# Novel Predictors for Type A Dissections: Ascending Aortic Biomechanics

Elaine Tseng, MD
Professor of Surgery, University of California San Francisco
Chief of Cardiothoracic Surgery, San Francisco VA

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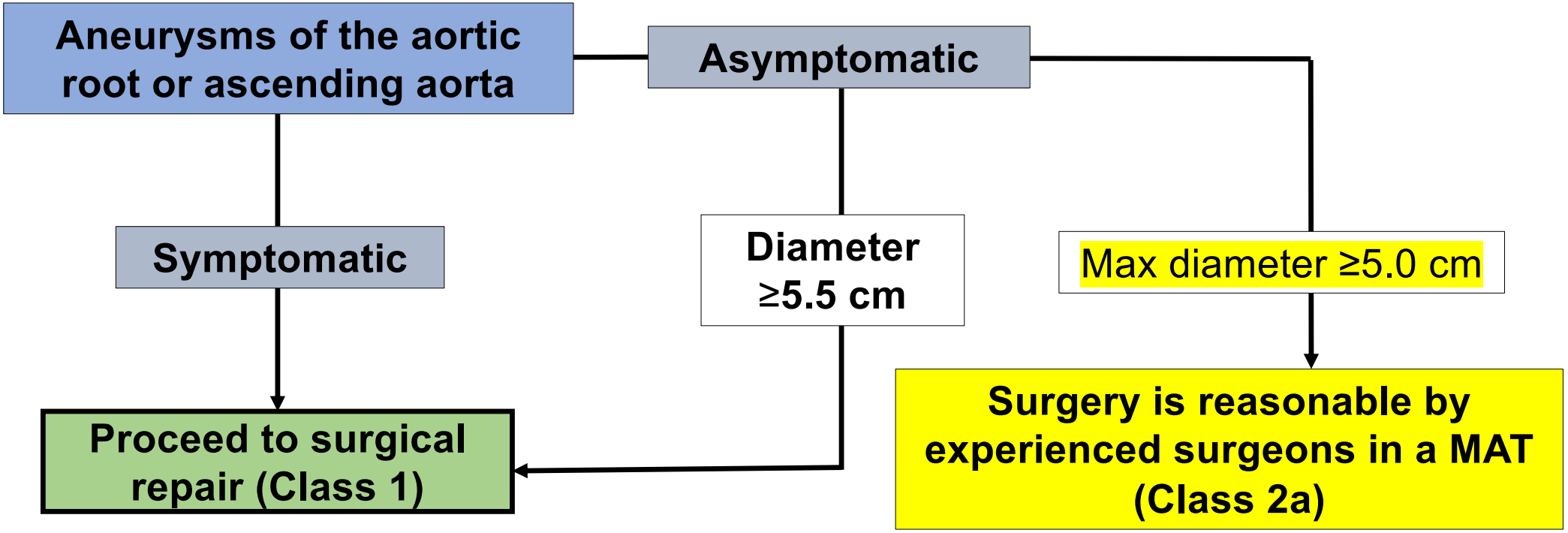
# Disclosures

- No disclosures.

# Recommendations for Surgery for Sporadic Aneurysms of the Aortic Root and Ascending Aorta

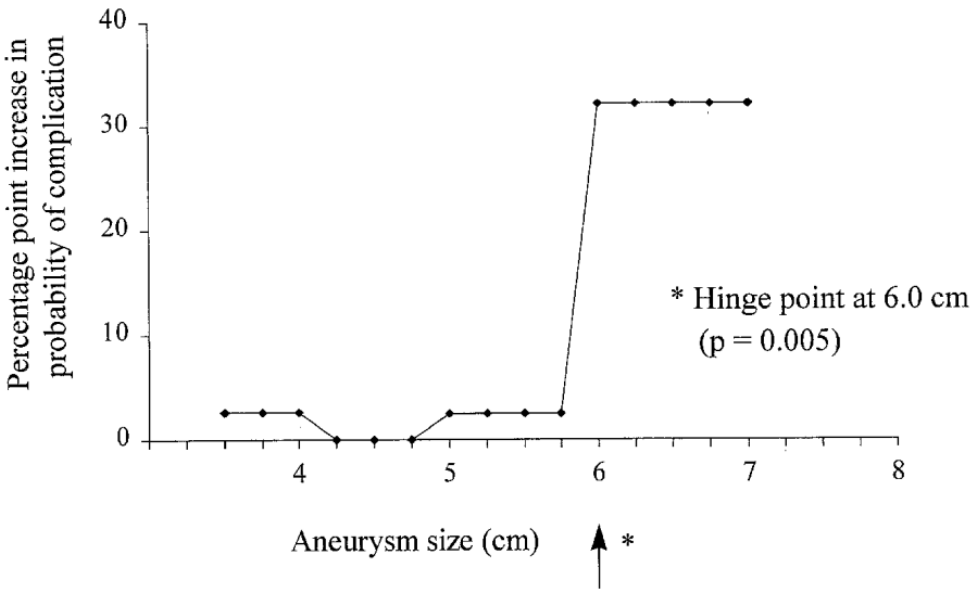



MAT, multidisciplinary aortic team; max, maximal;

Isselbacher, E. M., et al. 2022 ACC/AHA Guideline for the Diagnosis and Management of Aortic Disease. *Circulation*.

# Historic Aortic Event Rates

Original Studies: Yale 1985-1997




- 230 pts with TAA
- 111 pts with ascending TAA
- Hinge point at 6.0cm
- Increased probability of dissection or rupture relative to aneurysm size

Coady JTCVS 1997;113:476-91

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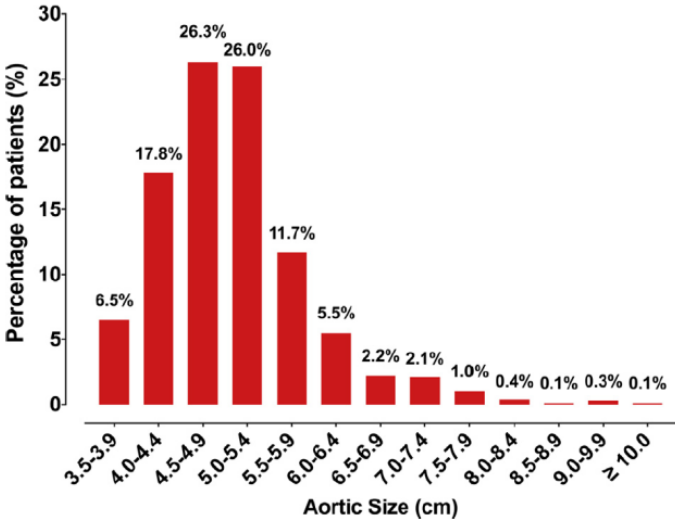
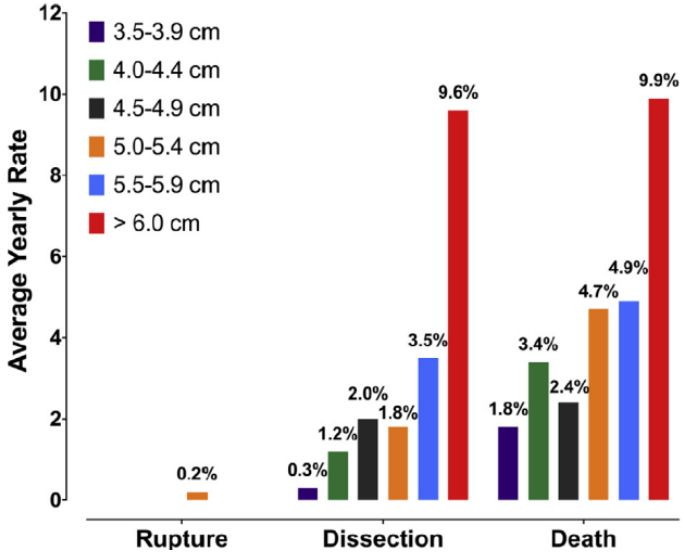
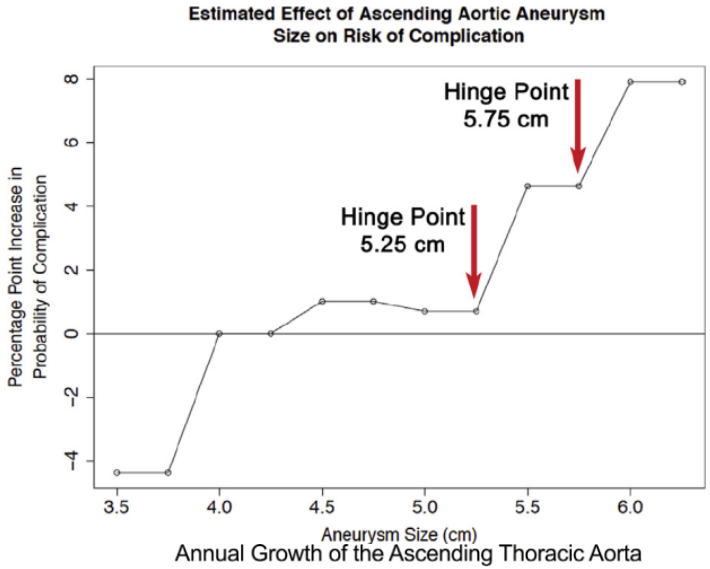
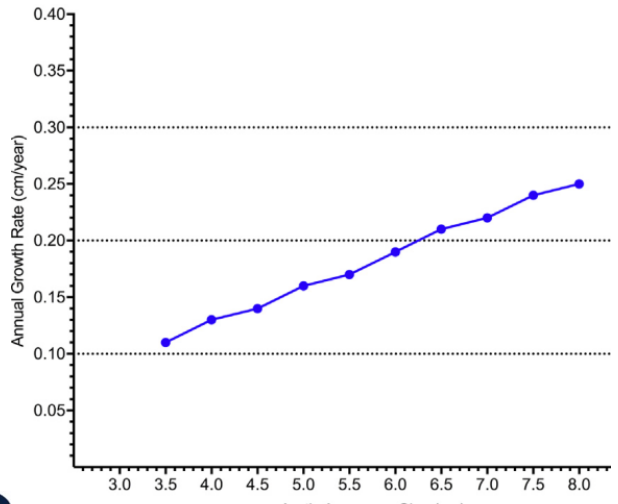
# Yale Aortic Event Rates

