CONSTITUENT-BASED QUASI-LINEAR VISCOELASTICITY: CAPTURING NON-LINEAR VISCOELASTICITY WITH QUASI-LINEAR MODELS

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Introduction

Arteries exhibit complex viscoelastic behaviours, which are highly non-linear both in terms of elasticity and viscosity [1]. Although previous works have proposed different solutions to model elastic non-linearity which capture well the arterial wall response to quasi-static deformations [1,2], in vivo the arterial wall is subjected to pulsatile loads for which viscoelastic phenomena cannot be neglected. Unlike for elasticity, effective solutions to model non-linear viscoelasticity are lacking. On the one hand, quasi-linear viscoelasticity (QLV) offers a practical solution to viscoelastic modelling [3], but its linear viscosity assumption is unsuitable to capture the viscoelastic behaviour of the arterial wall as a whole [1]. On the other hand, deformation-dependent parameters make fully non-linear viscoelastic models impractical. Indeed, their application to experimental data often leads to identifying specific solutions for each tested loading condition [1]. In the present study, we address this issue by applying QLV theory at the wall constituent rather than at the whole-wall level.

Methods

Five murine common carotid arteries were subjected to an experimental protocol of quasi-static and harmonic biaxial loading conditions for characterising their viscoelastic mechanical properties. In our constituent-based QLV (cbQLV) framework, the arterial wall was modelled as a constrained mixture of an isotropic elastin matrix and four families of collagen fibres in which collagen and elastin were assigned different stress relaxation functions [2,3]. Non-linearity in viscoelasticity was quantified in terms of dependency of the dynamic-to-quasi-static stiffness ratio on pressure, and the performance of our model was compared to that of standard QLV (sQLV).

Results

The experimentally measured dynamic-to-quasi-static stiffness ratio was negligible at low pressures (1.03±0.03 at a pressure range 40–80 mmHg; mean±standard deviation) and rose with increasing pressure (1.58±0.22 at 120–160 mmHg, Figure 1A). By assigning viscoelastic behaviour to collagen and almost purely elastic behaviour to elastin, cbQLV captured well the pressure dependency of this ratio (Figure 1B). Conversely, sQLV failed to capture this complex behaviour, yielding significant stiffening at low pressures and little increase at higher pressures (Figure 1C).

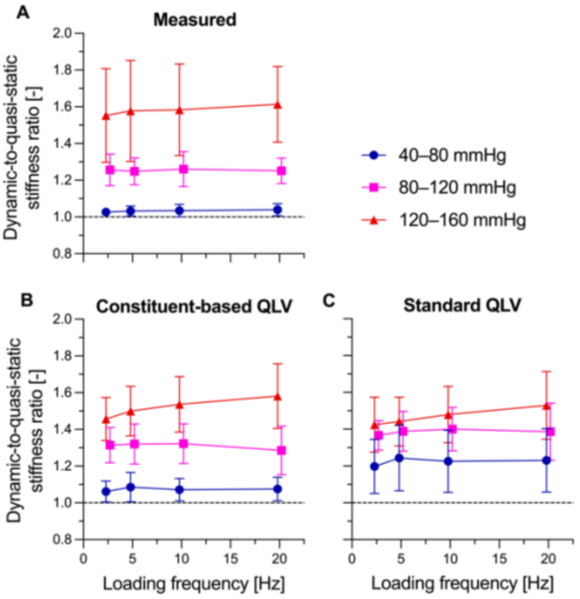

Figure 1: Pressure and frequency dependence of the dynamic-to-quasi-static stiffness ratio of the mouse carotid artery, as measured experimentally (Panel A) and as modelled with constituent-based (cbQLV, Panel B) and standard quasi-linear viscoelasticity (sQLV, Panel C).

Discussion

Constituent-based QLV offers a practical solution to model complex non-linear viscoelastic behaviours using one set of deformation-independent viscous parameters. Its use in experimental studies on vascular disease will provide novel insights into how pathological changes in wall microstructure affect the mechanical behaviour of the arterial wall in *in vivo*-like dynamic loading conditions.

References

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