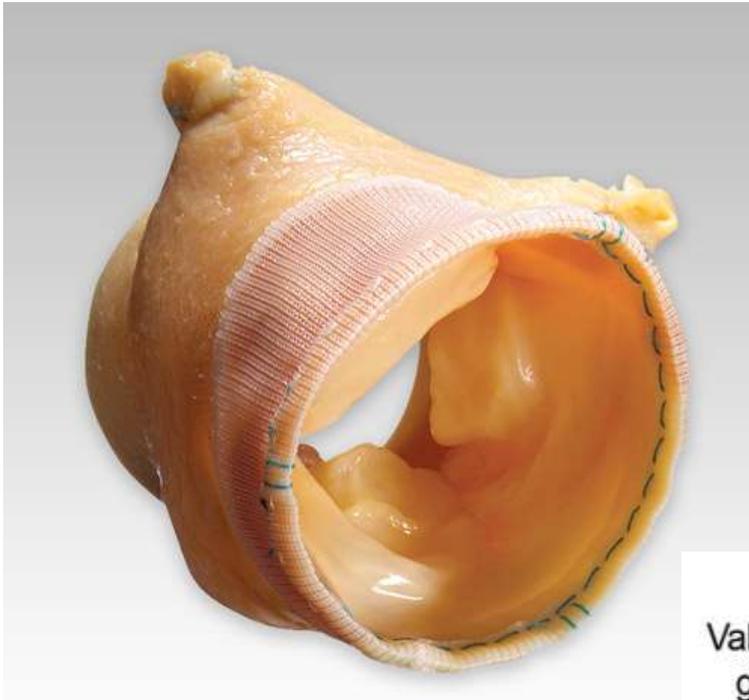


Composite Graft



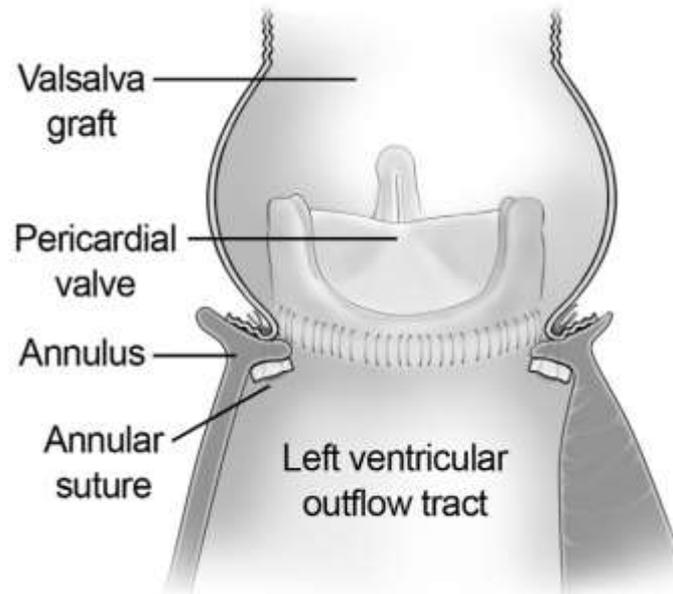
Valve Sparing Aortic Root

# Aortic Root Composite Grafts



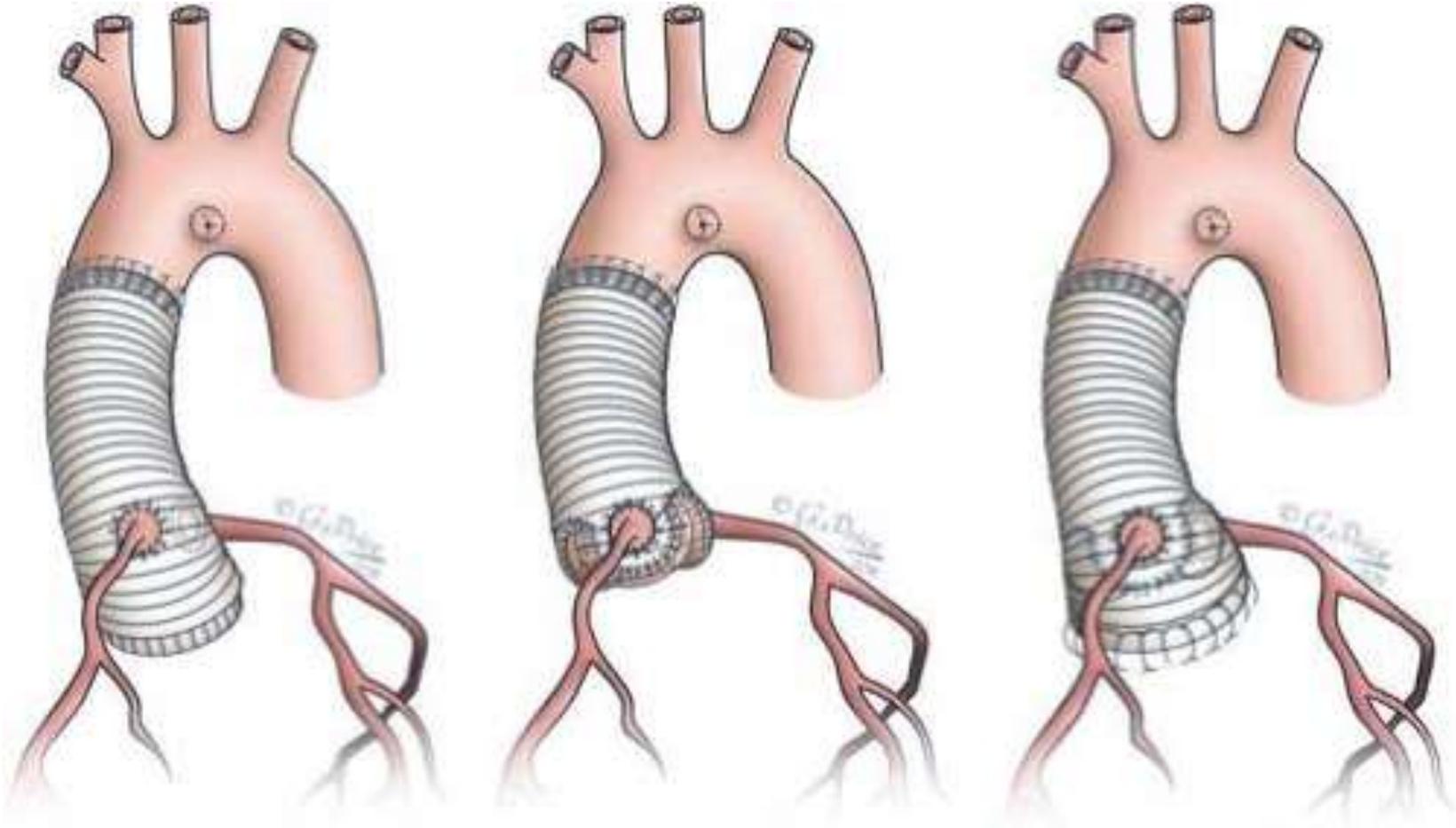
<http://www.medtronic.com/us-en/healthcare-professionals/products/cardiovascular/heart-valves-surgical/freestyle-aortic-root-bioprosthesis.html>

<http://www.livanova.sorin.com/products/cardiac-surgery/aortic/carbomedics-carbo-seal-valsalva>



Tabata M et al. Ann Thorac Surg 2009;87:1969-70.

# Techniques for Aortic Root Replacement



A Bentall

B Remodeling

C Reimplantation



# Valve-Sparing Aortic Root Operation: Re-implantation

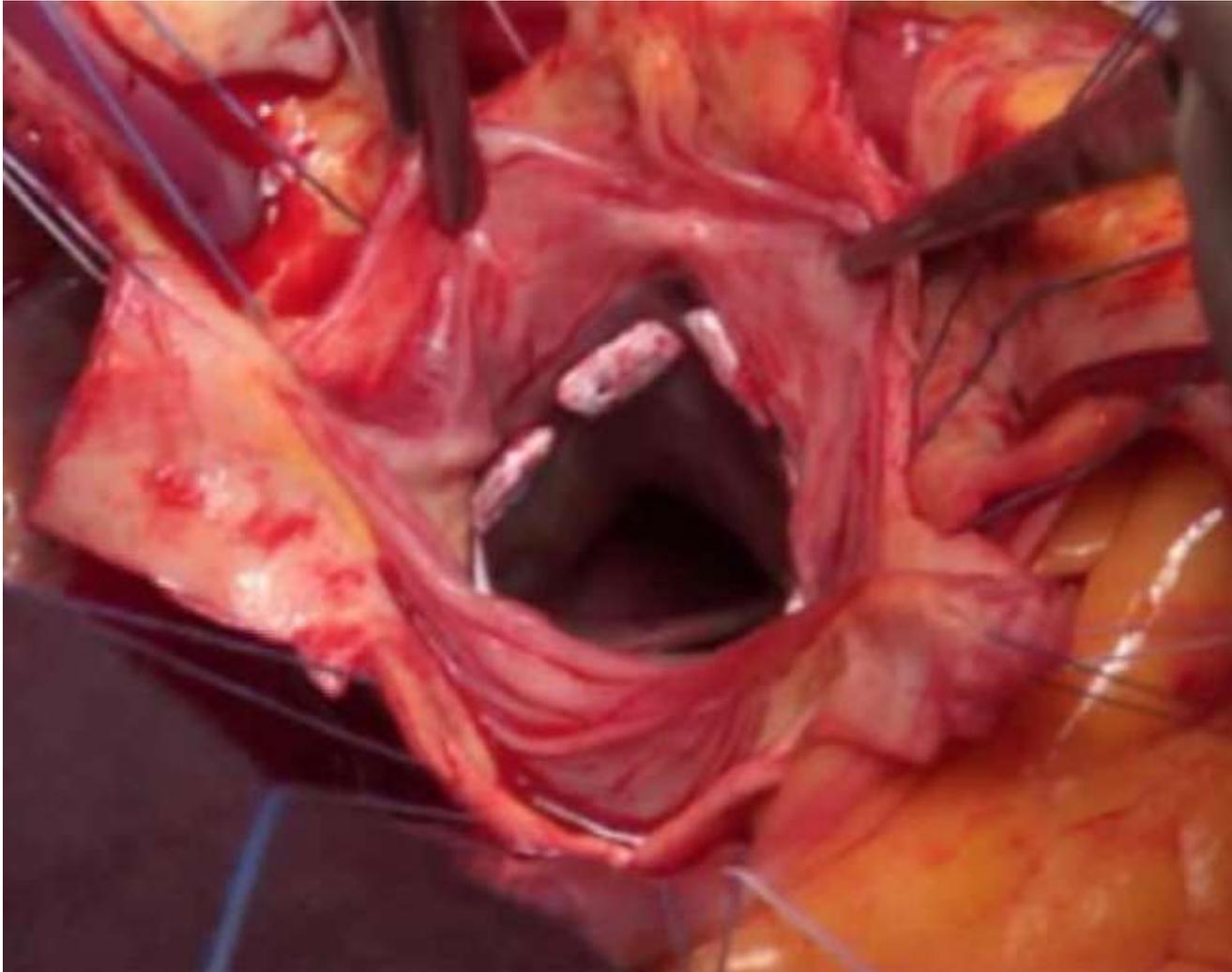


Photo courtesy of Thomas E. MacGillivray



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# Valve-Sparing Aortic Root Operation: Re-implantation