## Update of Yale Series




- 3349 TAA pts: 780 aTAA pts (1272 size measurements), mean f/u 47.7 mo
- First hinge point 5.25cm, second 5.75cm
- Updated growth rate: 1.4mm/yr (females and Marfan risk factors for growth)

Zafar JTCVS 2018;155:1938-50

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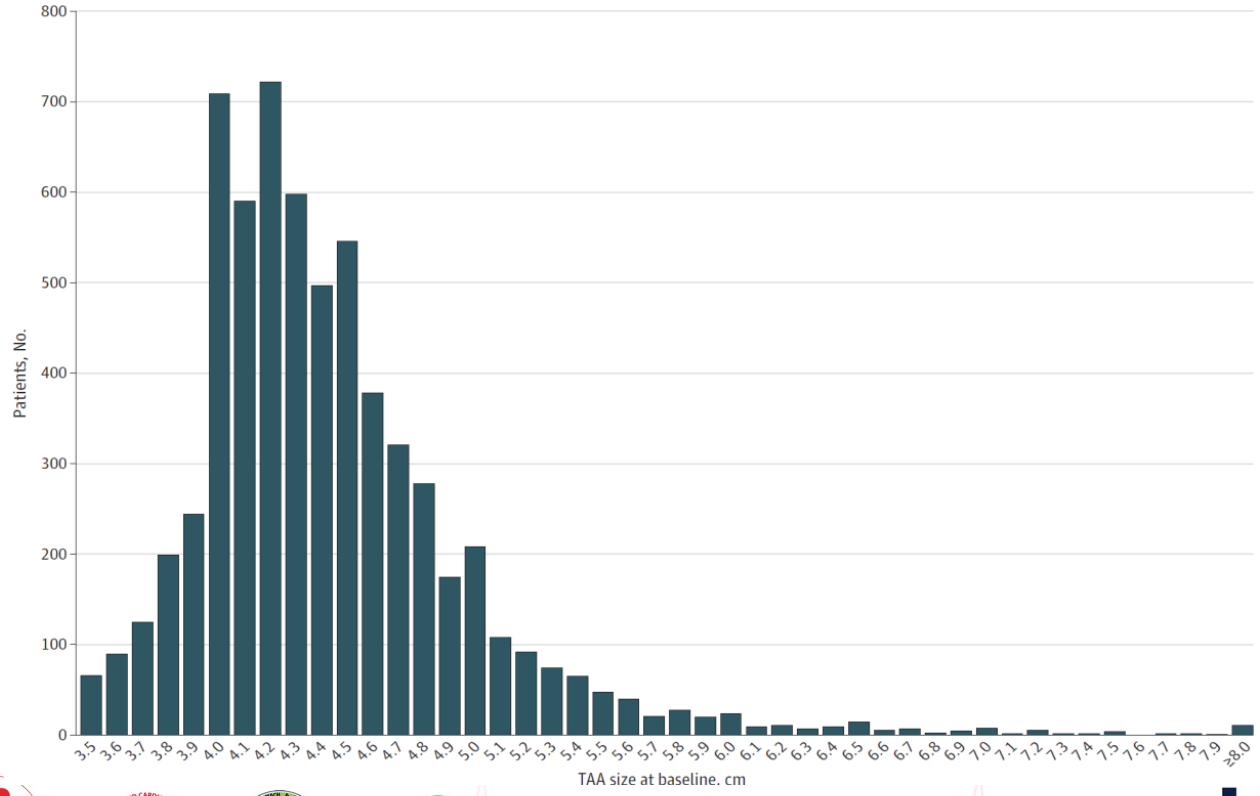
# ATAA Size and Long-Term Outcomes

JAMA Cardiology | Original Investigation

## Association of Thoracic Aortic Aneurysm Size With Long-term Patient Outcomes
The KP-TAA Study

Matthew D. Solomon, MD, PhD; Thomas Leong, MPH; Sue Hee Sung, MPH; Catherine Lee, PhD; J. Geoff Allen, MD; Joseph Huh, MD; Paul LaPunzina, MD; Hon Lee, MD; Duncan Mason, MD; Vicken Melikian, MD; Daniel Pellegrini, MD; David Scoville, MD, PhD; Ahmad Y. Sheikh, MD; Dorinna Mendoza, MD; Sahar Naderi, MD; Ann Sheridan, MD; Xinge Hu, MD, PhD; Wendy Cirimele, BSN, MPA; Anne Gisslow, RN, MSN; Sandy Leung, RN; Kristine Padilla, RN; Michael Bloom, MA; Josh Chung, MD; Adrienne Topic, MD; Paniz Vafaei, MD; Robert Chang, MD; D. Craig Miller, MD; David H. Liang, MD, PhD; Alan S. Go, MD; for the Kaiser Permanente Northern California Center for Thoracic Aortic Disease




- Kaiser-Permanente TAA study: 6372 aTAA pts from 2000-2016
- TAA ≥3.5cm, >18 yrs, no aortic surgery or dissection, no genetic aortic disease
- 32% women, 68% men
- Mean TAA size at dx: 4.3cm
- Mean f/u 3.7 yrs
- BAV 11%

Solomon JAMA Card 2022;7(11):1160-9

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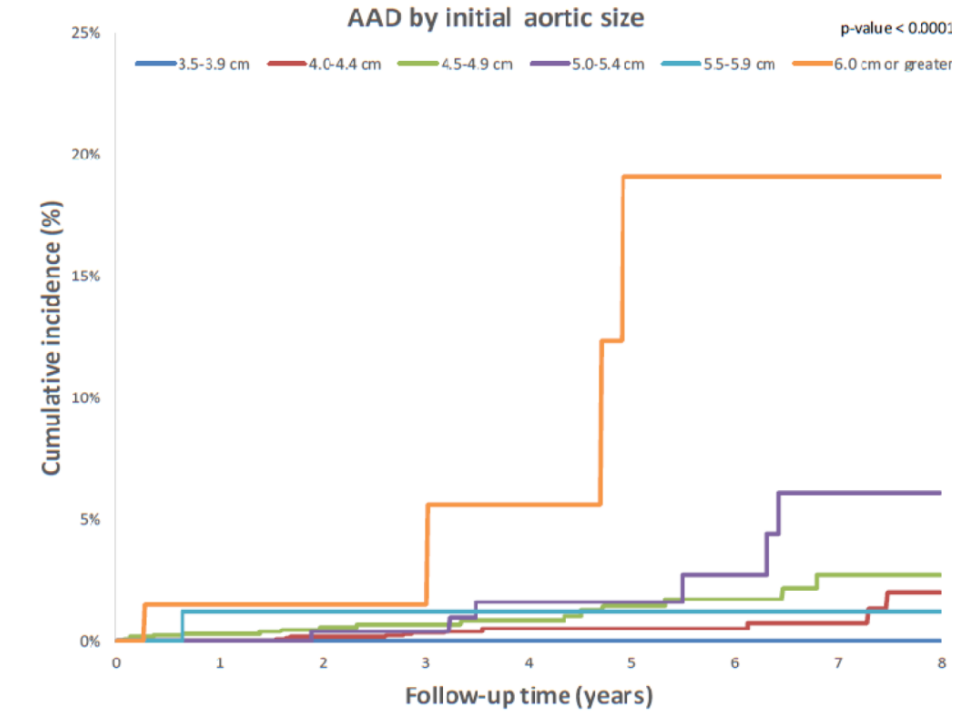
# ATAA Size and Long-Term Outcomes




Patients at risk

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3.5-3.9 cm | 726 | 630 | 503 | 400 | 304 | 219 | 155 | 76 | 43 |
| 4.0-4.4 cm | 3120 | 2604 | 1954 | 1416 | 990 | 681 | 454 | 222 | 96 |
| 4.5-4.9 cm | 1698 | 1312 | 996 | 782 | 566 | 400 | 285 | 164 | 95 |
| 5.0-5.4 cm | 548 | 323 | 239 | 186 | 136 | 104 | 70 | 40 | 26 |
| 5.5-5.9 cm | 156 | 76 | 54 | 40 | 31 | 25 | 22 | 12 | 7 |
| 6.0 cm or greater | 124 | 45 | 33 | 24 | 16 | 12 | 8 | 4 | 1 |

Solomon JAMA Card 2022;7(11):1160-9

- Aortic dissection 44pts (0.7%)
  - Only 1 BAV (1/747pts)
  - 27 Ascending, 13 Root, 4 Arch
  - 37 dissection, 3 IMH, 4 rupture
- Overall Incidence 0.22/100pt-yrs
- Median age at AD 75.2yrs (63.7-81.0yrs)
- No AD <4.0cm
- Dissection rates:
  - >4cm <6cm <0.5/100pt-yr, <1%/yr
  - ≥6cm 2.19/100pt-yr
- Hinge point 6cm for AD and AD + all-cause mortality

