Multi-Resolution / Multi-Scale Model of Abdominal Aortic Aneurysm Enlargement

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Development of abdominal aortic aneurysms (AAAs) is characterized by significant alterations of the architecture of the aortic wall, notably loss of functional elastin and smooth muscle. Because collagen is the primary remaining load-bearing constituent of the aneurysmal wall, we hypothesized that specific characteristics of its turnover play fundamental roles in the natural history of the lesion. A finite element membrane model of the growth and remodeling of idealized AAAs was used to investigate parametrically four aspects of collagen turnover: rates of production, half-life, deposition stretch (i.e., pre-stretch), and material stiffness. The rate of aneurysmal expansion, wall thickness, circumferential and axial stress, maximum fiber stretch, and simulated clinical endpoint (e.g., progressive expansion, rupture, or arrest) were found to depend strongly on these factors. Simulations also demonstrated a hastened expansion after invoking a damage criterion for individual collagen fibers independent of a traditionally defined whole-wall rupture stress. We conclude, therefore, that assessment of rupture-risk will be improved by future experiments that elucidate and quantify patient-specific control of specific characteristics of collagen turnover within the aneurysmal wall, and that multi-resolution / multi-scale models that consider separately the collagen fiber level mechanics and whole wall mechanics are essential for understanding the evolving histopathology.

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