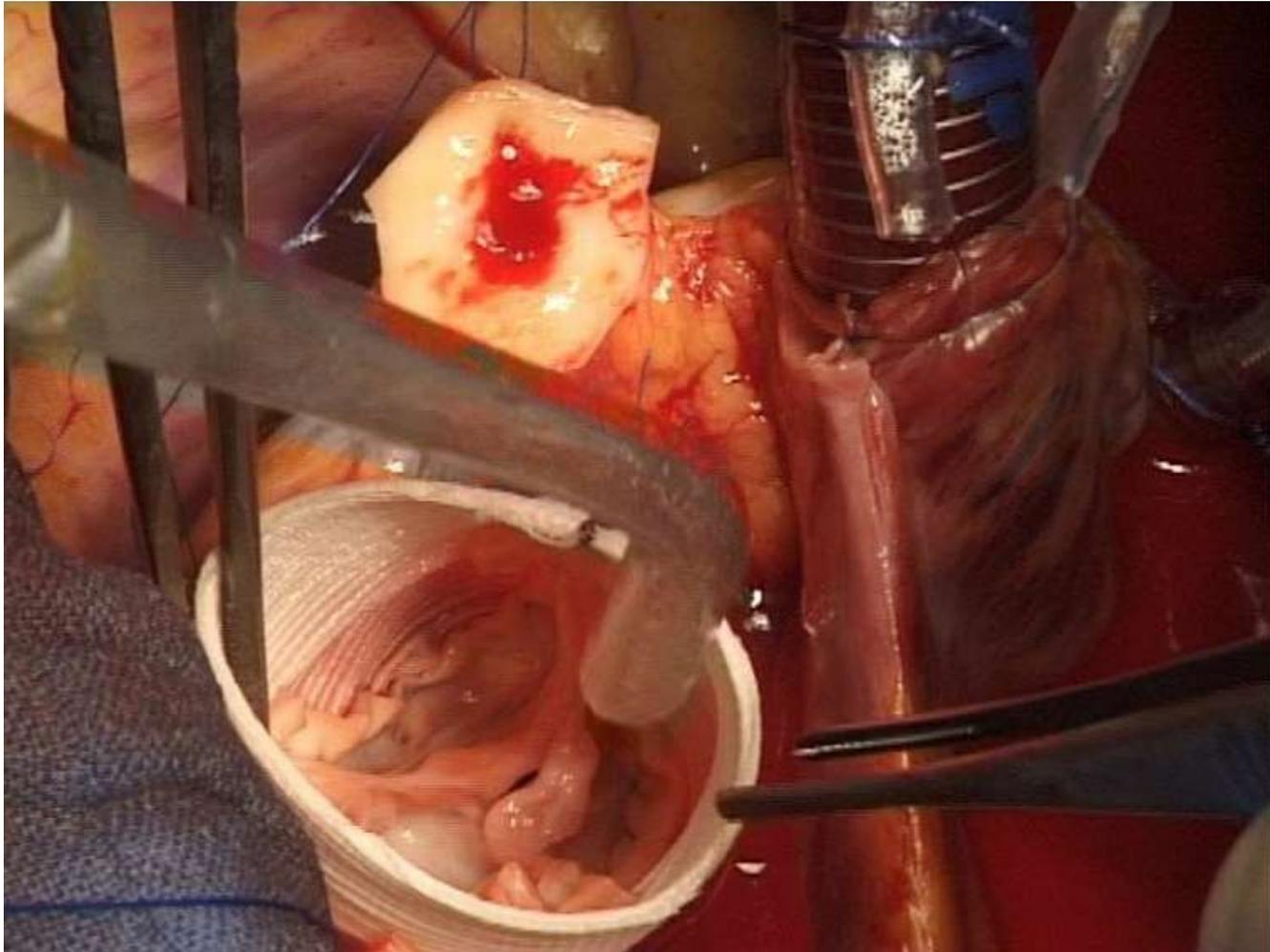


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# Surgical Management of Ascending Aortic Aneurysm/Dissection: Hemiarch

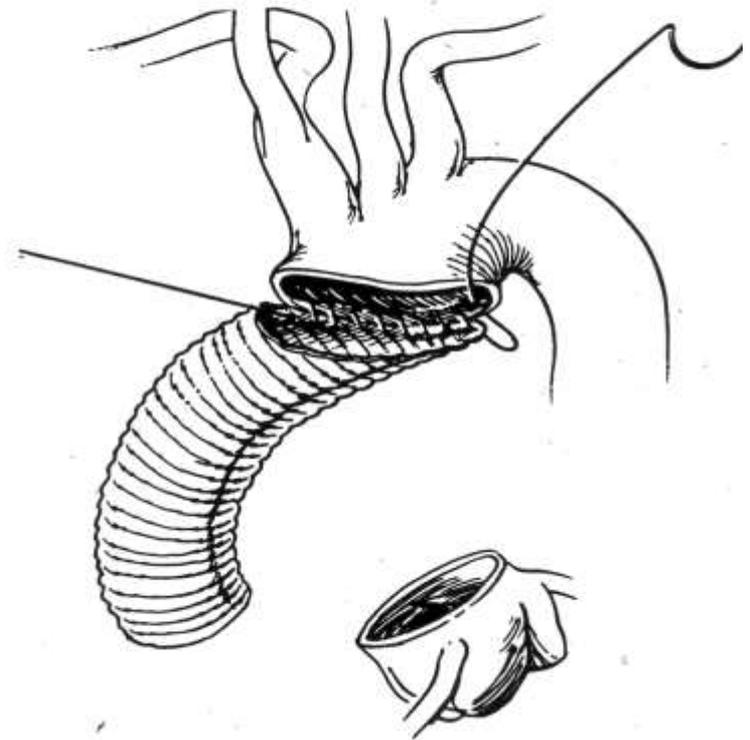
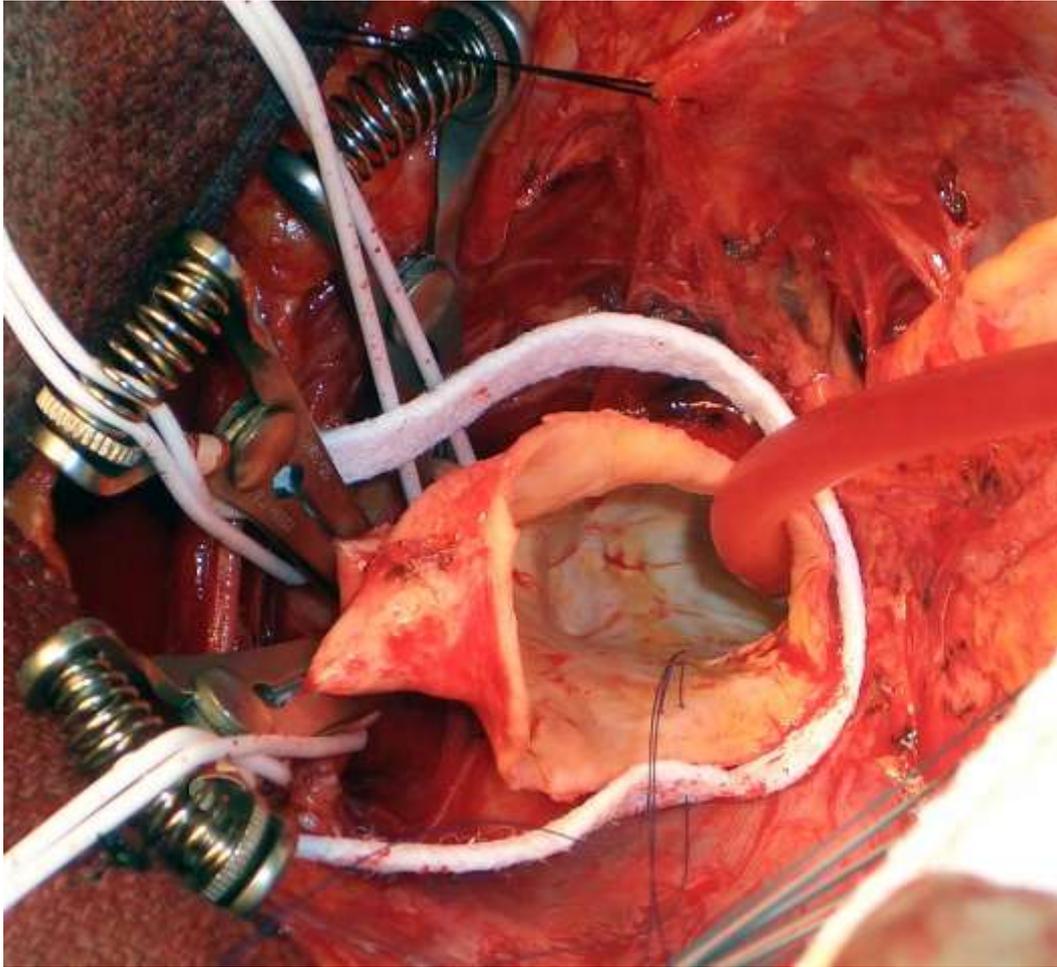


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# Surgical Management of Ascending Aortic Aneurysm/Dissection: Total Arch