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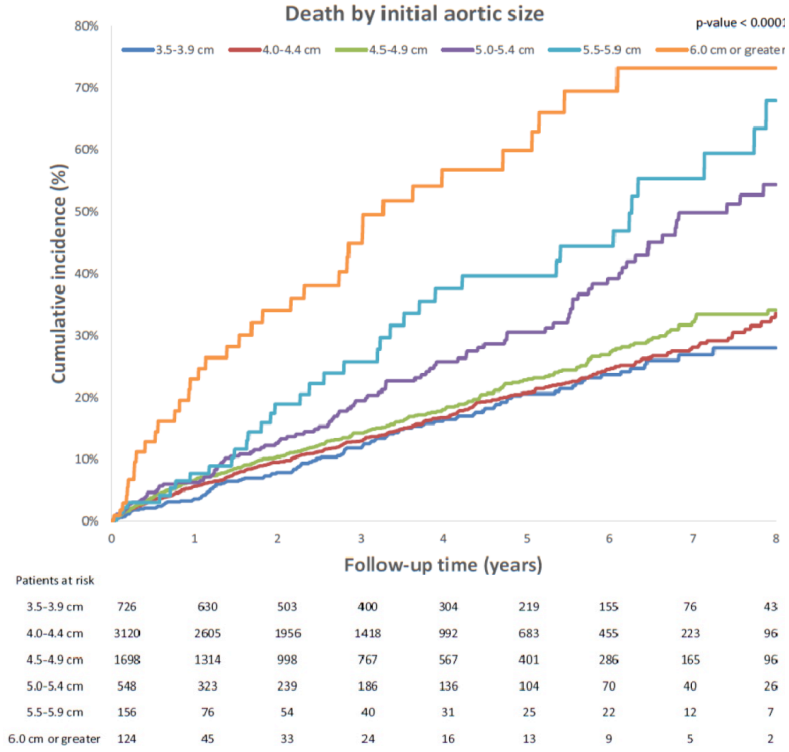
# ATAA Size and Long-Term Outcomes

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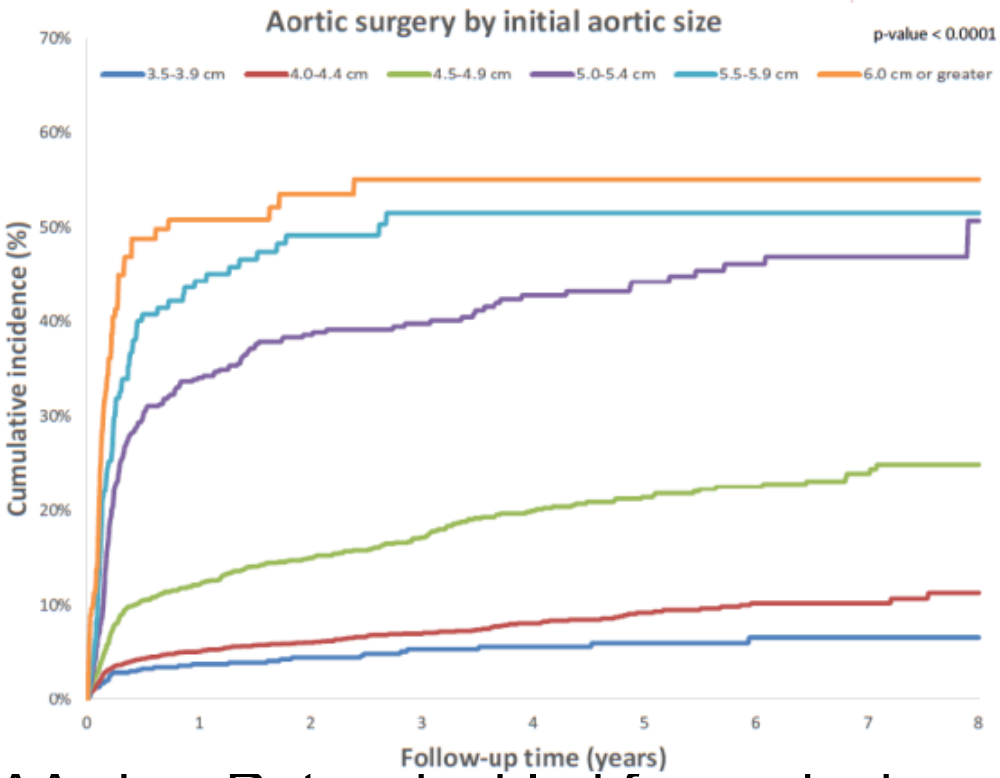
| 6.0 cm or greater | 124 | 45 | 33 | 24 | 16 | 13 | 9 | 5 | 2 |




- Dissection rates by time-updated ATAA size: Rates doubled for each size category from 4.0-5.5cm
  - <5.5cm AD <1%/yr

5.5-5.9cm AD 1.15/100pt-yr (~1% risk/yr)

Solomon JAMA Card 2022;7(11):1160-9

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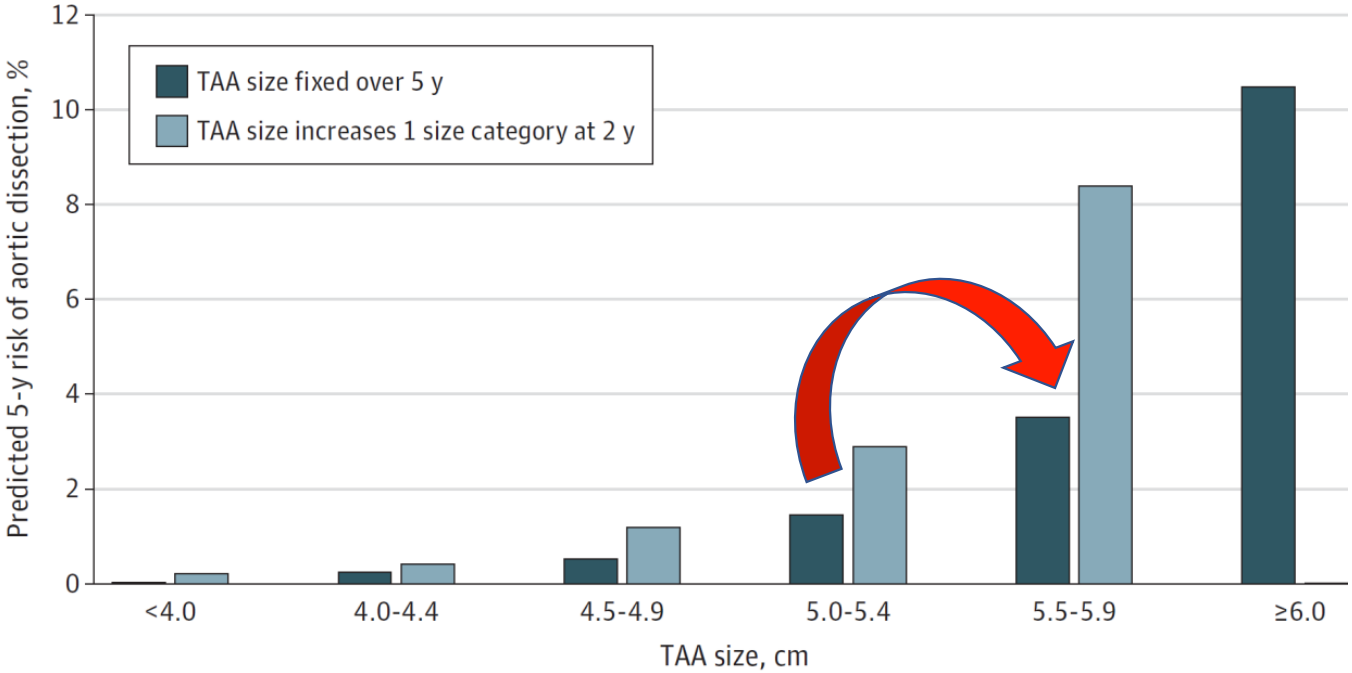
# ATAA Size and Long-term Outcomes

## Predicted Risk of Aortic Dissection Over 5 Years Based on Size & Growth




- Predicted risk AD in 5yrs:
  - 4-4.4cm 0.3% (CI 0.3-0.7)
  - 4.5-4.9cm 0.6% (0.4-1.3)
  - 5.0-5.4cm 1.5% (1.2-3.9)
  - 5.5-5.9cm 3.6% (1.2-12.8)
  - ≥6cm 10.5% (2.7-44.3)

- No difference in predictive power: diameter vs aortic size index

Solomon JAMA Card 2022;7(11):1160-9

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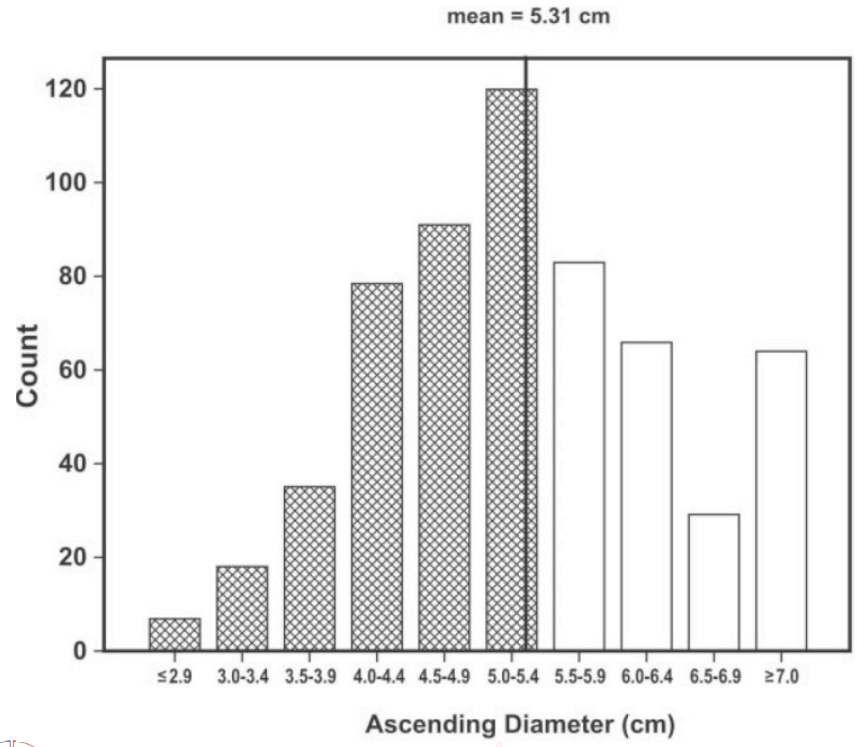
# TAA Size Paradox: 5.5cm Not Good Predictor of Type A Dissection

