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Biomechanical rupture risk prediction with abdominal aortic aneurysm growth

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Abdominal aortic aneurysms (AAA) are repaired when they meet diameter criteria or when they become symptomatic or rupture. The use of aortic diameter as the primary criterion in the decision to repair fails address the considerable numbers of AAA that rupture below this operative threshold,[1] particularly in women.[2] Improved prediction of AAA behavior is required to prevent significant morbidity and mortality.

AAA are thought to rupture when aortic wall mechanical stress exceeds wall strength.[3,4] Finite element analysis has been used to model the physical characteristics of the AAA wall from computed tomography reconstructions, allowing the determination of peak wall stress (PWS) and the peak wall rupture index (PWRI). PWS is a measure of maximal tensile stress, whereas PWRI is a ratio of maximal wall stress to strength. The PWRI serves as a predictor of AAA rupture risk; however, to date it has yet to consistently predict the outcome for specific AAA geometries.[5,6] This lack of predictability likely reflects the multifactorial involvement of hemodynamics, intraluminal thrombus (ILT), and inflammatory effects of cytokines and proteases (7) and may also reflect constant aortic remodeling associated with growth.[3]

The current article examined the biomechanical and morphological changes associated with AAA growth using a finite element analysis linear transformation-based comparison. The authors hypothesized that AAA growth would accompanied by significant changes in biomechanical and geometrical characteristics. It was also hypothesized that the PWRI, PWS, and ILT would change location with AAA growth. AAA diameter and volume, neck configuration, α and β angulation, vessel tortuosity, ILT volume, PWS, and PWRI were determined at two time points.

There was a significant increase in AAA and ILT volume, maximal ILT thickness, neck angulation, and iliac tortuosity with AAA growth. The change in PWRI was most correlated with an increase in AAA volume, whereas the change in PWS was best correlated with neck angulation. These findings suggest that AAA wall stresses vary with growth and that AAA volume may be a better predictor of AAA rupture risk than diameter.

The observation that maximum ILT thickness, in comparison with the positions of maximum PWS and PWRI, was the most pronounced with AAA growth suggests that ILT volume may play an important role in predicting AAA behavior. Using a computational fluid dynamics approach, Lasheras et al[7,8] have previously shown that alterations in aortic length and tortuosity with AAA growth have been associated with the development of turbulent flow vortexes, with changes in wall shear stress. A low wall shear stress is thought to play a role in initiating and propagating ILT deposition in AAA, which may play a role in promoting aortic wall degeneration and rupture.[9] Future studies aimed at improving understanding of AAA rupture risk will require both hemodynamic and finite element analyses in a large cohort with patient-specific physiologic and anatomic data.

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