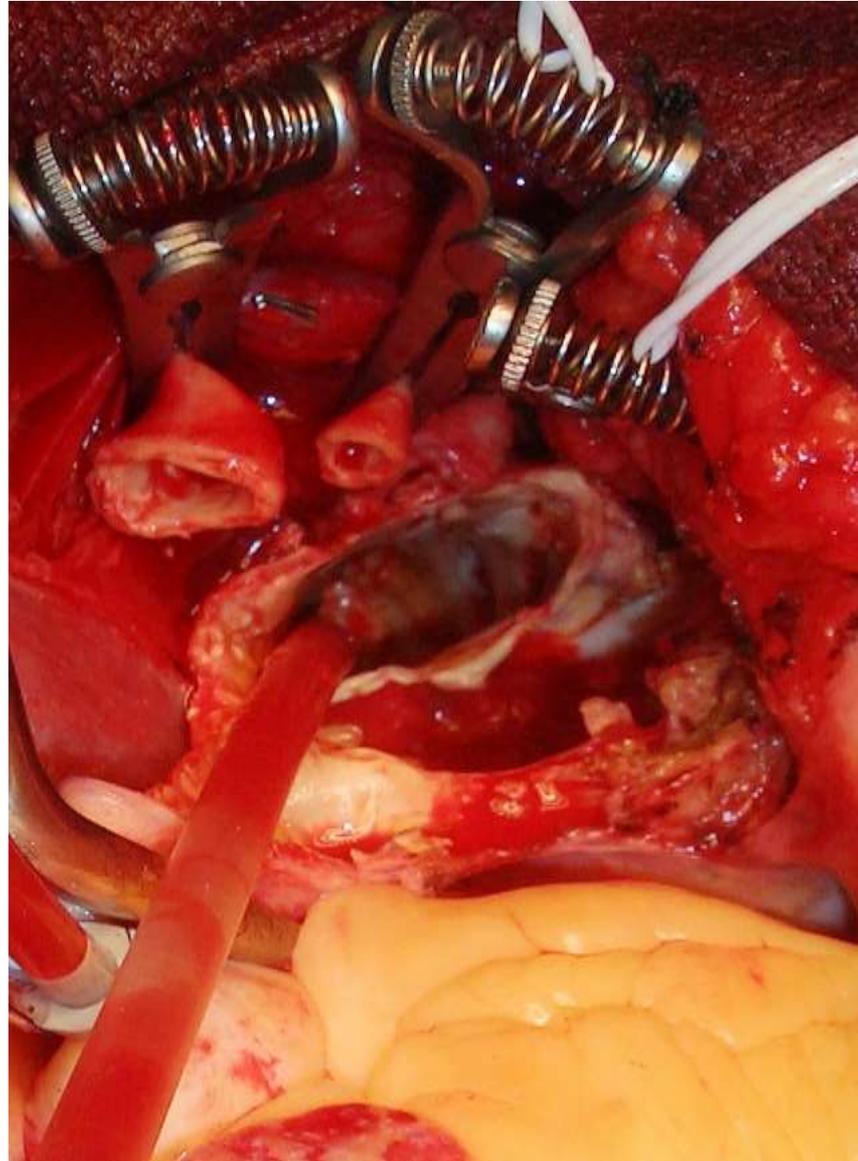


Photo courtesy of Thomas E. MacGillivray

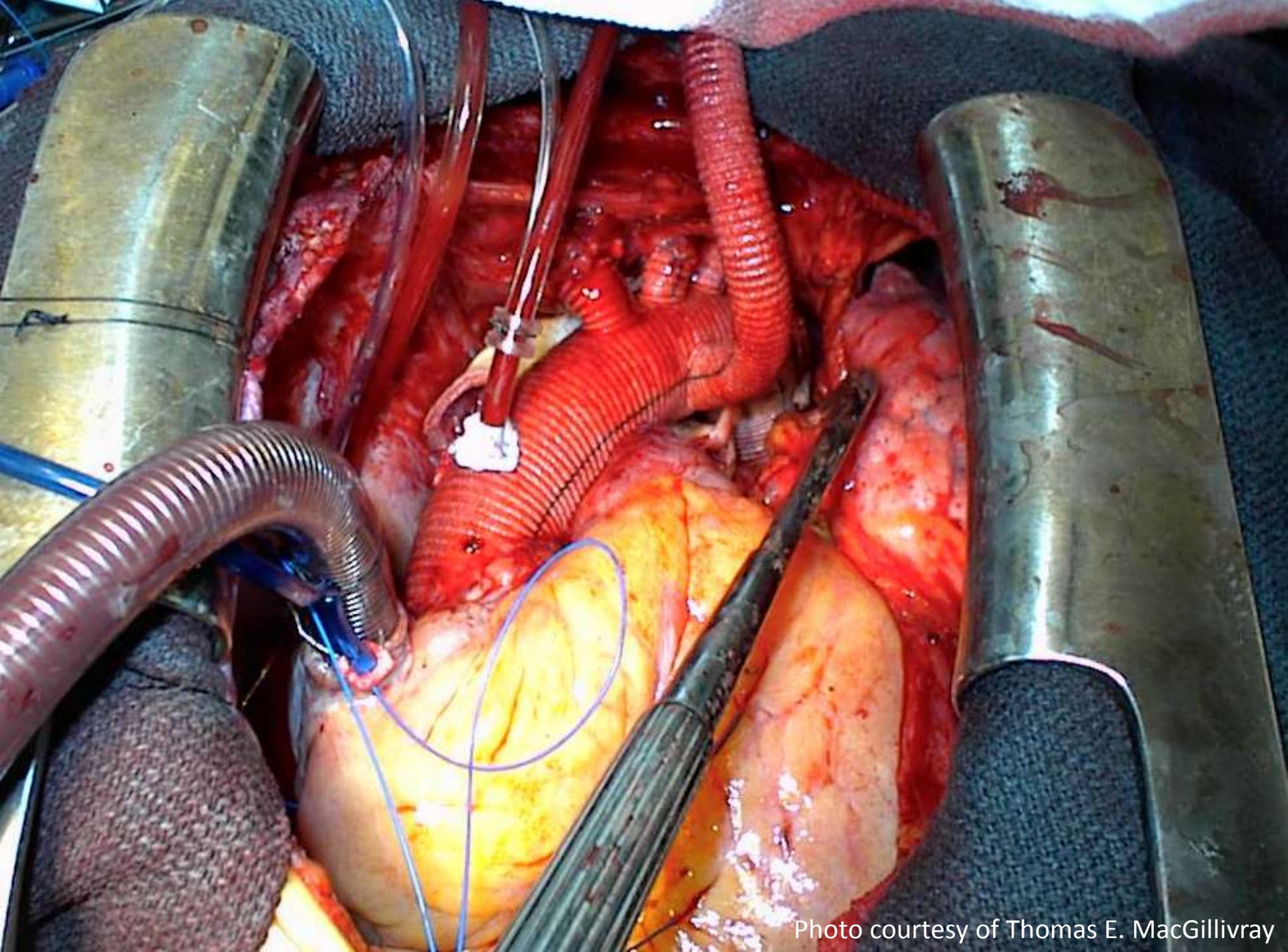
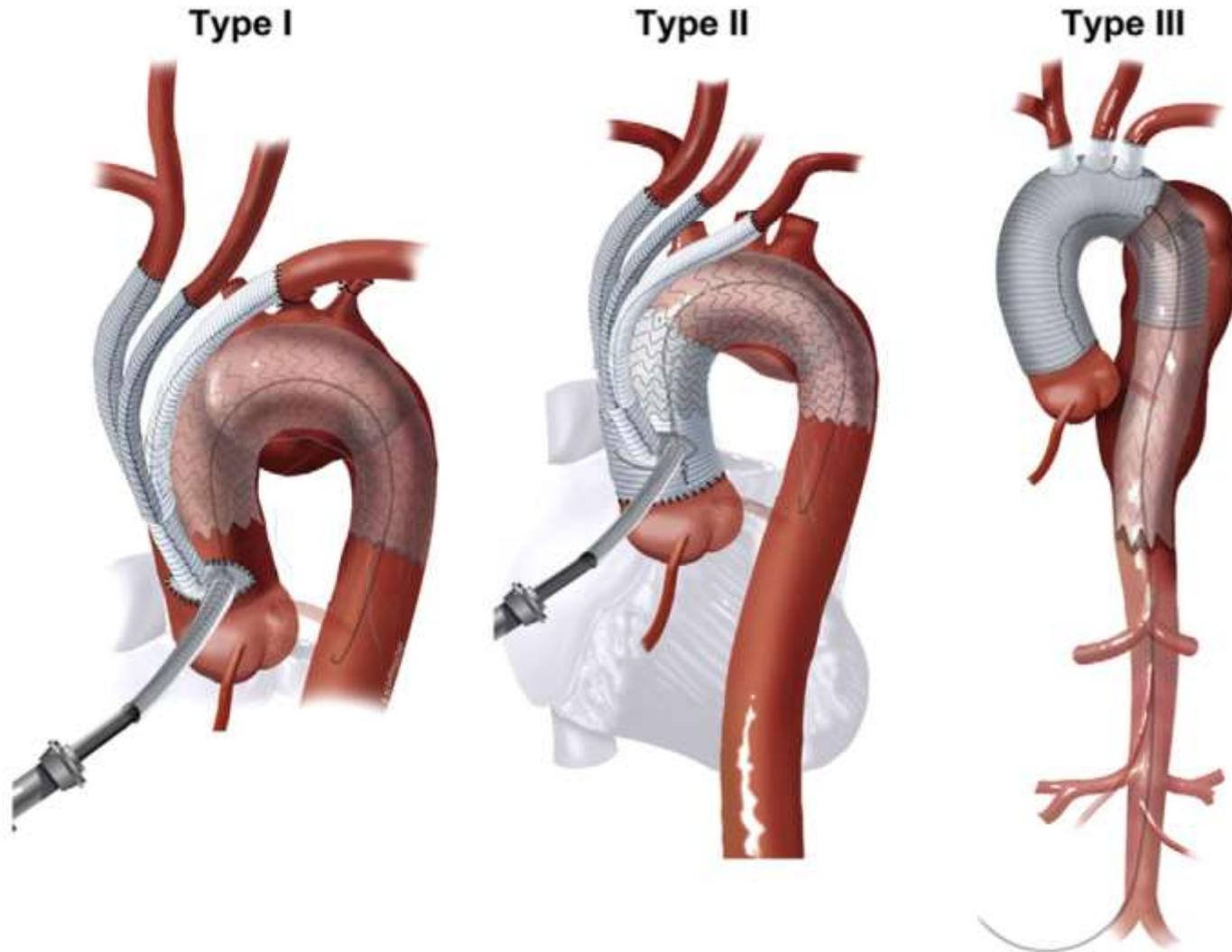


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# Surgical Management of Ascending Aortic Aneurysm: Hybrid Arch



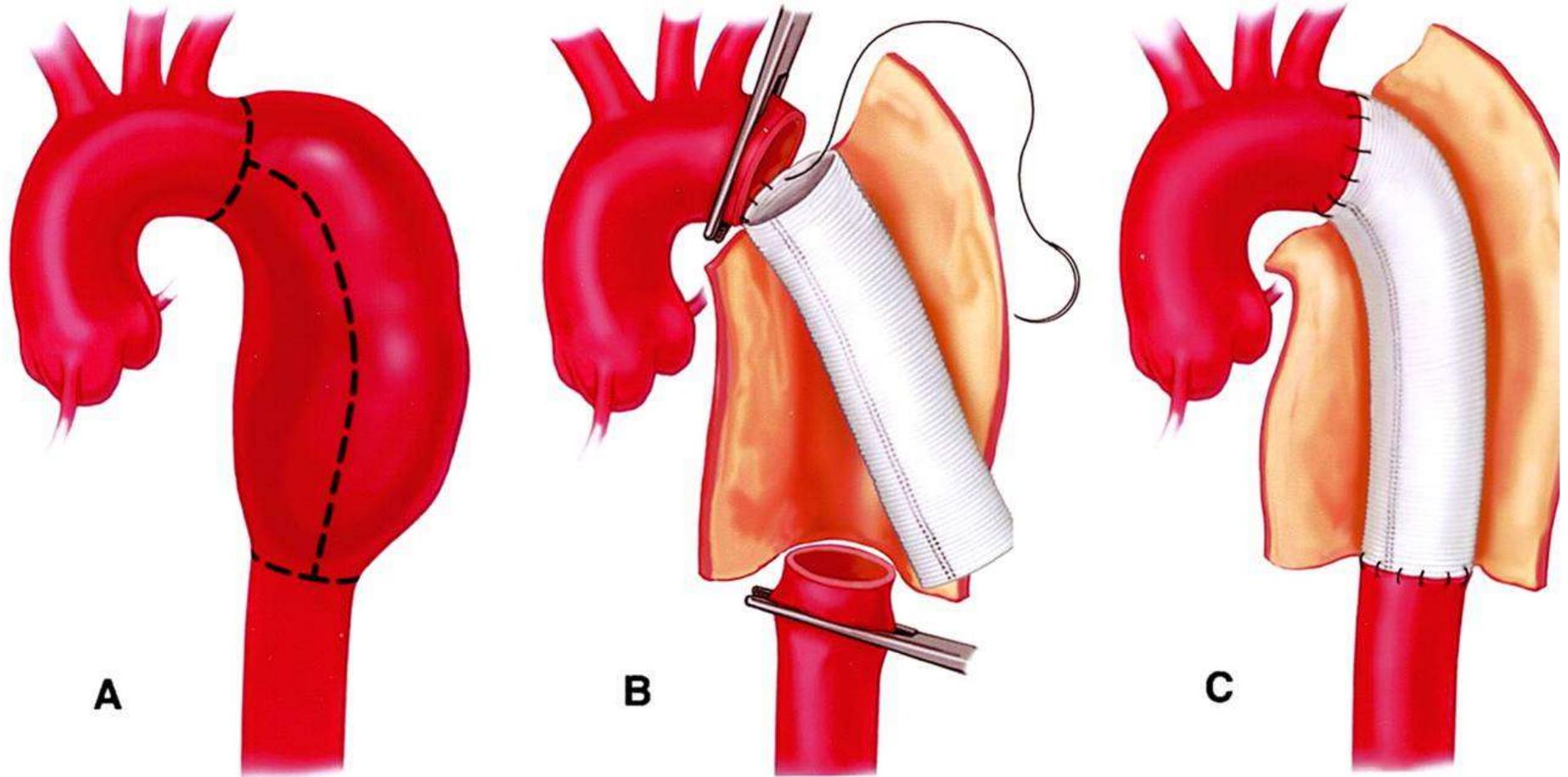
# Indications for Surgical Intervention: Descending Thoracic and Thoracoabdominal Aorta

## Class I

1. For patients with chronic dissection, particularly if associated with a connective tissue disorder, but without significant comorbid disease, and a descending thoracic aortic diameter exceeding 5.5 cm, open repair is recommended.<sup>371,382,468</sup> (*Level of Evidence: B*)
2. For patients with degenerative or traumatic aneurysms of the descending thoracic aorta exceeding 5.5 cm, saccular aneurysms, or postoperative pseudoaneurysms, endovascular stent grafting should be strongly considered when feasible.<sup>371,469</sup> (*Level of Evidence: B*)
3. For patients with thoracoabdominal aneurysms, in whom endovascular stent graft options are limited and surgical morbidity is elevated, elective surgery is recommended if the aortic diameter exceeds 6.0 cm, or less if a connective tissue disorder such as Marfan or Loeys-Dietz syndrome is present.<sup>371</sup> (*Level of Evidence: C*)