International Registry of Acute Aortic Dissection (IRAD)




- Distribution of aortic size at time of type A presentation (total n=591)
- 59% of pts <5.5cm
- 40% of pts <5.0cm

Pape Circulation 2007;116:1120-1127

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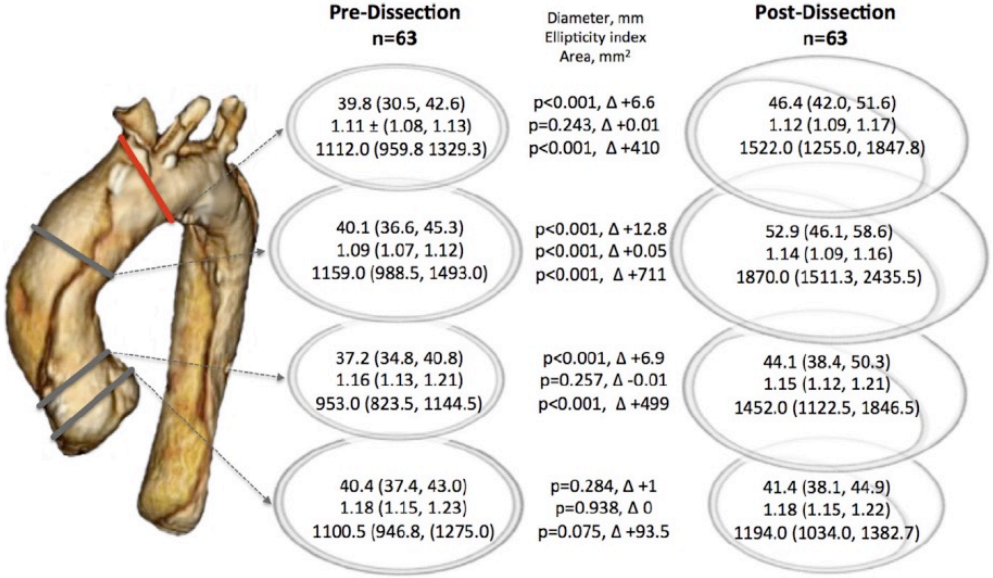
# ATAA Size Paradox: Pre-Dissection Size

## How Does the Ascending Aorta Geometry Change When It Dissects?




| | All (n = 63) | Spontaneous AADA (n = 27) |
|---|---|---|
| Sinus of Valsalva | 40.4 (37.4;43.0) | 40.5 (36.7;46.2) |
| Sinotubular junction | 37.2 (34.8;40.8) | 38.3 (34.9;42.2) |
| Mid-ascending aorta | 40.1 (36.6;45.3) | 43.1 (36.8;47.9) |
| Proximal aortic arch | 39.8 (36.1;42.6) | 38.8 (36.8;43.9) |
| Distal aortic arch | 33.8 (30.5;40.6) | 31.1 (27.9;33.8) |
| Proximal descending thoracic aorta | 36.0 (32.0;43.0) | 32.4 (28.0;34.3) |
| Mid-descending thoracic aorta | 32.5 (28.6;40.0) | 28.3 (26.0;30.2) |

- 6 tertiary centers across 2 continents with n=1821 type A dissection pts
- Excluded Marfan and BAV
- Included CTA <2 yrs before and within 12 hrs after dissection onset
- N=63 (27 spontaneous, 36 retrograde)
- Median age 68
- 54% men
- 62/63 max ascending diameter <5.5cm
- Prior to dissection largest diameter at mid-ascending with median 40.1mm (36.6, 45.3). Increased to 52.9 (46.1, 58.6)
- After dissection, 44% (28/63) ≥5.5cm and 60% (38/62) ≥5.0cm

Rylski JACC 2014;63:1311-9

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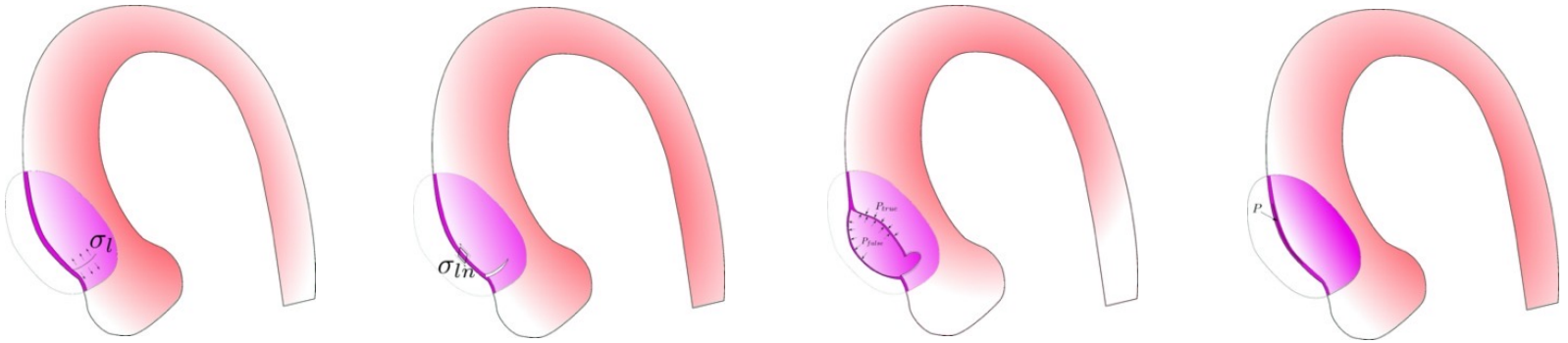
# How Can We Better Risk Stratify aTAA Pts?

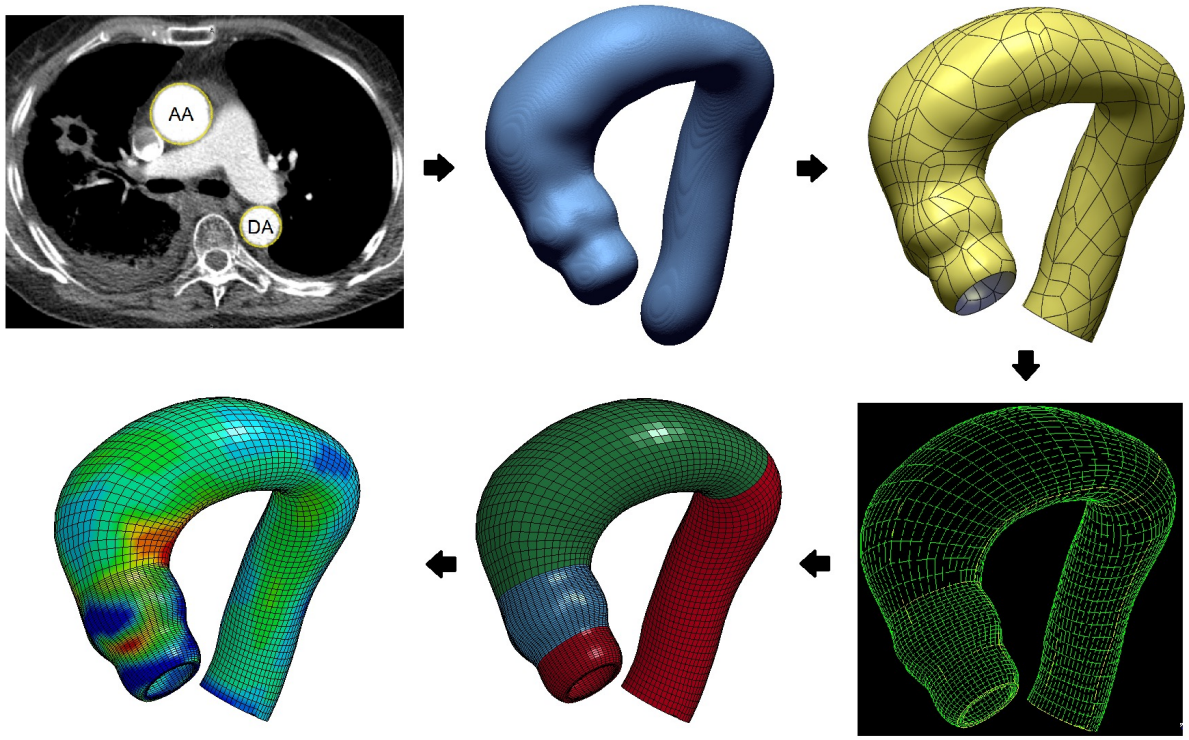
Aortic Dissection as a Biomechanical Failure



- The phenomena of dissection is a biomechanical event
  - Intimal tear in the aortic wall
  - Separation of the aortic layers
  - **Stress on aortic wall exceeds failure strength**
- The biomechanics approach seeks to quantify the physical forces on the aortic wall.

