See Article page XXX.

Commentary: May the force(s) be with you: Loading conditions and the aorta

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Advances in diagnostic imaging, anesthetic and postoperative management, and significant developments in endovascular techniques, have expanded the pool of patients with treatable aortic disease. The current no man's land for endovascular surgery is the zone zero aorta, the region from the aortic annulus to the innominate artery origin. Understanding the biomechanics of this region could aid in conquering this zone.

Durbak and other Multidisciplinary Study of Ascending Tissue Characteristics and Hemodynamics for the Development of Novel Aortic Stentgrafts investigators¹ provide a comprehensive analysis of zone zero aortic biomechanical properties. This study used the elastic energy stored in the aortic tissue to better identify and characterize regional variations along zone zero. The main finding was that the elastic energy varies significantly along the ascending aorta and the calculated energy decreases with age. Using the elastic energy to characterize an elastic material, including soft biological tissue, is an established approach in solid (bio)mechanics. There is a clear relationship between age and distensibility (elastic energy) of tissue samples, the older the age, the lower the distensibility, as previously

George Green (1793-1841). British physicist and originator of the strain energy concept.

CENTRAL MESSAGE

State-of-the-art experimental studies of aortic mechanics may have important implications for the endovascular treatment of aortic diseases.

shown for aged human iliac arteries.² The authors used an inflection point from which the elastic energy was calculated. Our primary comments regarding this study are as follows:

- The term *inflection point* is misleading. By definition, an inflection point is a point at which the curvature changes sign. Instead, this inflection point was defined as a transition from a low-stiffness (stiffness being the ratio of stress to strain) range of strains to a high-stiffness range. Such transitions cannot be seen in the plots of the article because the curvature in all stress-strain curves transitions gradually.
- As defined, the circumferential normal stress at the inflection point almost always appears to be below the 100 kPa level, which is well below the stress level present at physiological range mean arterial pressure, so no conclusion can be drawn on this basis.
- The elastic strain energy is equal to the integral of stress through strain; that is, the area under the stress-strain relationship. However, there is no apparent reason why the authors chose the so-called inflection point strain as the upper bound for the integration to calculate the strain energy.
- Such an approach results in some energy stored in the aortic segment, but certainly not in the correct elastic energy because this is not a 1-dimensional problem. The biaxial tests carried out can also be used to determine longitudinal normal stress. Thus, strains occur in the

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circumferential and axial direction, and due to incompressibility (constant density when subjected to loading), the strain in the radial direction can also be calculated (it is a 3-dimensional problem). It is then possible to derive the strain energy from the full set of strains. This could be done by fitting the experimentally obtained data to an anisotropic material equation to obtain the material properties, and then the strain energy³ (elastic energy stored in the tissue) can be calculated for a certain state of physiological strains. These scalar measures can then be compared with each another on a reliable theoretical basis.

Despite these technical misgivings, the authors are to be congratulated on this innovative approach. Studies such as this are critical in understanding the tissue properties of the aorta.

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