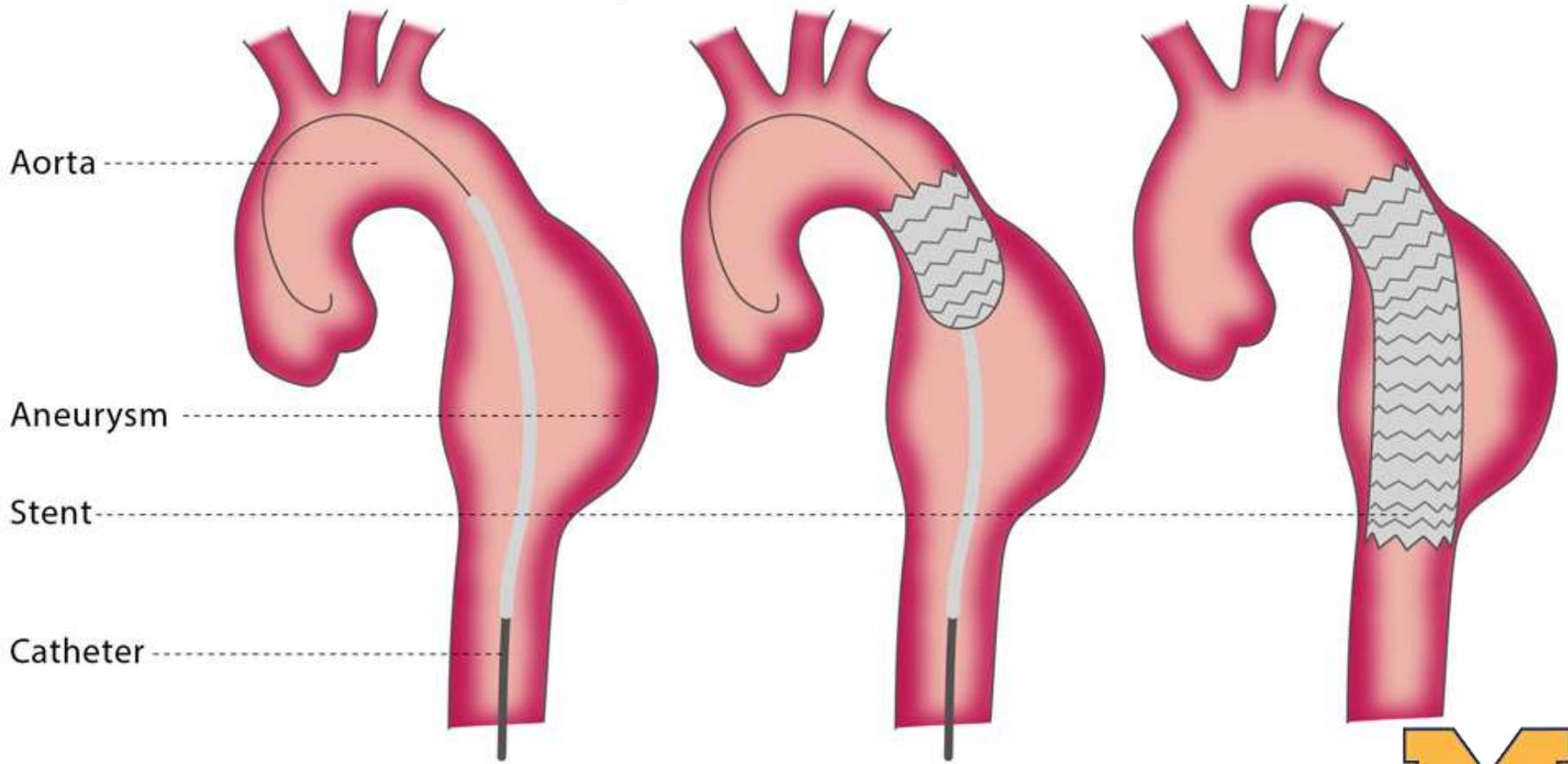


# Open Surgical Descending Thoracic Aortic Replacement for Aneurysm

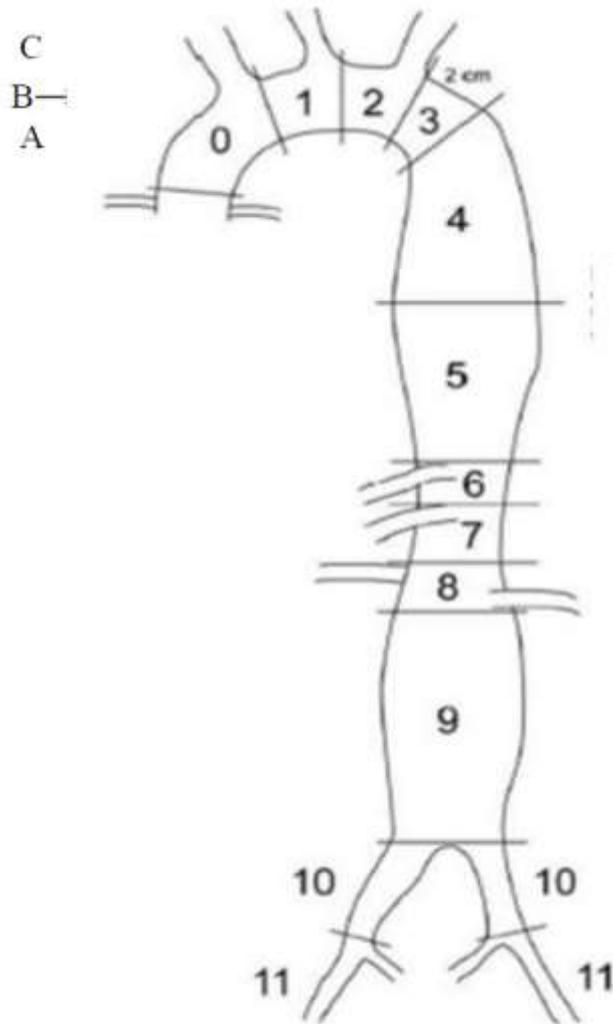


# Thoracic Endovascular Aortic Repair (TEVAR) for Descending Thoracic Aortic Aneurysm

## Thoracic endovascular aortic repair (TEVAR)

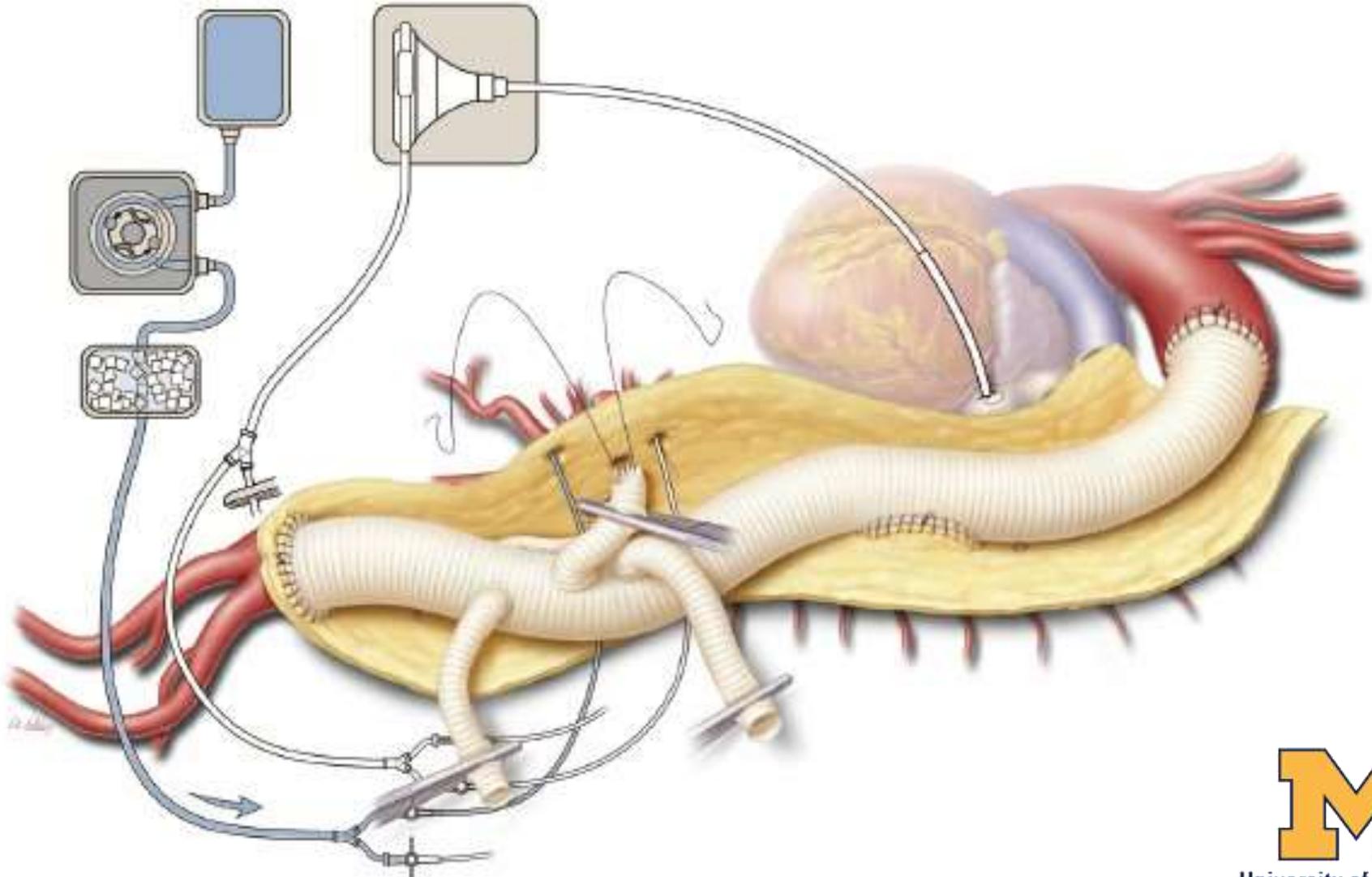


# Endovascular Zones of the Aorta



- A. Below sinotubular junction
- B. Sinotubular junction to mid ascending
- C. Mid ascending to distal ascending
- D. Zone 1 (between innominate and left carotid)
- E. Zone 2 (between left carotid and left subclavian)
- F. Zone 3 (first 2 cm. distal to left subclavian)
- G. Zone 4 (end of zone 3 to mid descending aorta ~ T6)
- H. Zone 5 (mid descending aorta to celiac)
- I. Zone 6 (celiac to superior mesenteric)
- J. Zone 7 (superior mesenteric to renals)
- K. Zone 8 (renal to infra-renal abdominal aorta)
- L. Zone 9 (infra-renal abdominal aorta)
- M. Zone 10 (common iliac)
- N. Zone 11 (external iliacs)