# How Do We Better Predict Dissection?

Patient-specific Ascending Thoracic Aortic Aneurysm Wall Stress > Wall Strength




- Computed Tomography Imaging
- Image Segmentation and Geometry Reconstruction
- Geometry meshing
- Cardiac cycle simulated
- Finite element analyses
- Mechanical Failure: Aneurysm wall stress > wall strength

Tseng et al. Ann Thorac Surg 2020 Sep;110(3)807-814

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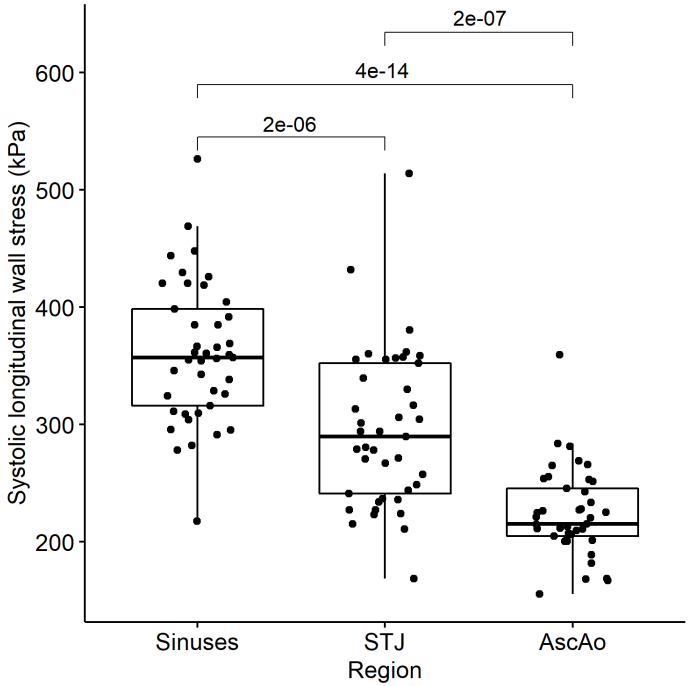
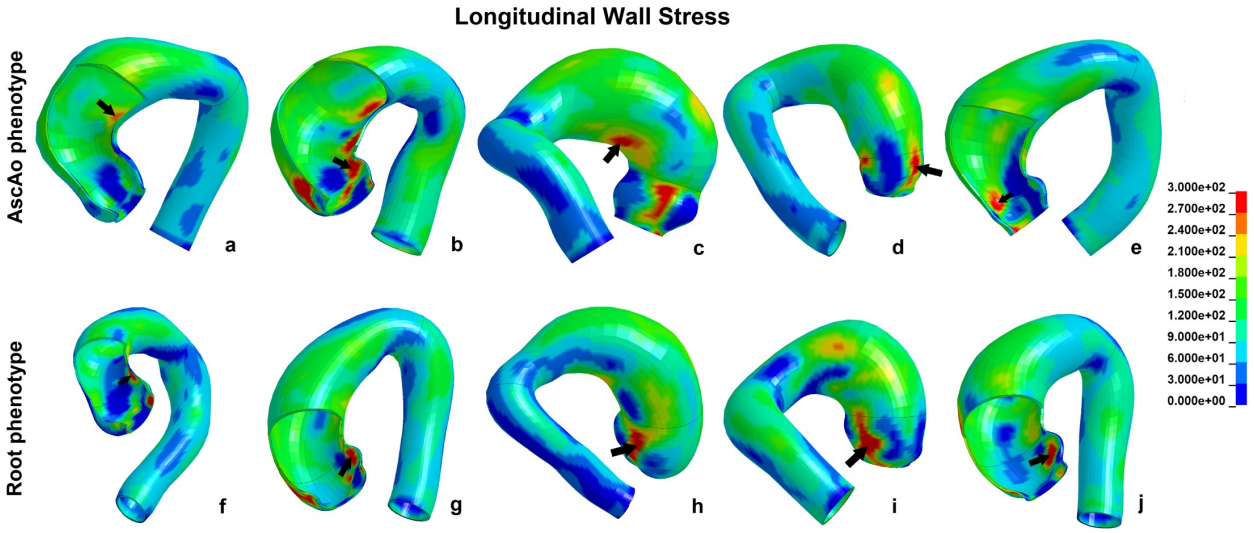
# How Is Wall Stress Distributed?

- Bicuspid Aortic Valve (BAV)




- **Wall Stress in Sinuses > Sinotubular Junction > Ascending Aorta**

Tseng et al. Ann Thorac Surg 2020 Sep;110(3)807-814

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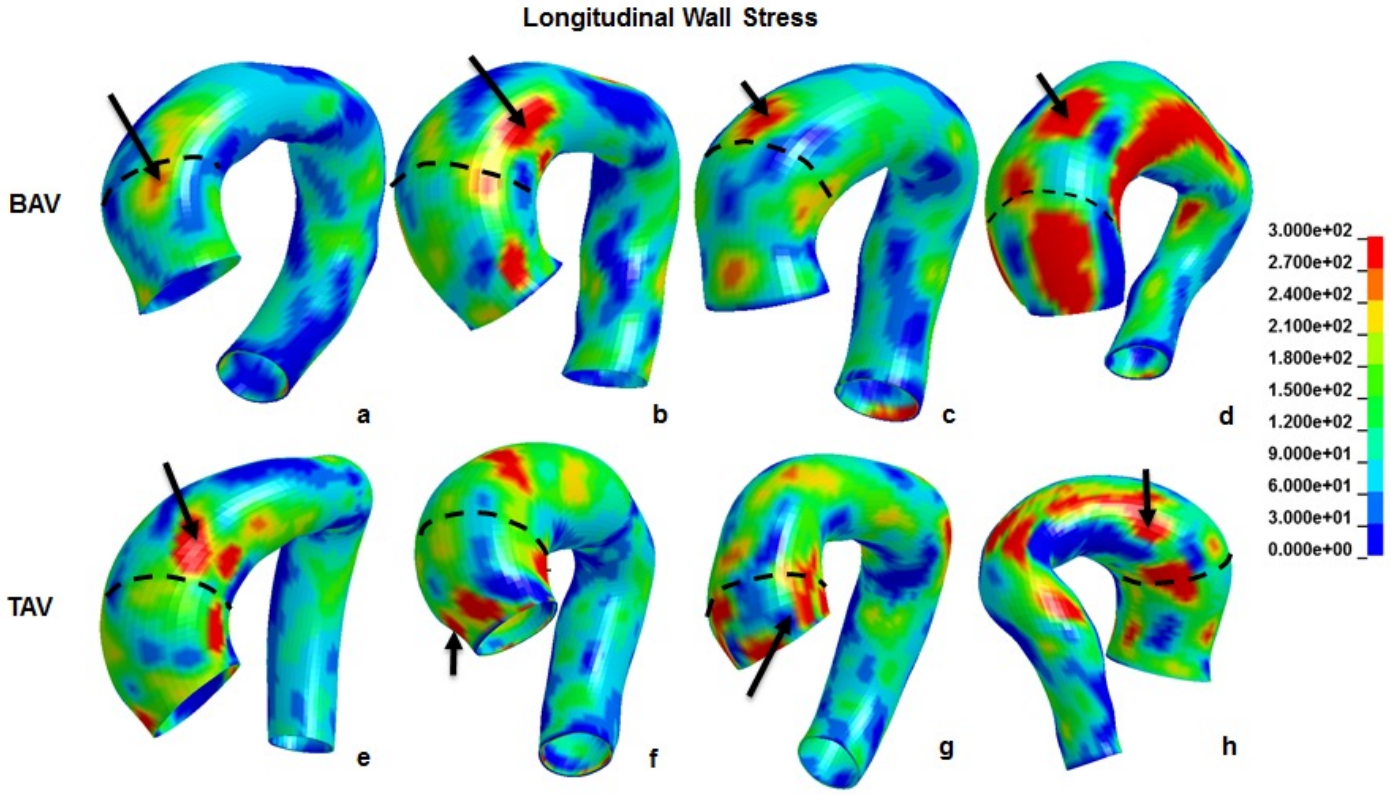
# Where is Peak Wall Stress vs Max Diameter?

## BAV and TAV Peak Wall Stress Is Not at Location of Max Diameter




Tseng et al. J Thorac Cardiovasc Surg. 2018 Aug;156(2):492-500.

