8. Green DJ, Hopman MTE, Padilla J, Laughlin MH, Thijssen DHJ. Vascular adaptation to exercise in humans: role of hemodynamic stimuli. *Physiol Rev*. 2017;97:495-528.
9. Saeyeldin A, Zafar MA, Li Y, Tanweer M, Abdelbaky M, Gryaznov A, et al. Decision-making algorithm for ascending aortic aneurysm: effectiveness in clinical application? *J Thorac Cardiovasc Surg*. 2019;157:1733-45.
10. Sundt TM. Indications for aortic aneurysmectomy: too many variables and not enough equations? *J Thorac Cardiovasc Surg*. 2013;145:S126-9.
11. Ma WG, Chou AS, Mok SCM, Ziganshin BA, Charilaou P, Zafar MA, et al. Positive family history of aortic dissection dramatically increases dissection risk in family members. *Int J Cardiol*. 2017;240:132-7.
12. Ziganshin BA, Bailey AE, Coons C, Dykas D, Charilaou P, Tanriverdi LH, et al. Routine genetic testing for thoracic aortic aneurysm and dissection in a clinical setting. *Ann Thorac Surg*. 2015;100:1604-11.

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**REPLY FROM
AUTHORS: AORTIC
ANEURYSM
BIOMECHANICS:
PERFECT IS THE
ENEMY OF GOOD
Reply to the Editor:**

The primary criterion used clinically to evaluate the risk of life-threatening type A dissection is maximum ascending thoracic aortic aneurysm (aTAA) diameter of 5.5 cm or greater. What this approach achieves in simplicity it lacks in accuracy—approximately 60% of patients with acute dissection had diameters less than 5.5 cm—and improved indicators for surgery are an unmet clinical

need.¹ One paradigm is to use biomechanics-based risk stratification. Biomechanics dictate that dissection can occur when stress in the aortic wall exceeds its strength. Direct measurement of aortic wall strength requires destructive testing, merely estimated by surrogate markers. However, wall stress can be calculated with finite element analysis (FEA). In our article, we applied a practical method for screening patients with aTAA for operative repair—aortic wall stress calculated through models integrating patient-specific anatomy with material property data gathered in ex vivo testing from aTAA specimens.² We believe this approach can advance our ability to predict dissection and be applied at scale to the surge of newly diagnosed aTAAs in a streamlined, clinical approach.

At the most basic level, diameter already screens patients on the basis of wall stress using Laplace's Law, which states that stress in the thin-walled cylinder is proportional to its diameter (Figure 1). However, aneurysms are not cylindrical. In our study, we examined the relationship of aneurysm diameter and FEA-calculated wall stress. Diameter correlated poorly with peak wall stress, which may explain why a large proportion of acute dissections occur in aneurysms that do not meet size guidelines for surgery—high stress occurred due to local geometry, not overall diameter.² In the absence of aneurysm tissue, further improvements to stress calculation accuracy can be made through refinement of FEA models, which require zero-pressure geometry, wall material properties, wall thickness, and residual stress. One refinement we applied used our novel method to ascertain zero-pressure geometry from in vivo imaging. Accounting

FIGURE 1. Patient-specific FEA calculated circumferential stress (kPa) under diastolic pressure of a 50-cm aTAA (left); Laplace Law calculated circumferential stress (right).15370-

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for prestressed geometry is important for accurately determining wall stresses.³ Another refinement was using ex vivo experimentally derived bicuspid aortic valve (BAV) versus tricuspid aortic valve (TAV) aTAA material properties and wall thickness. Future refinements are estimating patient-specific material properties and measuring aortic wall thickness with higher resolution in vivo imaging. We determined patient-specific aortic deformation via magnetic resonance imaging, which although feasible,⁴ has proved time-consuming and inefficient presently for clinical application. Although promising, active research areas, these added refinements do not provide a clear, significant benefit beyond our current FEA models. Interestingly, when we compared FEA-calculated stresses using patient-specific versus population-averaged material properties, aTAA stress results did not differ significantly.⁵ Therefore, in our current² and 2018 publications,⁶ we used averaged BAV and TAV-aTAA mechanical properties from our laboratory. Material property differences in these articles simply reflect additional BAV and TAV-aTAA specimens. Current and subsequent articles will detail averaged mechanical properties as sample size increases. Further work in developing automated aTAA geometry from computed tomography angiography can streamline biomechanical assessment for clinical application.

Although we agree that using multiple imaging modalities to combine different information could provide dissection prediction, coordination/application of such a vast computational enterprise among 3 modalities may not be clinically useful. Rather, investigating individual candidate parameters from imaging sources—whether stress calculations, strength surrogates, or flow

parameters—in prospective clinical observational trials of patients with aneurysm may yield applicable risk factors feasible for guideline use. Simplifying aTAA wall stress calculations may be one avenue, whereas machine learning to predict FEA-calculated stresses may be an attractive alternative to rapidly apply across vast patient numbers. Either is superior to diameter, which has proven to be a poor predictor of peak aneurysm wall stress. Perfect is the enemy of good and broadly applicable, computationally efficient simplified wall stress analysis holds a promising future to aid clinicians in preventing lethal type A dissection.

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References

1. Pape LA, Tsai TT, Isselbacher EM, Oh JK, O'Gara PT, Evangelista A, et al. Aortic diameter $\geq$ 5.5 cm is not a good predictor of type A aortic dissection: observations from the international registry of acute aortic dissection (IRAD). *Circulation*. 2007;116:1120-7.
2. Wang Z, Flores N, Lum M, Wisneski AD, Xuan Y, Inman J, et al. Wall stress analyses in patients with $\leq$ 5 cm versus $<$ 5 cm ascending thoracic aortic aneurysm. *J Thorac Cardiovasc Surg*. February 19, 2020 [Epub ahead of print].
3. Krishnan K, Ge L, Haraldsson H, Hope MD, Saloner DA, Guccione JM, et al. Ascending thoracic aortic aneurysm wall stress analysis using patient-specific finite element modeling of in vivo magnetic resonance imaging. *Interact Cardiovasc Thorac Surg*. 2015;21:471-80.
4. Haraldsson H, Hope M, Acevedo-Bolton G, Tseng E, Zhong X, Epstein FH, et al. Feasibility of asymmetric stretch assessment in the ascending aortic wall with DENSE cardiovascular magnetic resonance. *J Cardiovasc Magn Reson*. 2014; 16:6.
5. Wang Z, Yuan X, Guccione JM, Tseng EE, Ge L. Impact of patient-specific material properties on aneurysm wall stress: finite element study. *J Heart Valve Dis*. 2020 [In press].
6. Xuan Y, Wang Z, Liu R, Haraldsson H, Hope MD, Saloner DA, et al. Wall stress on ascending thoracic aortic aneurysms with bicuspid compared with tricuspid aortic valve. *J Thorac Cardiovasc Surg*. 2018;156:492-500.

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