# Open Thoracoabdominal Aneurysm Repair

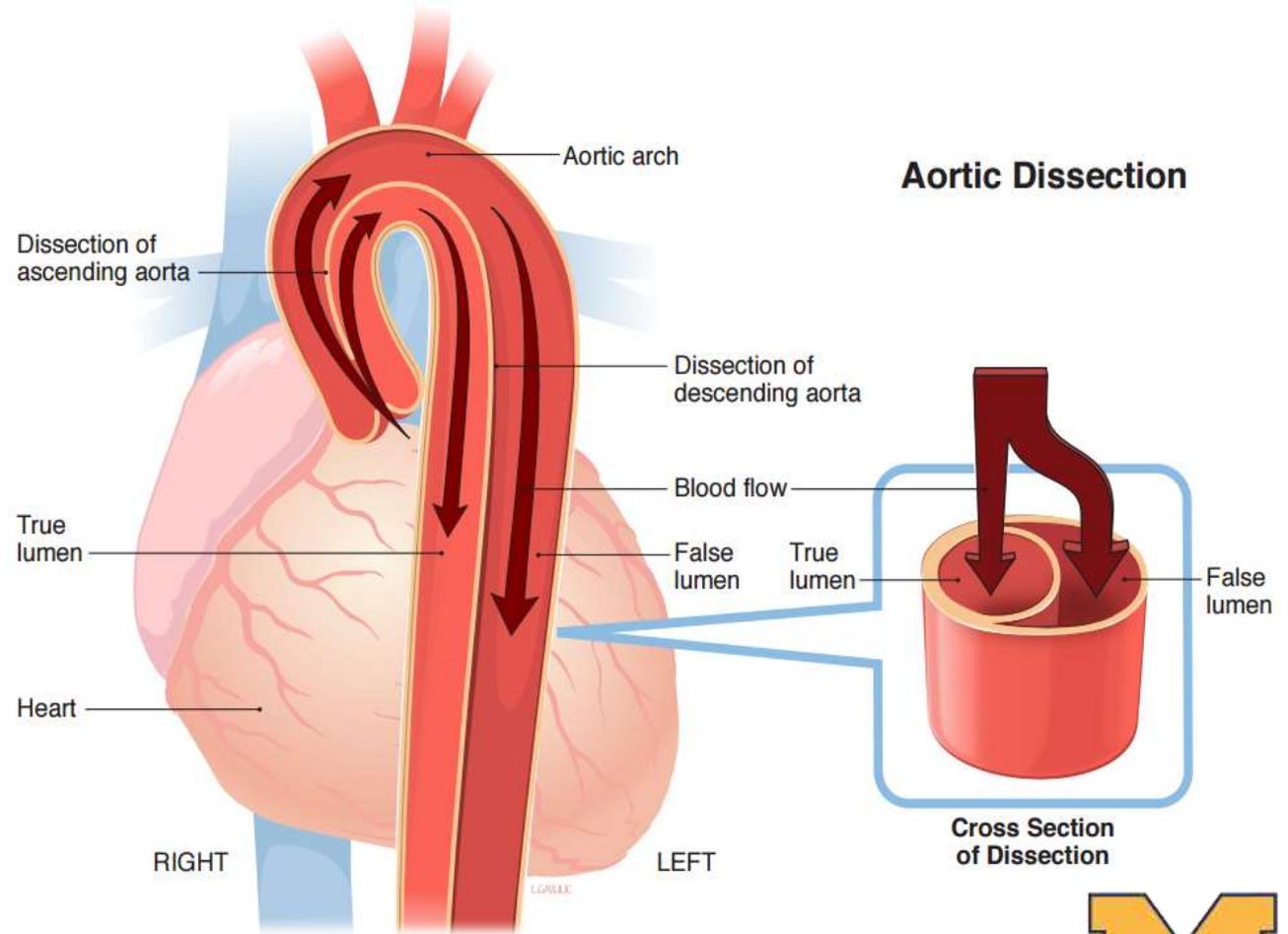


# Aortic Dissection

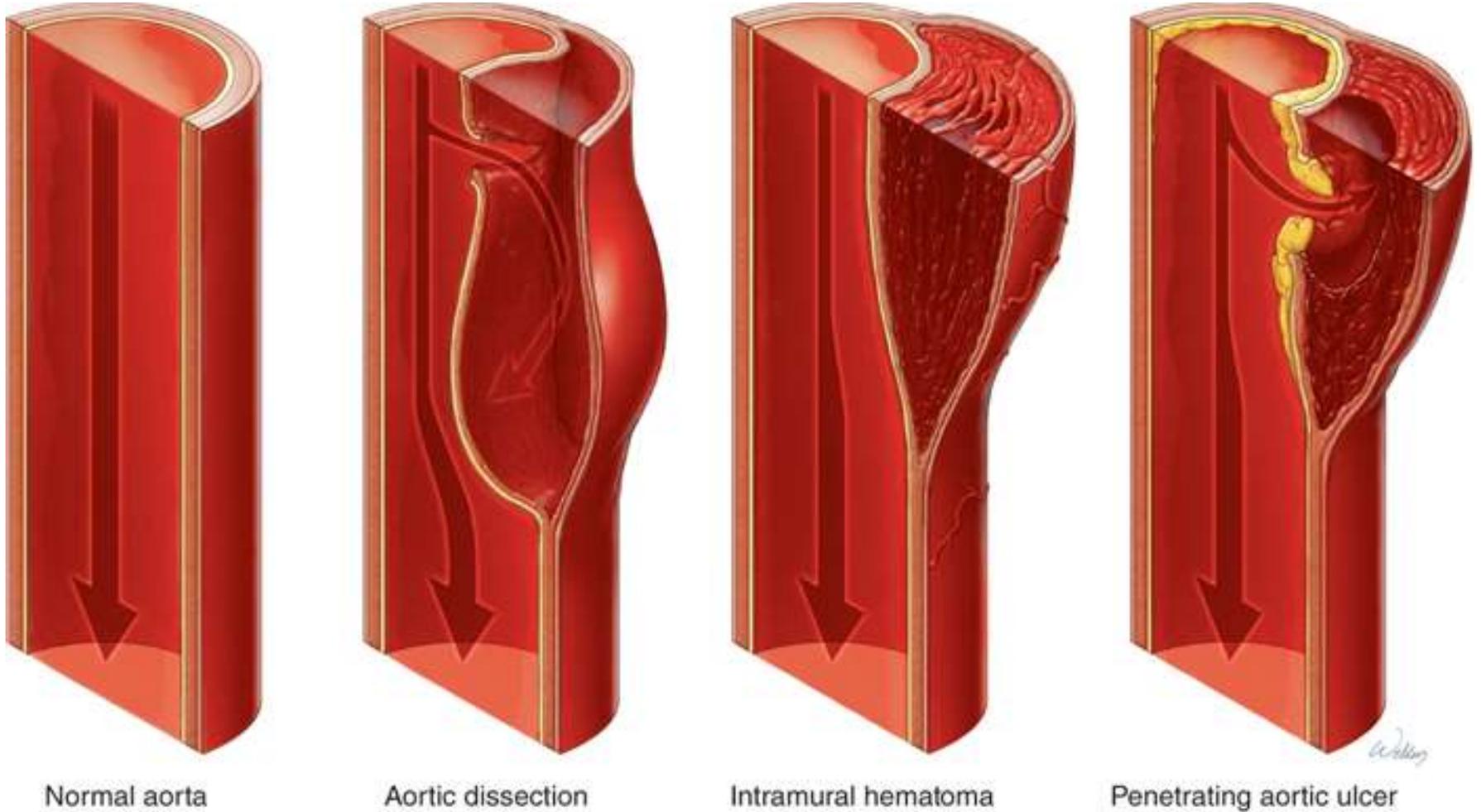
- Incidence ~3/100,000 per year
- Most common catastrophe of the aorta
- Life-threatening condition
  - Early mortality 1-2% per hour
  - Survival is improved with prompt therapy
- Peri-operative mortality increased with “complicated” dissections



# Aortic Dissection



# Aortic Dissection vs. Intramural Hematoma vs. Penetrating Atherosclerotic Ulcer



# Classification of Aortic Dissection

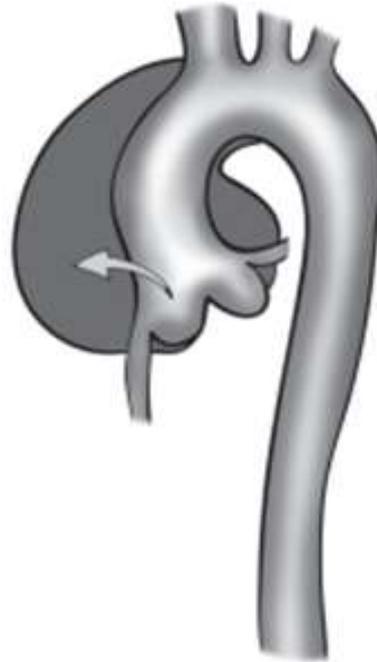
**DeBakey I**

**DeBakey II**

**DeBakey III**

**Stanford Type A**

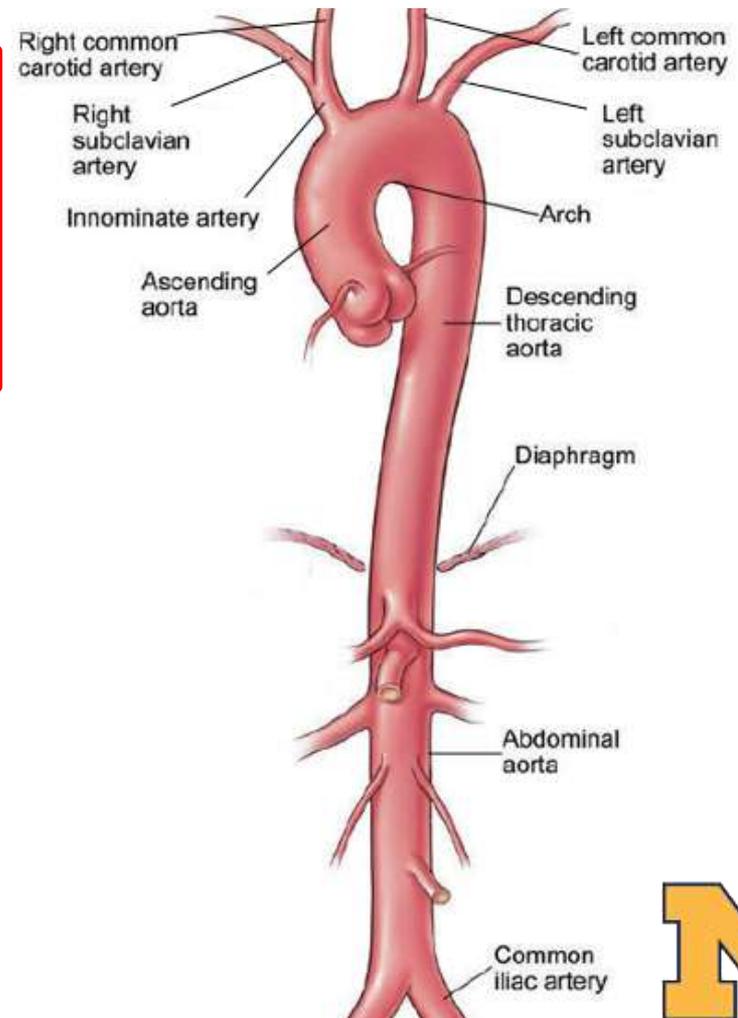
**Stanford Type B**



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# Complications of Acute Type A Dissection

- Acute aortic insufficiency
- Myocardial infarction
- Rupture/tamponade
- Stroke
- Rupture/exsanguination
- Paralysis
- Intestinal ischemia
- Acute kidney injury
- Lower extremity ischemia



# Complications of Acute Type A Dissection

**Table 4** Main clinical presentations and complications of patients with acute aortic dissection

	Type A	Type B
Chest pain	80%	70%
Back pain	40%	70%
Abrupt onset of pain	85%	85%
Migrating pain	<15%	20%
Aortic regurgitation	40–75%	N/A
Cardiac tamponade	<20%	N/A
Myocardial ischaemia or infarction	10–15%	10%
Heart failure	<10%	<5%
Pleural effusion	15%	20%
Syncope	15%	<5%
Major neurological deficit (coma/stroke)	<10%	<5%
Spinal cord injury	<1%	NR
Mesenteric ischaemia	<5%	NR
Acute renal failure	<20%	10%
Lower limb ischaemia	<10%	<10%

NR = not reported; NA = not applicable. Percentages are approximated.

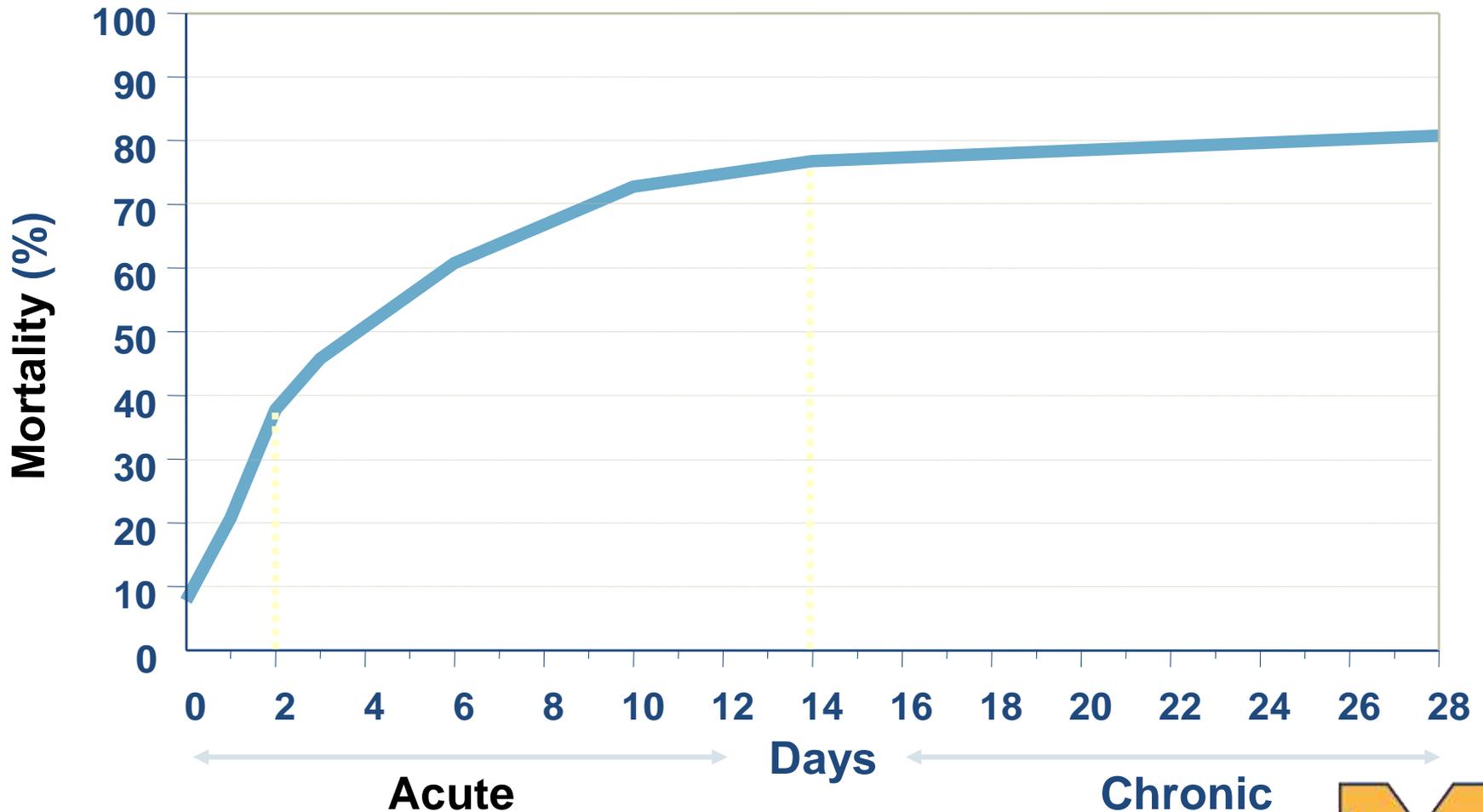


# Aortic Dissection: Initial Management

- ABC's
- Invasive hemodynamic monitoring
- Anti-impulse therapy to decrease shear stress
- Prompt surgical/endovascular repair
  - Acute Type A
  - Complicated Type B
- Medical therapy vs. endovascular repair
  - Uncomplicated Type B