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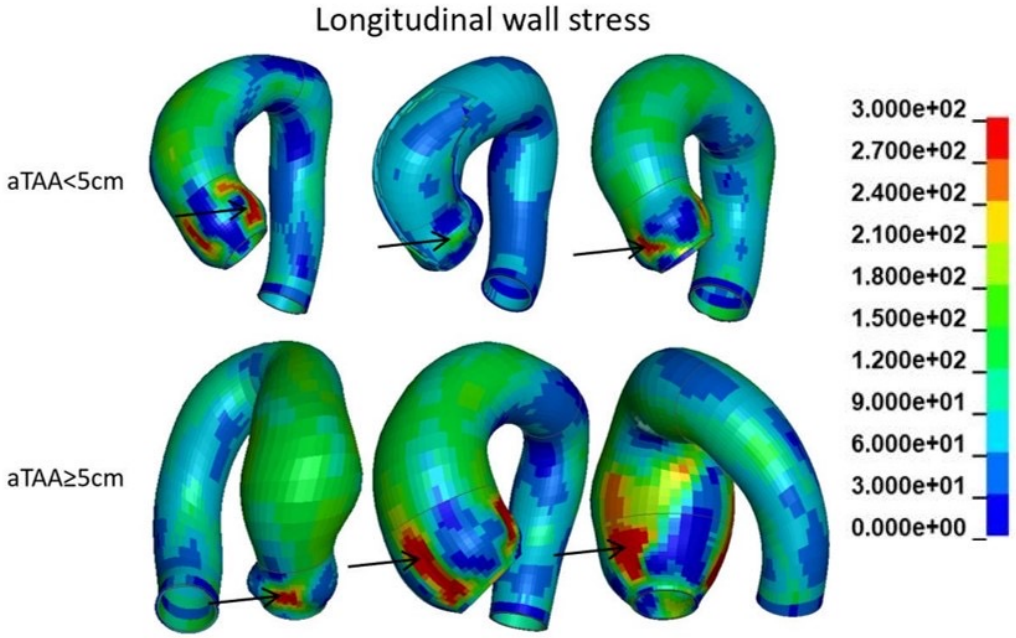
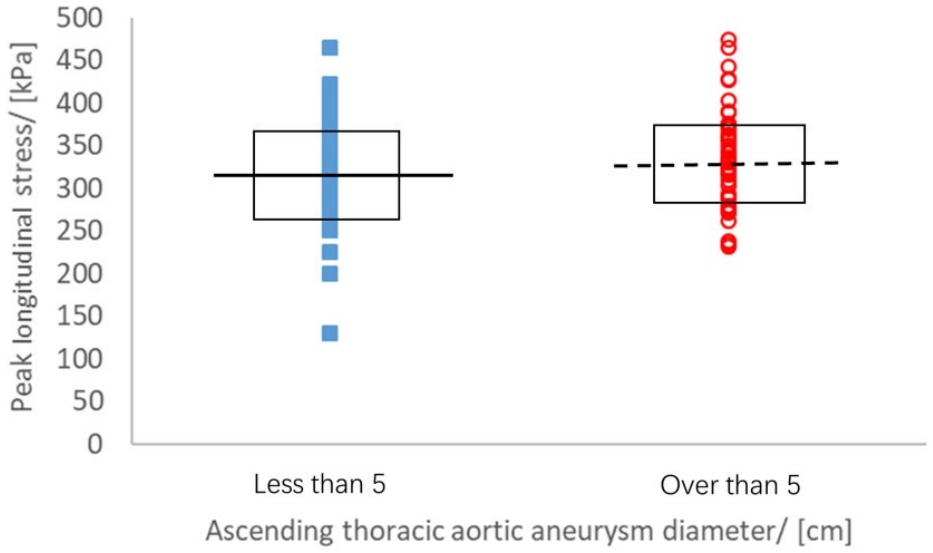
# What is Wall Stress in <5cm vs ≥5cm ATAA?




- Peak wall stresses do not differ significantly between <5cm and ≥5cm aTAA.

Tseng et al. J Thorac Cardiovasc Surg 2021 Nov;162(5):1452-1459

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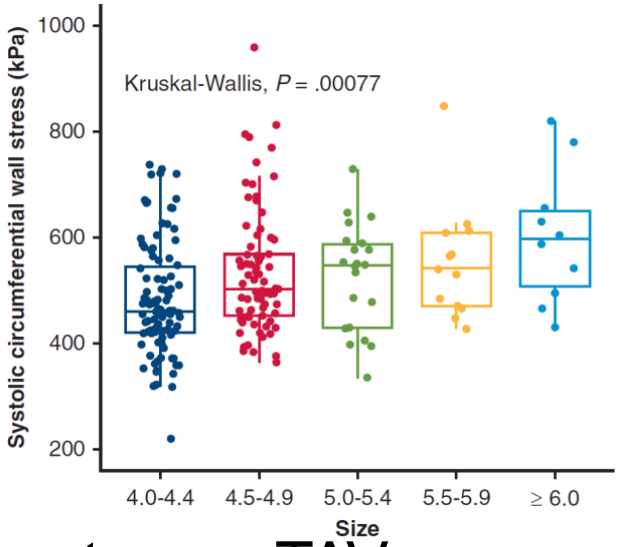
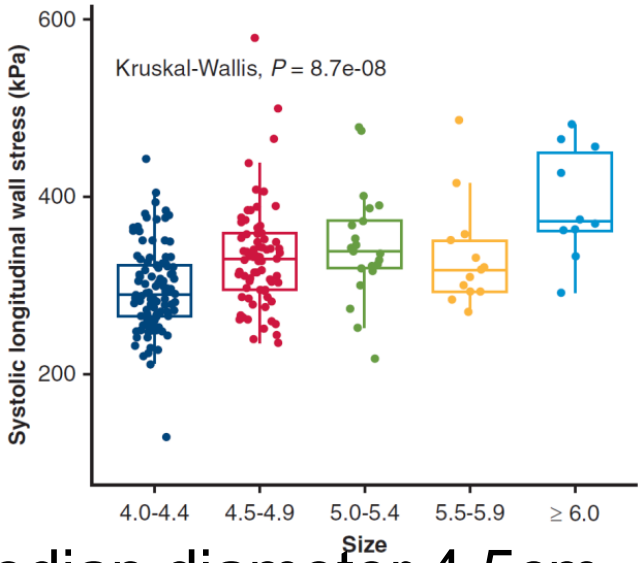
# Does Wall Stress Correlate with Diameter?

Tricuspid Aortic Valve (TAV) Aneurysm Peak Wall Stress Correlates with Diameter




- N=221 veterans TAV aneurysms and median diameter 4.5cm.
- Both peak circumferential and longitudinal wall stresses increased with diameter (p<0.001) in aneurysm as whole and each subregion, sinuses, STJ, and ascending Ao.
- Large overlap of stress ranges among groups.

Tseng et al. J Thorac Cardiovasc Surg. 2022 164(5):1365-75.

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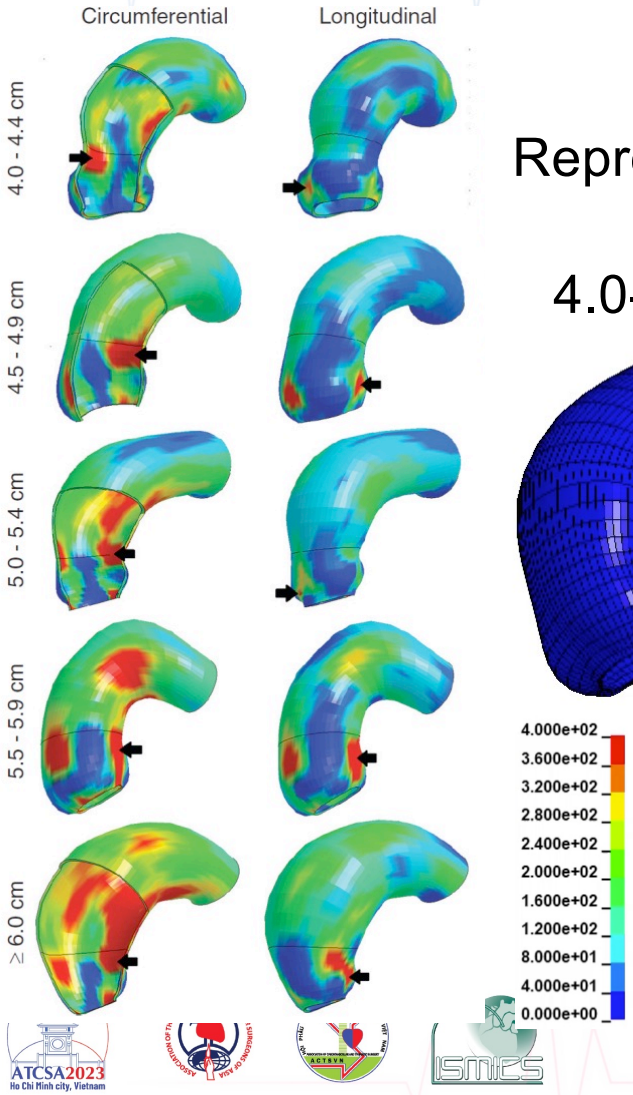
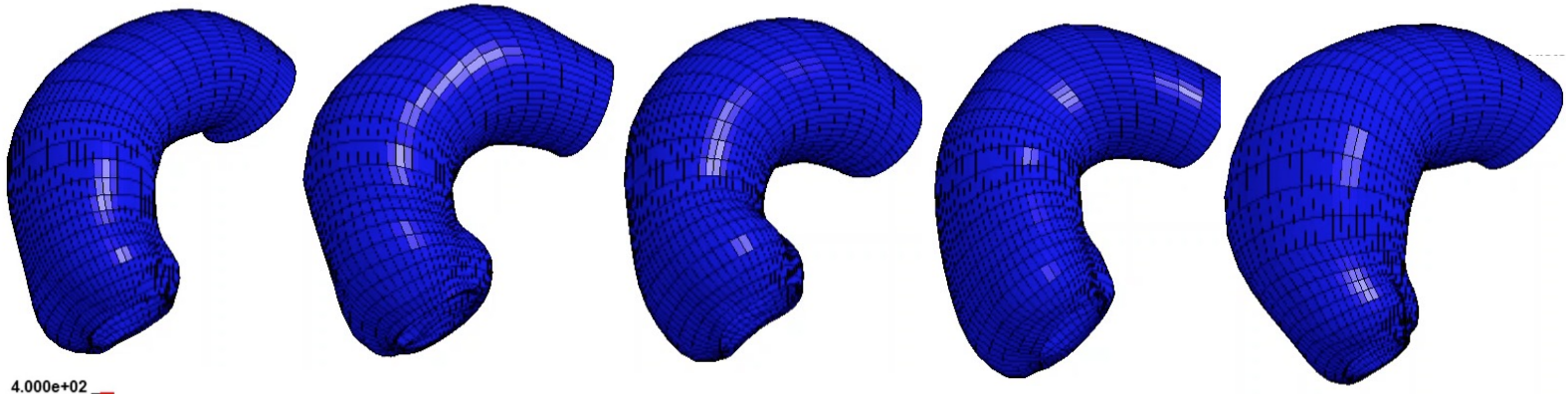
# TAV-ATAA Wall Stress FEA




Representative Simulations Based on Diameter Ranges

4.0-4.4cm | 4.5-4.9cm | 5.0-5.4cm | 5.5-6.0cm | >6.0cm



- Circumferential >> longitudinal stresses.

