Global and Local Mechanics of the Aortic Media Under Radial Extension

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Abstract

Radial tensile strength of the aorta may be significantly reduced due to pathological conditions that predispose patients to dissection – one of the most devastating complications of thoracic aortic disease. The mechanical behavior of arteries under such loading has rarely been investigated. We compare how the global and local mechanical response of the aortic media differs between dissected human and healthy porcine aorta using optical coherence tomography (OCT) and digital volume correlation (DVC).

Porcine ascending aortas and human ascending aortas were obtained from a local slaughterhouse and the donors undergoing surgery, respectively. Prior to preparing 5×5 mm (circumferential×axial) specimens, adventitia was removed from the porcine aortas, and the outer layer of the dissection was removed from the human aortas, with the aim of leaving intima and media intact in both sample types. Specimens were then mounted on the holders using cyanoacrylate adhesive with the circumferential-radial plane facing the OCT camera. After the glue was allowed to harden for 10 mins, the test chamber was filled with 0.9% PBS and the specimen was allowed to rehydrate for 10 mins. Subsequently, a 4×1×1.6 mm (radial × circumferential × axial) volume was imaged with OCT. After 5 preconditioning cycles, radial displacement was applied in $100\mu m$ increments until failure and the volume was imaged immediately after each increment while force was recorded. DVC was then applied to the volumetric images using DaVis 8.4 (LaVision) to obtain the displacement fields, and Green-Lagrange strain fields were derived using a custom Matlab code. Additional specimens were collected next to the mechanical testing specimens and optically cleared for investigations with multiphoton microscopy.

The loading curves initially showed a plateau, then the stress increased continuously to failure with the subsequent loading steps. Dissected tissues failed at lower loads, and voids that merged into larger defects appeared before the peak force during the initial loading steps. DVC revealed complex deformations and early strain localizations. Healthy porcine aortas can withstand significant radial stretches, likely caused by sucking up fluid. Large radial stretches also lead to induce localization effects and ultimately to mechanical damage, which, like GAG pools, can play an important role in triggering a dissection. Ongoing microstructural investigations will provide information about the influence of pathological structural changes on the global response and the local deformations.

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