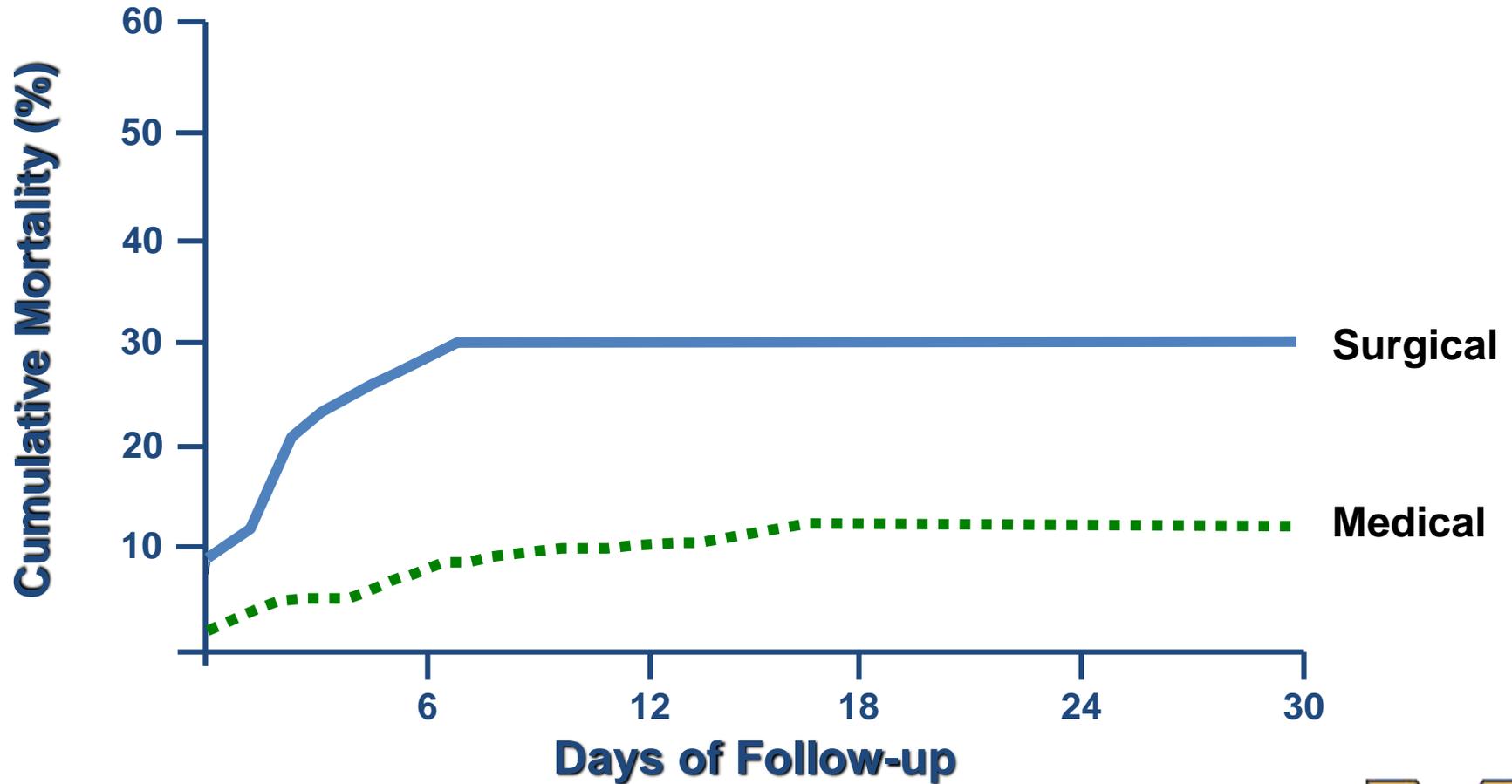
# Mortality from Acute Type A Dissection



International Registry of Acute Aortic Dissection (IRAD)  
Trimarchi S et al. J Thorac Cardiovasc Surg 2005;129:112-22.



# Mortality from Acute Type B Dissection



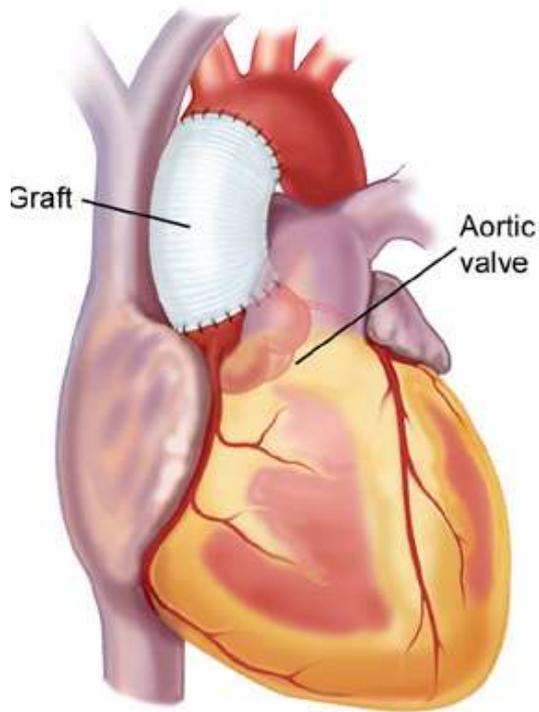
International Registry of Acute Aortic Dissection (IRAD)  
Suzuki T et al. Circulation 2003;108[suppl 1]:II312-7.

# Timing of Dissection

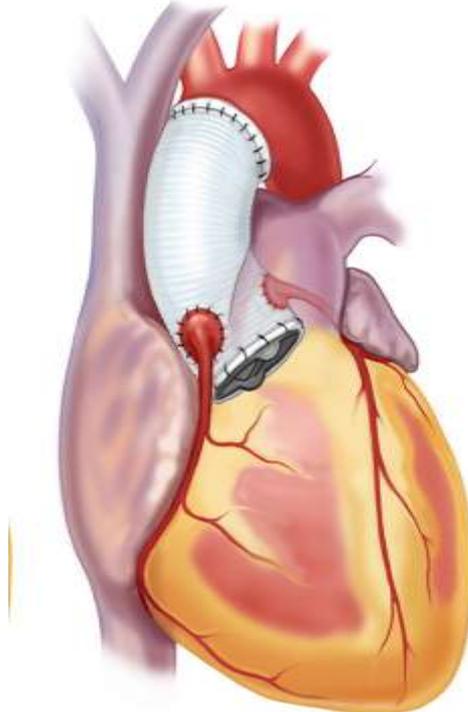
- Hyperacute < 48 hrs
- 48 hrs  $\leq$  Acute < 2 wks
- 2 wks  $\leq$  Subacute < 90 days
- Chronic > 90 days



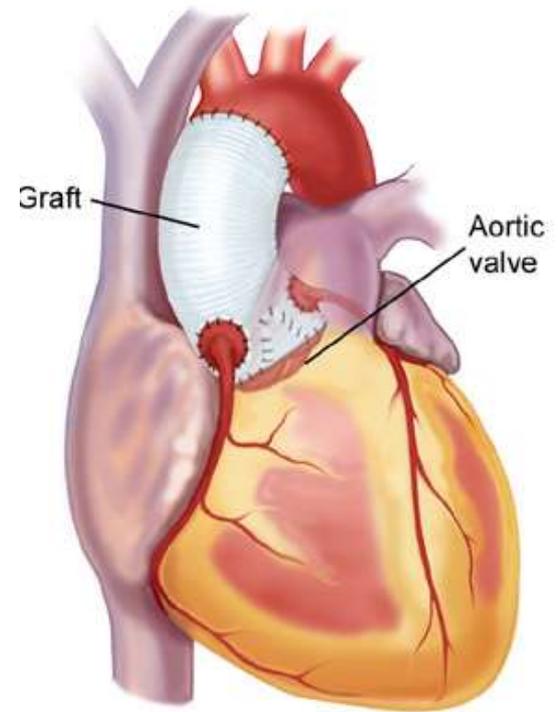
# Surgical Management of Type A Dissection



Supra Coronary Graft

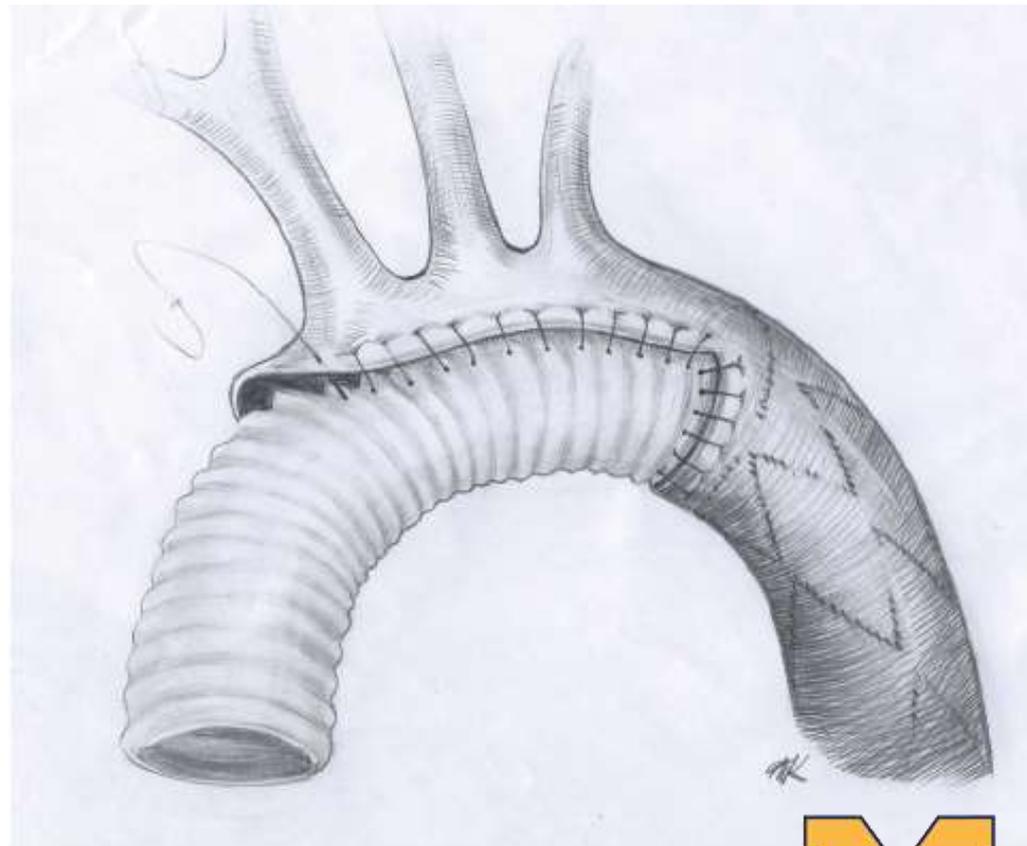
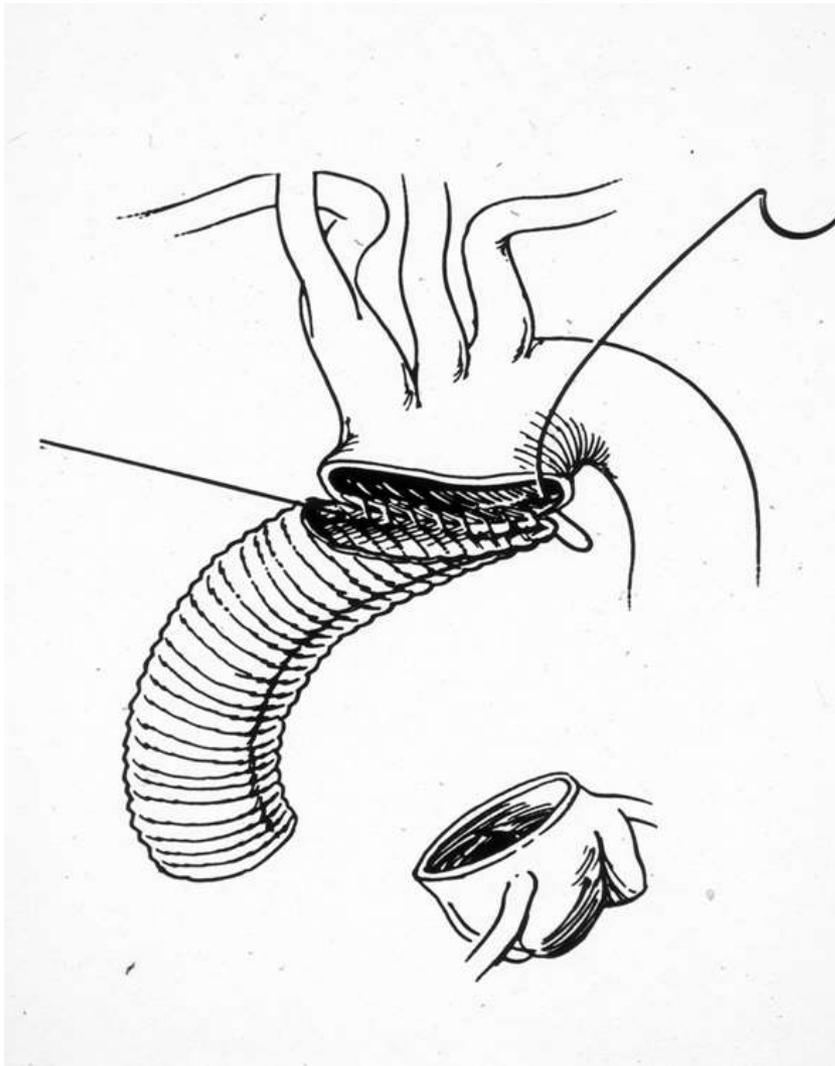