Tseng et al. J Thorac Cardiovasc Surg. 2022 164(5):1365-75.

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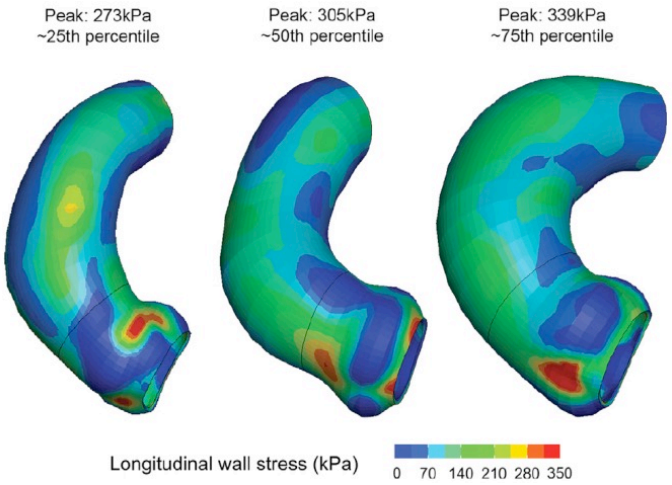
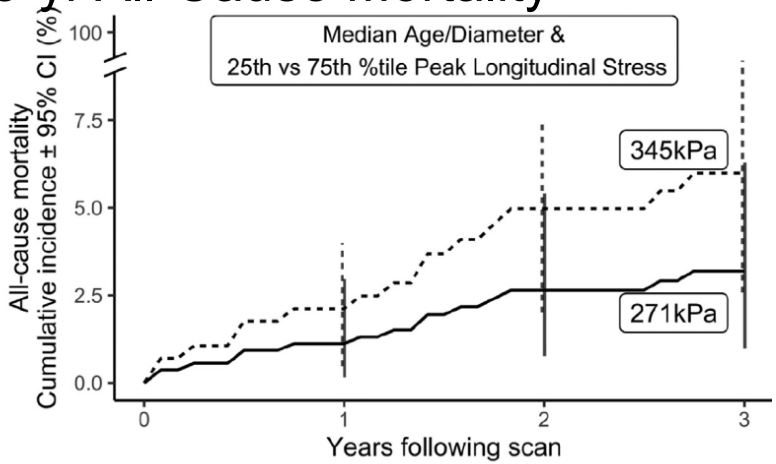
# Peak ATAA Wall Stresses & 3-yr Mortality

## Peak Longitudinal Stresses Associated with 3-yr All-Cause Mortality




| | | | | |
|---|---|---|---|---|
| Number at risk | 273 | 214 | 171 | 148 |
| Cumulative repairs | – | 51 | 52 | 53 |
| Cumulative deaths | – | 6 | 13 | 15 |

- N=273 veterans, 17% BAV
- Median diameter 4.5 (4.3, 4.9). 9% (25/273 pts) ≥5.5cm
- Median f/u 3 yrs.
- During f/u 19% (53/273) elective TAA repair with 0% mortality
- All-cause mortality 5.5% (15/273)

Tseng et al. Semin Thorac Cardiovasc Surg 2022. S1043-0679(22)00133-2

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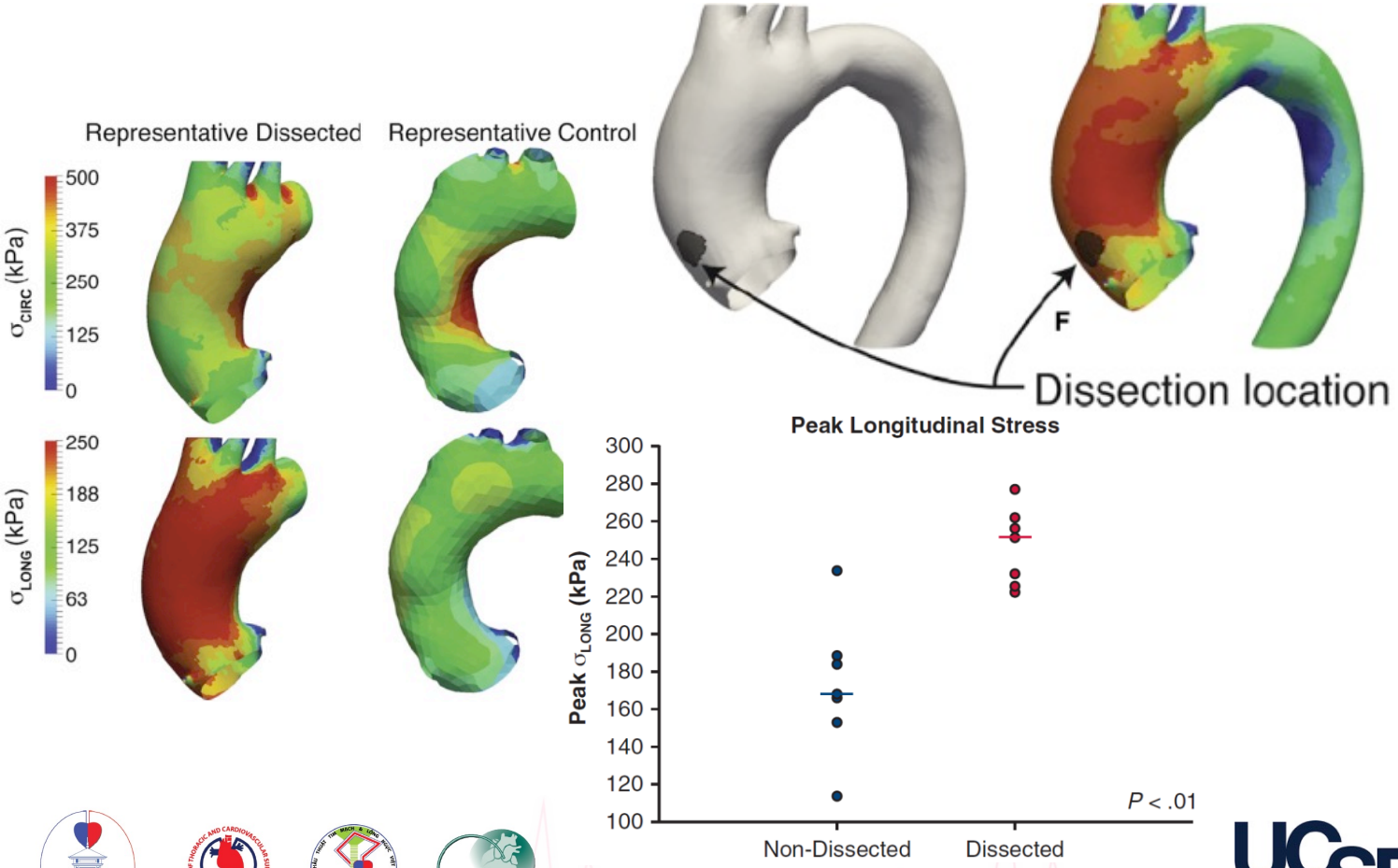
# Peak Longitudinal Stress & Dissection

Peak Longitudinal but not Circumferential Stress Increased with Type A Dissection




- N=7 Dissection
  - Dissection CTA
  - ≥2 predissection CTA ≥1yr before dissection
  - 1 predissection TTE
- N=7 controls
  - No BAV, CTD, aTAA
  - Matched Age, BSA

Emerel JTCVS 2018; :1-9

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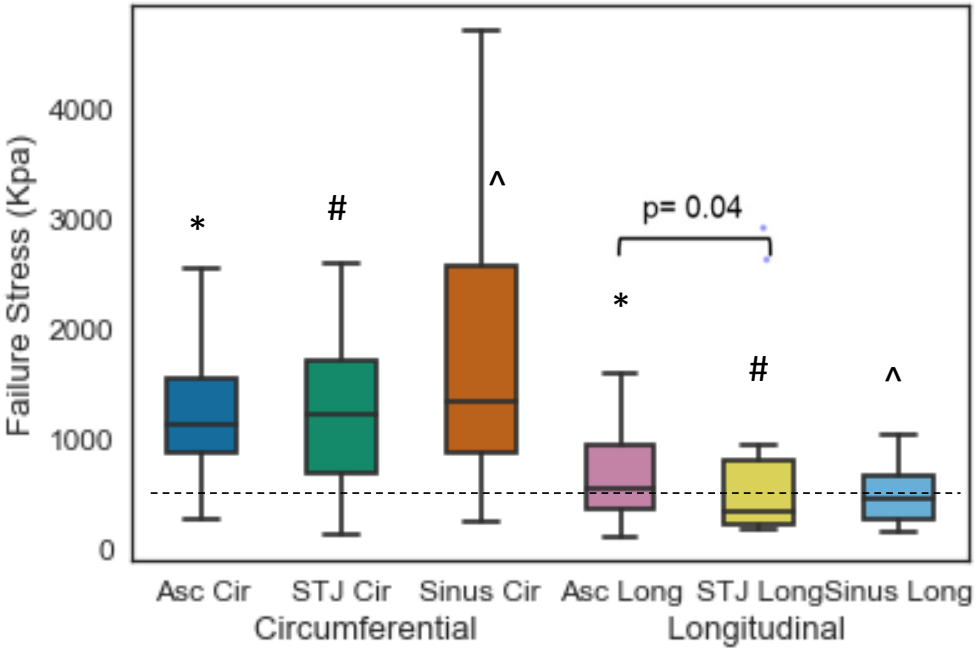
# Why Longitudinal Stress and Mortality?

