VISCOELASTIC CHARACTERISATION OF PIG LIVER IN UNCONFINED COMPRESSION

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Introduction

Understanding and modelling liver biomechanics represents a significant challenge due the complex nature of this organ. Several methods and models based on direct measurements on the liver (e.g. rheological, compressive or indentation tests) or image-based techniques (e.g. magnetic resonance or ultrasound-based elastography) are reported in literature to characterise the liver viscoelastic behaviour *in-vitro* or *in-vivo* [Marchesseau *et al*, 2010]. Unfortunately, there is no consensus on liver viscoelastic properties, and results are strongly dependent on adopted testing method, sample type, status and testing conditions. We focused on *in-vitro* unconfined bulk compressive tests for deriving liver viscoelastic parameters in the linear viscoelastic region (i.e. small strain region). We propose the use of the εM (epsilon dot method) which we developed to address the major drawbacks of standard tests (e.g. step response or dynamic mechanical tests) such as long test duration and initial contact between sample and testing apparatus, that may significantly pre-stress/strain very soft and hydrated samples and alter their status [Tirella *et al*, submitted]. With the εM, samples are characterised using standard compressive tests at different strain rates ($\dot{\varepsilon}$). Stress-time series collected at various $\dot{\varepsilon}$ are then fitted using a multi curve shared parameter fitting approach. Liver viscoelastic parameters estimated with εM were compared to those obtained using conventional dynamic mechanical (DMA) testing systems.

Methods

Cubic liver samples (1 cm^3) were collected from 1 year old healthy pigs avoiding Glisson's capsule and macroscopic vasculature. Samples were equilibrium swollen in PBS 1X and then tested at room temperature keeping them partially immersed in PBS to preserve their hydration. Samples were compressed at different strain rates (i.e. 0.01, 0.02, 0.03 s^{-1}) using a Zwick/Roell ProLine Z005 equipped with a 10 N load cell to obtain εM dataset. A Generalized Maxwell (GM) model with one or two spring-dashpot series arms in parallel to a pure spring were used to fit experimental stress-time series. DMA analysis was performed using the GABO Eplexor 150 N. The frequency dependence of the compressive modulus, *E(f)*, was assessed in the range 0.5-50Hz. *E(f)* was reconstructed via a *step analysis* performing several frequency sweep tests at specific *f* (i.e. 0.5, 1, 2, 3, 5, 50 Hz) to avoid significant sample deterioration observed due to long testing duration.

Results

Instantaneous and equilibrium compressive moduli (k_{inst} and k_{eq}) as well as characteristic relaxation times ($\tau_1=\eta_1/E_1$, $\tau_2=\eta_2/E_2$) estimated with εM are summarised in table 1, showing that liver behaves like a *lossy* system (justified by the absence of the Glisson's capsule) and suggesting that one viscoelastic arm is enough to describe its linear viscoelastic behaviour. Hence, a 1-arm GM model was used to fit *E(f)* obtained from DMA measurements (Table 1).

	Epsilon dot method (εM)		**DMA**
Parameter	***1-arm GM***	***2-arm GM***	***1-arm GM***
k_{inst} [kPa]	1.30 ± 0.07	1.30 ± 0.07	2.67 ± 0.06
k_{eq} [kPa]	0	0	0
τ_1 [s]	4.22 ± 0.32	4.26 ± 0.35	0.29 ± 0.02
τ_2 [s]	-	4.28 ± 0.43	

Table 1: Estimated liver viscoelastic parameters

Discussion

k_{inst} estimated with DMA was significantly higher than that obtained using the εM mainly due to the minimum contact force required by the former (~ 0.01 N) that causes a pre-strain of about 10% on tested samples. The different testing conditions also affected the characteristic relaxation time which was found to be significantly lower than that estimated with εM. In conclusion, even though *step analysis* did not significantly degrade samples during the test, we believe that εM gives better results since it avoids sample pre-stress.

References

Marchesseau *et al*, Progress in biophysics and molecular biology, 103(2–3):185–96, 2010.

Tirella *et al*, submitted.