Mechanical behavior of hyper-calcified cerebral embolus analogs in acute ischemic stroke

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Abstract:
Stroke is a leading cause of death worldwide, with approximately 20% of surgical interventions resulting in complications. The underlying causes of these complications remain unclear, but calcified emboli are thought to pose a significant risk. This study aims to characterize the nonlinear mechanical behavior of calcified cerebral emboli and fit these data to viscoelastic models.

To create clot analogs, human donor blood was reconstituted and recalcified in a Chandler loop at 37°C for 1 hour. Clots were then incubated in either 0.2M or 2M $CaCl_2$ for 1 or 10 days. Uncalcified clots were aged in cell media, while unaged clots were tested immediately (day 0). Mechanical testing was performed under tension and compression at strain rates of 5%, 10%, and 15% per second, with clots deformed to 80% strain to characterize their rate-dependent behavior.

Clots exhibited strain stiffening in compression and linear behavior in tension. Hypercalcified clots (2M $CaCl_2$) showed a tenfold increase in high-strain stiffness. Day 10 clots exhibited more than twice the peak stress of day 1 clots and nearly quadruple the stresses of clots extracted from patients. The mechanical response of hypercalcified clot analogs was well captured by an Arruda-Boyce viscoelastic model.

Age-dependent calcification significantly increased clot stiffness and fracture risk. Reduced porosity and increased stiffness suggest a clot phenotype that is more resistant to thrombectomy and thrombolytic treatments, highlighting the need for improved therapeutic strategies. This dataset provides a library of mechanical properties that can be integrated into numerical simulations of endovascular thrombectomy (EVT) to improve treatment outcomes.