Failure Strength of the Aorta Lower in Longitudinal than Circumferential Direction




*, #, ^ p<0.01 circumferential vs longitudinal

- N=23 normal aortic roots
- 47% women
- Aorta is **weaker longitudinally** than circumferentially
- Longitudinal stresses result in transverse intimal tear
- Weakest region: **sinotubular junction (STJ)**

Tseng et al. J Mech Behavior Biomed Mat 2021. 123;104705

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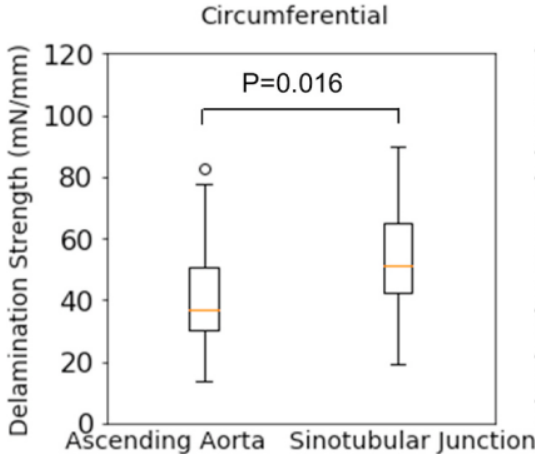
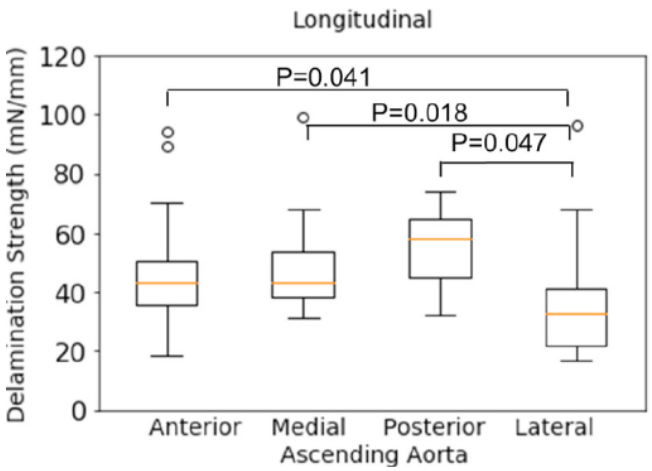
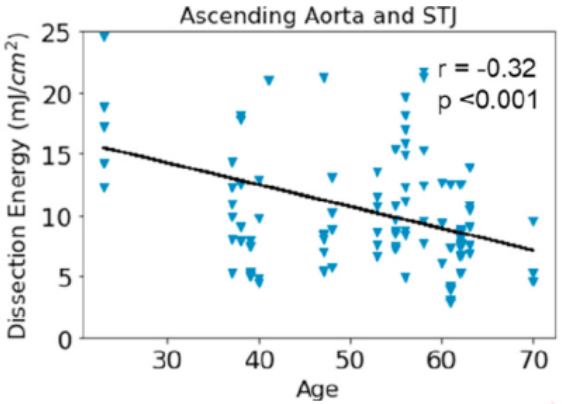
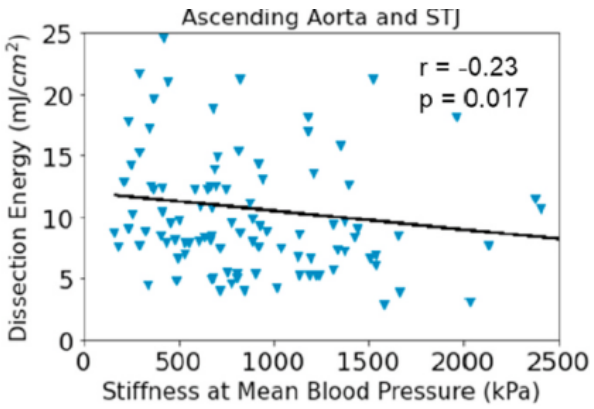
# Dissection Peeling Properties of Aorta

## Normal Aorta with Lower Delamination Strength in Ascending Aorta than STJ




- N=19 normal aortas
  - 53% men
  - Mean age 51 yo
- Delamination strength circumferentially Ascending Ao < STJ
- Delamination strength longitudinally lowest in the greater curve Ao

Tseng et al. J Mech Behavior Biomed Mat 2023;138:105603

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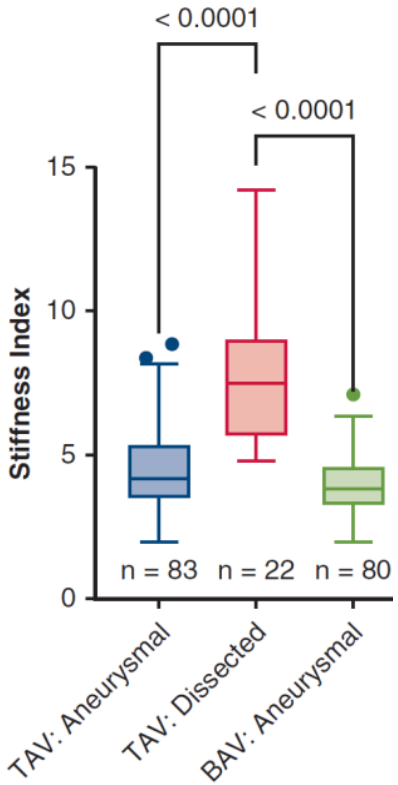
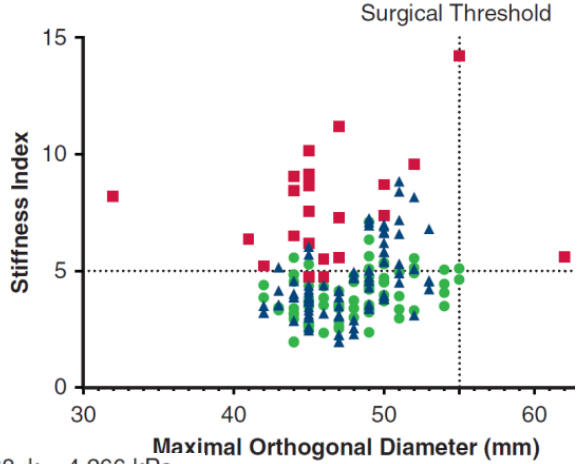
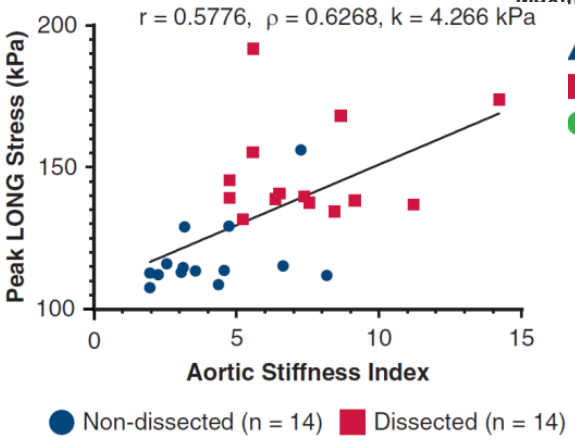
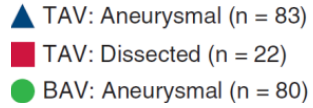
# Aortic Stiffness Predicts Dissection in TAA

$$Stiffness\ Index = \frac{\ln(SBP/DBP)}{AoS - AoD} AoD$$




- N=22 Dissection, 73% men
  - ≥1 TTE and ≥1 CTA predissection ≥1yr before dissection
  - 46mm, Stiffness Ind 7.73
- N=83 TAV pts, 83% men
  - 48mm, Stiffness Ind 4.51
- N=80 BAV pts, 65% men
  - 48mm, Stiffness Ind 3.92
- Stiffness Index >5 predicted Aortic Dissection
- Stiffness Index Correlates w Peak Longitudinal Stress

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# Conclusions

- Ascending thoracic aortic aneurysm dissection rates are lower than previous literature:
  - ~1%/yr for 5.5cm and <1%/yr for <5.5cm
  - Hinge point at 6cm
- Dissection Paradox: rate of dissection low at smaller sizes but most dissections occur at smaller sizes
  - Presentation of Dissection: ~60% are <5.5cm and 40% are < 5.0cm
- Given the dissection size paradox, better predictors of dissection are required than the present diameter based guidelines

# Conclusions

- Peak longitudinal stress has been shown to correlate with type A dissection (n=7) and all-cause mortality (n=273)
- Aortic stiffness index > 5 may be predictive of type A dissection (n=22) and correlates with peak longitudinal stress.
- Circumferential delamination during dissection is easier in ascending aorta than STJ
- Longitudinal delamination is easier in greater curvature of ascending aorta
- Dissection energy is lower at older age and increasing aortic stiffness

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# Thank you

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