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Biomechanical failure properties and microstructural content of ruptured and unruptured abdominal aortic aneurysms

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ABSTRACT

Purpose: To test the hypothesis that ruptured abdominal aortic aneurysms (AAA) are globally weaker than unruptured ones.
Methods: Four ruptured and seven unruptured AAA specimens were harvested whole from fresh cadavers during autopsies performed over an 18-month period. Multiple regionally distributed longitudinally oriented rectangular strips were cut from each AAA specimen for a total of 77 specimen strips. Strips were subjected to uniaxial extension until failure. Sections from approximately the strongest and weakest specimen strips were studied histologically and histochemically. From the load-extension data, failure tension, failure stress and failure strain were calculated. Rupture site characteristics such as location, arc length of rupture and orientation of rupture were also documented.
Results: The failure tension, a measure of the tissue mechanical caliber was remarkably similar between ruptured and unruptured AAA (group mean $\pm$ standard deviation of within-subject means: 11.2 ± 2.3 versus 11.6 ± 3.6 N/cm; $p=0.866$ by mixed model ANOVA). In post-hoc analysis, there was little difference between the groups in other measures of tissue mechanical caliber as well such as failure stress (95 ± 28 versus 98 ± 23 N/cm^2; $p=0.870$), failure strain (0.39 ± 0.09 versus 0.36 ± 0.09; $p=0.705$), wall thickness (1.7 ± 0.4 versus 1.5 ± 0.4 mm; $p=0.470$) , and % coverage of collagen within tissue cross section (49.6 ± 12.9% versus 60.8 ± 9.6%; $p=0.133$). In the four ruptured AAA, primary rupture sites were on the lateral quadrants (two on left; one on left-posterior; one on right). Remarkably, all rupture lines had a longitudinal orientation and ranged from 1 to 6 cm in length.
Conclusion: The findings are not consistent with the hypothesis that ruptured aortic aneurysms are globally weaker than unruptured ones.

1. Introduction

Rupture of abdominal aortic aneurysm (AAA) is a poorly understood phenomenon. Some aneurysms rupture as they grow larger, while many large ones do not. There has been considerable interest in studying the mechanical characteristics of these lesions under the premise that rupture occurs when the tangential tension and/or stretch on the AAA wall from blood pressure exceeds maximum allowable thresholds. Understanding the tolerable threshold of force and stretch – the mechanical failure properties – and the structural content that manifest in these properties can therefore be valuable in gaining insights into the phenomenon of rupture. Numerous studies have reported on the mechanical and structural properties of unruptured AAA tissue (Di Martino et al., 1998, 2006; He and Roach 1994; Raghavan et al., 1996; Vallabhaneni et al., 2004; Vorp et al., 1996, 2001; Thubrikar et al., 2001; Vande Geest et al., 2006a, 2006b). However, there have been only two studies that reported on mechanical properties of ruptured AAA presumably because they rarely become available for studies (Di Martino et al., 2006; Raghavan et al., 2006). This limits our ability to reliably assess differences between these lesions. A key question in this context is whether the aortic tissue in aneurysms that rupture is weaker and hence more susceptible to failure under the same pressure-induced wall tension than that in unruptured ones? This is the question motivating this study. A few additional, but related questions are as follows: is the location and orientation of the tear in a ruptured AAA consistent across patients or is it random? How does tissue microstructure such as collagen, elastin or smooth muscle cell content vary between ruptured and unruptured AAA? Further, what of regional variation in properties of AAA? Some

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