Composite Graft



Valve Sparing Aortic Root

# Hemiarch with and without Frozen Elephant Trunk

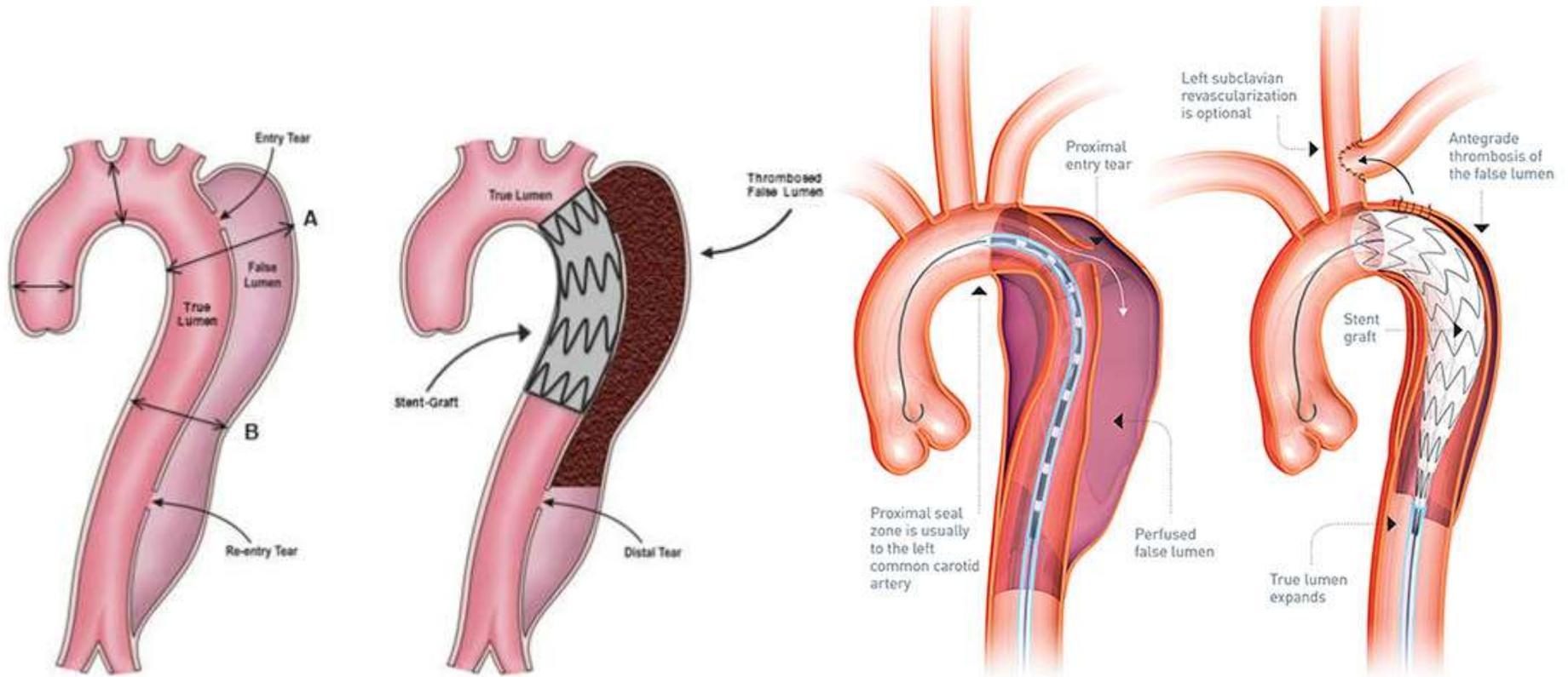


<http://www.annalscts.com/article/view/1697/2380>



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# Thoracic Endovascular Aortic Repair (TEVAR) for Acute Type B Dissection



<http://circ.ahajournals.org/content/120/25/2519.figures-only>

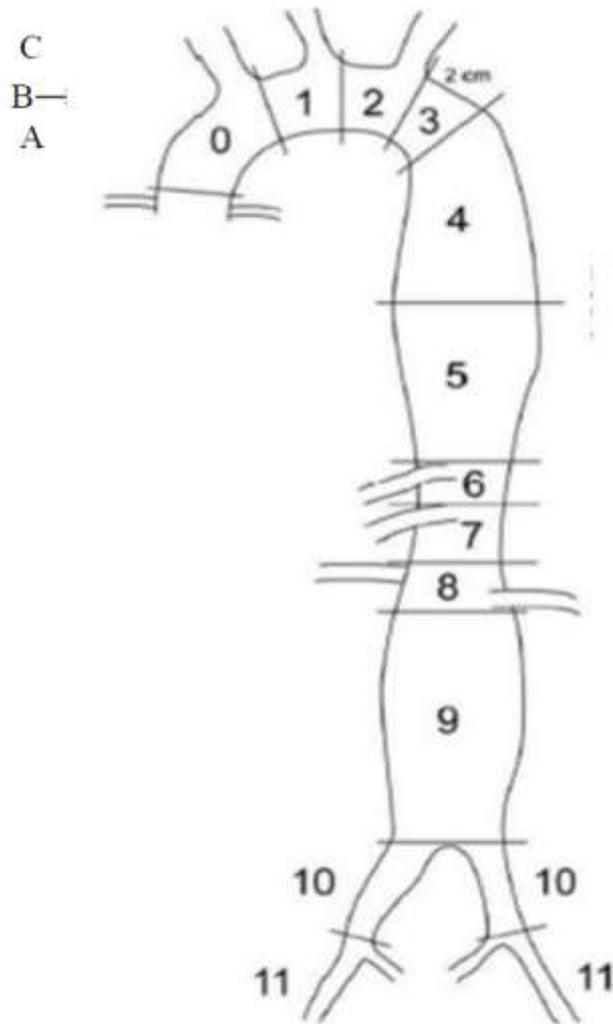
<http://www.massgeneral.org/about/newsarticle.aspx?id=5355>

ILLUSTRATION BY BRYAN CHRISTIE



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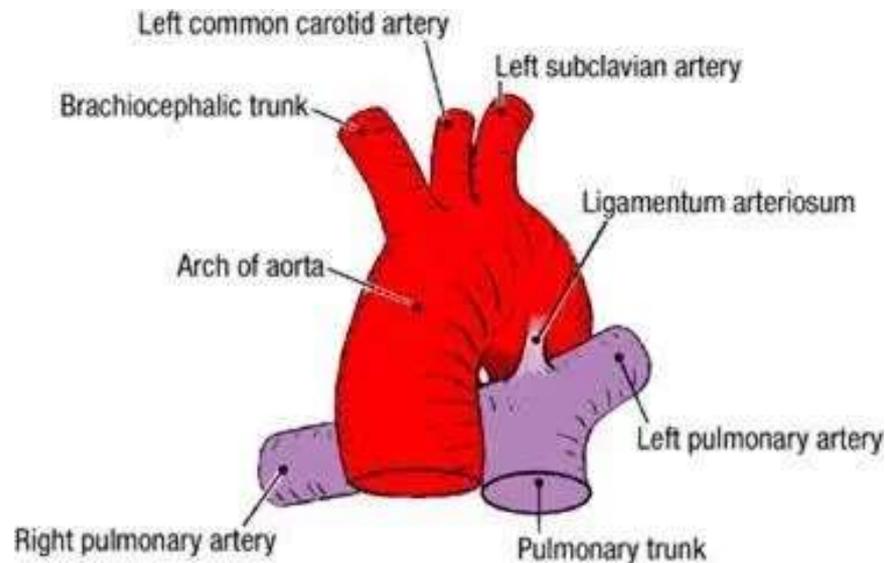
# Endovascular Zones of the Aorta



- A. Below sinotubular junction
- B. Sinotubular junction to mid ascending
- C. Mid ascending to distal ascending
- D. Zone 1 (between innominate and left carotid)
- E. Zone 2 (between left carotid and left subclavian)
- F. Zone 3 (first 2 cm. distal to left subclavian)
- G. Zone 4 (end of zone 3 to mid descending aorta ~ T6)
- H. Zone 5 (mid descending aorta to celiac)
- I. Zone 6 (celiac to superior mesenteric)
- J. Zone 7 (superior mesenteric to renals)
- K. Zone 8 (renal to infra-renal abdominal aorta)
- L. Zone 9 (infra-renal abdominal aorta)
- M. Zone 10 (common iliac)
- N. Zone 11 (external iliacs)

# Blunt Traumatic Aortic Injury

- Occurs in trauma population
- Results from acute deceleration injury and shear at ligamentum arteriosum
- Evolution of grading system and treatment strategy



