On the separation of equilibrium and inelastic effects in arteries

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Abstract

The mechanical behavior of vascular tissues is characterized by the presence of several inelastic effects. From a theoretical perspective, their constitutive behavior can be generally described by introducing an equilibrium term, assumed to be a rate-independent functional of the deformation history, and a non-equilibrium contribution encapsulating the material rate-dependency (1). Following this theoretical approach, it is convenient to design experimental protocols that allow the distinction of the different constitutive phenomena. In a recent study on porcine thoracic aorta, it was shown that the equilibrium relation cannot be properly assessed with continuous loading protocols, since rate-dependent effects are present even at low deformation rates (2). This makes the assumption of quasi-stationary inadequate for the isolation of the equilibrium relation, making the interpretation of such tests ambiguous.
Alternatively, the equilibrium response can be assessed through step-wise relaxation protocols, which enable the separation of dissipative characteristics by performing only one test. As noted by (3), a unique equilibrium response may not hold for all materials, although to the authors' knowledge no experimental evidence has been provided to substantiate this claim. As far as vascular tissues are concerned, a first attempt in this regard was presented in (2), albeit with a limited sample size and without verifying the homogeneity in the deformation field. In any case, multi-step protocols have not found widespread application in the mechanical characterization of soft tissues, although isolating inelastic effects is of paramount importance. For example, in tissues with a pathological condition, changes in arterial viscoelasticity can be used as an index to gauge wall integrity (4), as changes in wall viscosity have been correlated with different stages of atherosclerosis in the carotid artery (5).

In this work we follow up on the methods proposed in (2) and attempt to remedy its shortcoming by increasing the sample size and verifying the hypothesis of homogeneous deformation. We attempt to investigate the existence of unique equilibrium relations by repeating step-wise tests with different deformation rates on the porcine thoracic aorta under uniaxial tensile conditions. This may in turn imply a rate-dependency of inelastic effects, which motivates the formulation of constitutive models without a straightforward decomposition into rate-independent and rate-dependent contributions.

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