

Mechanical Stress Levels in Symptomatic Patients Scheduled for Carotid Endarterectomy

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Objective

Ischemic stroke is often caused by atherosclerotic plaque rupture in the carotid artery. Due to the traumatic nature of atherosclerotic plaque rupture, it has been hypothesized that assessment of tensile stress levels inside the fibrous cap could improve carotid risk stratification. Hitherto, calculating tensile stress levels has required 3D computational simulations with substantial temporal requirements limiting the clinical usefulness. In this study, we sought to evaluate longitudinal mechanical stresses in carotid atherosclerotic plaques using a novel longitudinal 2D approach based on magnetic resonance imaging (MRI) incorporating plaque morphology, plaque geometry, and local hemodynamics.

Methods

Nineteen symptomatic patients scheduled for carotid endarterectomy underwent a preoperative carotid magnetic resonance imaging (MRI) examination using a multispectral protocol (Yuan C: JMIR 19:710-19) to characterize plaque morphology and geometry (lipid-rich necrotic core, fibrous cap, thrombi, vessel lumen, and vessel wall). Two-dimensional longitudinal computational models were generated semi-automatically from the MRI data, and the longitudinal carotid stresses calculated (Kock SA: J Biomech 41:1651-8).

Results

Longitudinal mechanical stresses were shown to correlate with minimal fibrous cap thickness ($r = -0.61$, $P = 0.01$) and with the severity of stenosis ($r = 0.71$, $P = 0.003$). Maximal stress levels were asymmetrically distributed longitudinally, with 50% occurring proximal to the area of maximal stenosis, 25% level, and 25% distal, in accordance with the observed sites of plaque rupture. Plaque rupture occurred at the level of maximal first principal stresses coincident with the thinnest fibrous cap in six of seven patients with evidence of plaque disruption (top figure).

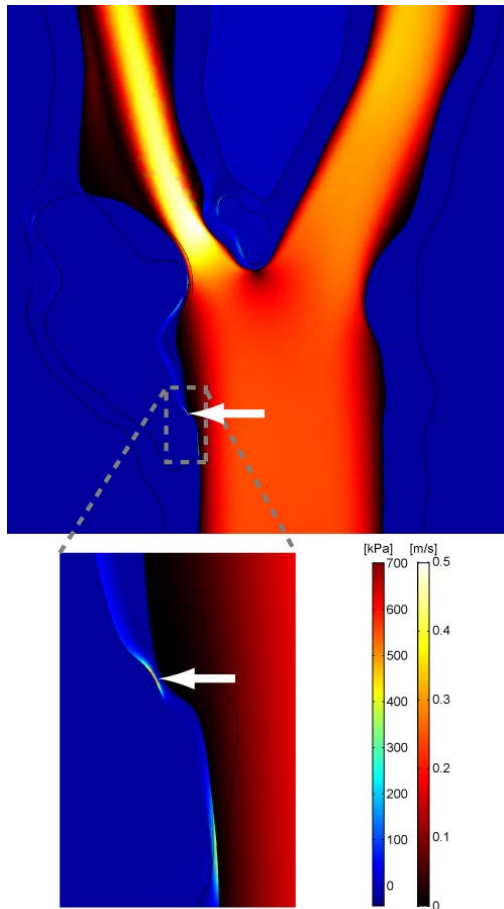


Figure 1: First principal stresses and velocity field from a patient with a 70% stenosis. Maximal stresses occurred below the flow divider (inset). Multispectral MRI revealed evidence of plaque disruption coincident with the maximal stresses at the minimal fibrous cap width location (white arrow).

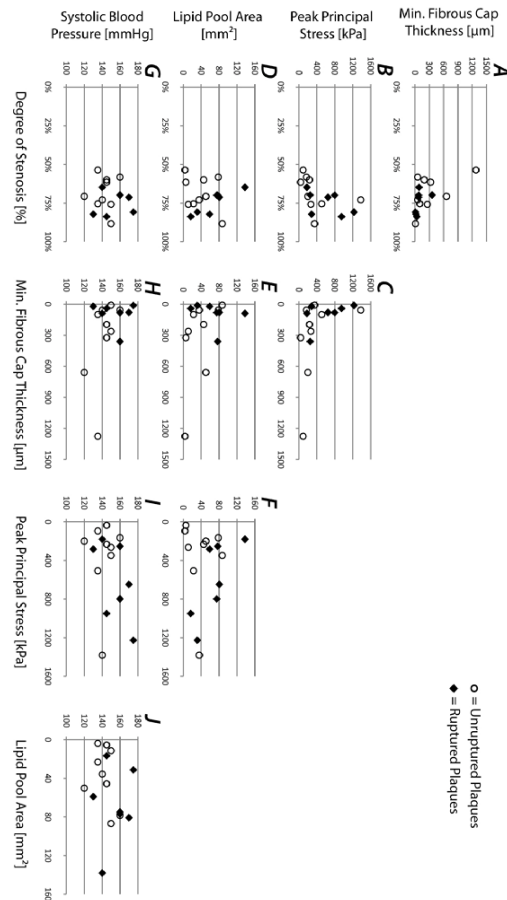


Figure 2: Correlations between first principal stresses and known predictors of plaque vulnerability: fibrous cap thickness, lipid pool size, systolic blood pressure, and the degree of stenosis. A, B, and C were statistically significant

Conclusions

In symptomatic patients with carotid atherosclerosis, the longitudinal mechanical stresses on the fibrous cap were shown to correlate with known markers of plaque vulnerability. The longitudinal distribution of plaque stresses indicated a clear correlation between physical forces affecting the vessel wall, the internal plaque structure, the degree of stenosis, and the risk of rupture. Evaluation of longitudinal mechanical stress levels may improve risk assessment in patients with carotid atherosclerosis.