<https://badem.co.za/ubuntu-4-curious-case-ligamentum-arteriosum/>

# Blunt Traumatic Aortic Injury (BTAI)

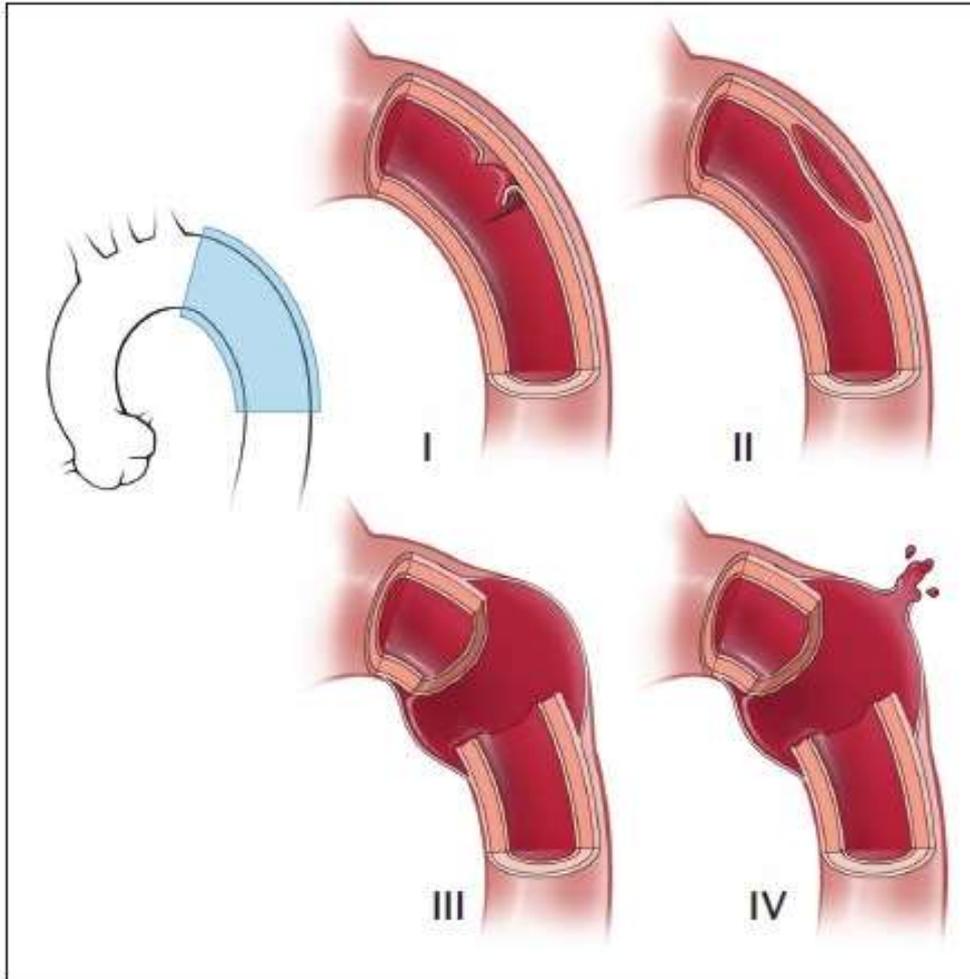


Figure 3. Classification system for BTAI. Illustration showing the different grades of BTAI including grade I (intimal tear/flap), grade II (intramural hematoma), grade III (pseudoaneurysm), and grade IV (rupture). This figure was adapted from the *Journal of Vascular Surgery*, Vol 49, Azizzadeh A, et al, Blunt traumatic aortic injury: initial experience with endovascular repair, Page 1403–1408, Copyright Society for Vascular Surgery 2009.



# Blunt Traumatic Aortic Injury (BTAI)

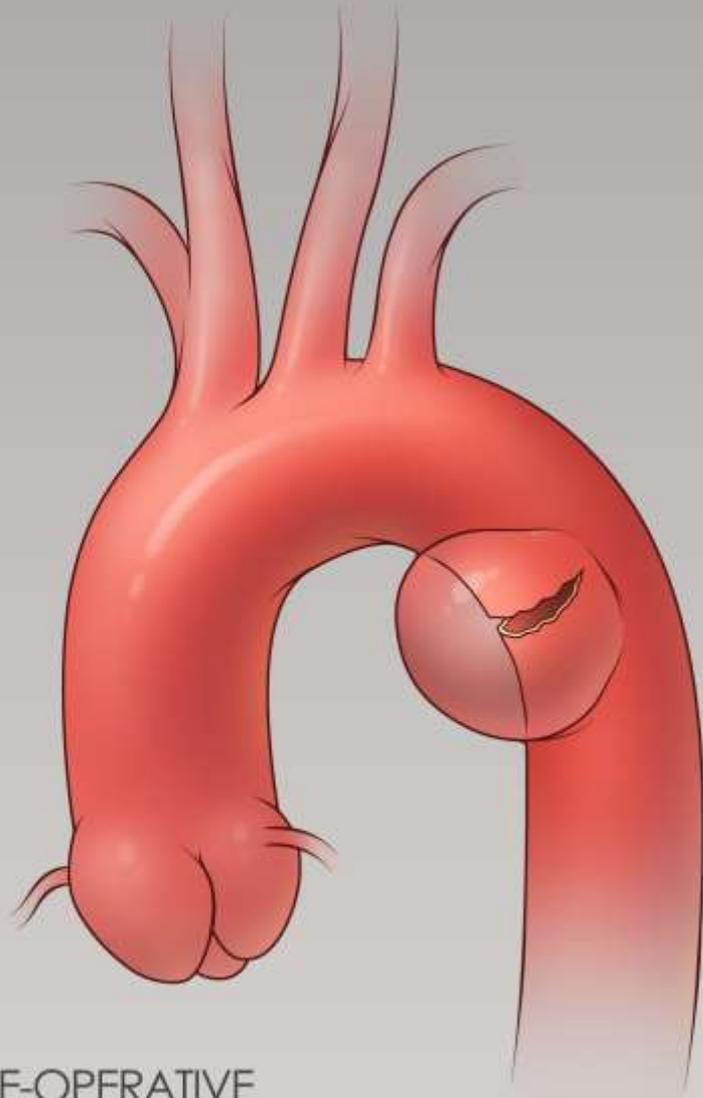


Photo courtesy of Amy Geltz

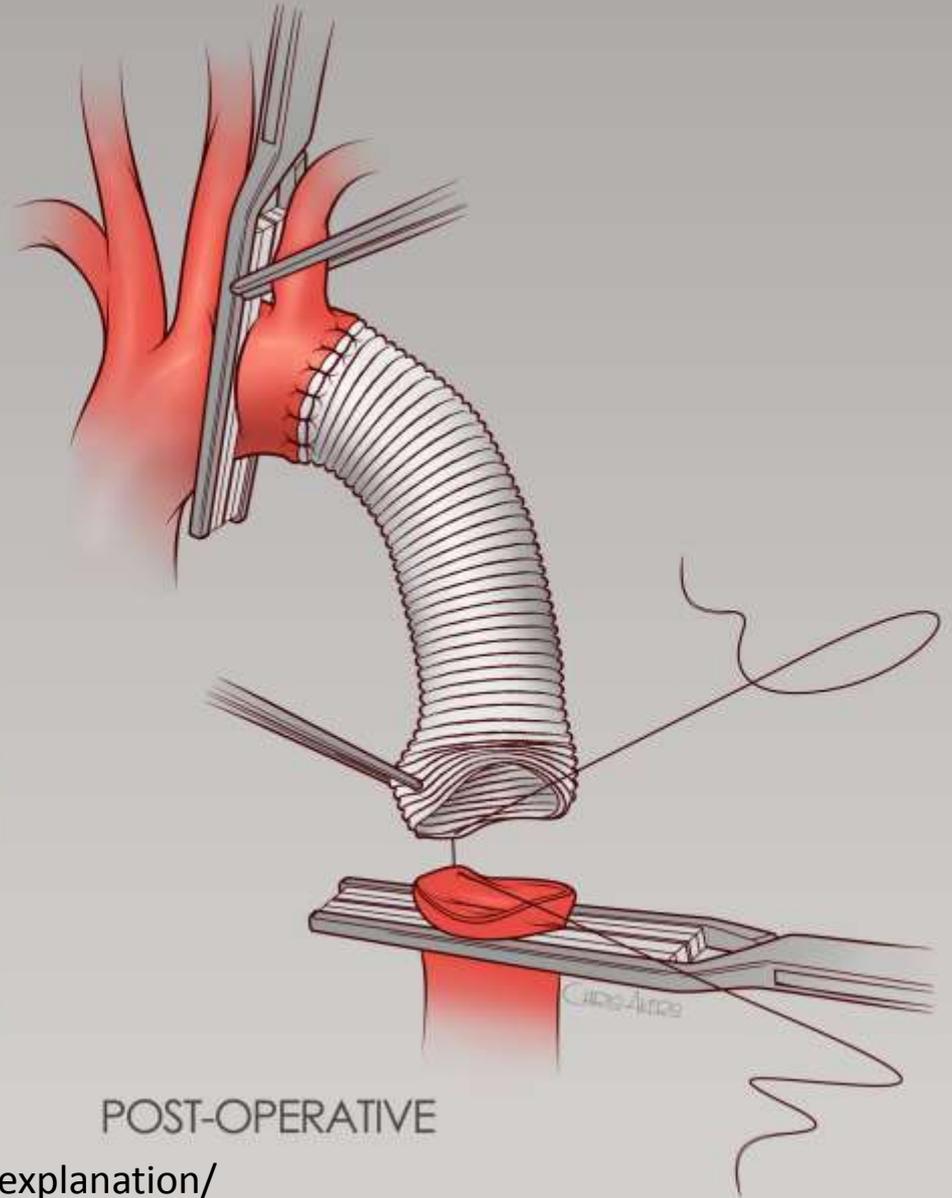


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# BTAI: Open Repair

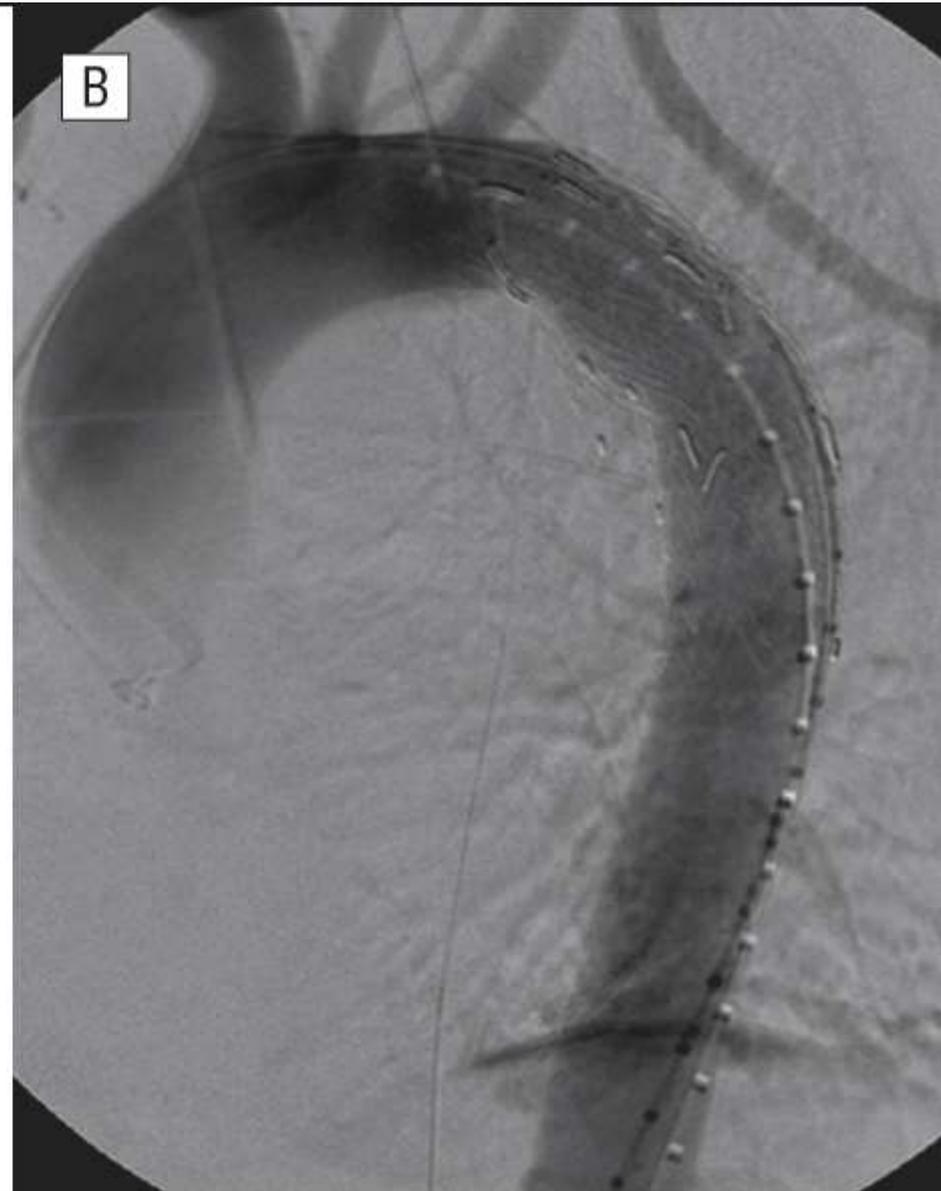


PRE-OPERATIVE



POST-OPERATIVE

# BTAI: Zone 3 TEVAR



# BTAI: Zone 2 TEVAR (covering LSC)



[https://www.researchgate.net/figure/50228072\\_fig4\\_Figure-5-Thoracic-endograft-placement-to-repair-an-injury-at-the-aortic-isthmus-Note-the](https://www.researchgate.net/figure/50228072_fig4_Figure-5-Thoracic-endograft-placement-to-repair-an-injury-at-the-aortic-isthmus-Note-the)

# Credits

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- Amy Geltz, for assistance with slides
- Thomas MacGillivray, for assistance with slides and the very useful Bounty paper towel analogy
- Google, for great pictures



# Thank you!



# Go Blue!