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Using static preload with magnetic resonance elastography to estimate large strain viscoelastic properties of bovine liver

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ABSTRACT

Traditional magnetic resonance elastography (MRE) applies small amplitude vibration to tissues. Thus currently MRE measures only the small deformation behaviour of tissues. MRE has the potential to estimate the strain-varying shear modulus of soft tissues, if applied at different static strains, which may allow prediction of the large-strain behaviour of tissues. This study uses MRE of bovine liver specimens under various levels of static compressive pre-strain up to 30%. Storage and loss moduli measured using MRE increased non-linearly with static compressive pre-strain, and exponential models fit well to these data to describe this relationship ($R^2 > 0.93$). Based on these models, a 10% linear compression of liver would result in a 47% overestimate of the 'true' storage modulus of the uncompressed tissue. The results of this study have implications for MRE transducer design and interpretation of results from in vivo MRE studies.

1. Introduction

Magnetic resonance elastography (MRE) is a relatively new imaging technique used for measurement of soft tissue mechanical properties (Muthupillai et al., 1995). The major advantage of MRE is that it can be used to objectively and non-invasively measure mechanical properties of tissues in vivo, making this a potentially powerful clinical and experimental tool. For example MRE can be used as a non-invasive method of quantitative 'palpation' of disease that is often accompanied by changes in tissue properties, such as tumours (Venkatesh et al., 2008), and fibrosis (Huwart et al., 2007, 2008). This is particularly useful for tissues that are difficult (or impossible) for clinicians to palpate by hand (e.g. the brain inside the skull). Experimental applications include the unique ability to quantitatively measure tissue properties in vivo for use in modelling and other applications. Previously the vast majority of tissue properties have been investigated in vitro, with the accompanying effects of changes in temperature, hydration and perfusion state on tissue properties.

MRE is already in use as a clinical tool for detecting liver fibrosis (Huwart et al., 2007, 2008) and is underway to being used in diagnosis of brain, liver, breast and other tumours (Venkatesh et al., 2008), based on the idea that diseased tissues have different mechanical properties than healthy ones. One of the methodological problems with applying the vibration necessary for MRE is that the apparatus may apply compressive pre-strain to the tissues. Owing to the nonlinear viscoelastic nature of most tissues, this pre-strain likely affects the mechanical properties measured using MRE and this may inadvertently cause an incorrect assessment. Knowledge of the extent of this problem and being able to predict its effects may aid in refining and developing MRE techniques.

It is well known that the apparent tangent modulus of soft tissues varies with applied strain, resulting in the 'j-shaped' stress strain curve that is characteristic of most tissues (Fung, 1993). Traditional MRE measures only the small deformation behaviour of tissues, as it applies a small amplitude vibration (typically 2–50 μm) to the tissue. However it has the potential to estimate the strain-varying shear modulus of soft tissues, if applied at different static pre-strains. This has not been previously investigated and may allow prediction of the large-strain behaviour of tissues. Furthermore the large strain behaviour of tissues has not been well established, and the current study describes apparatus and methods capable of studying the large strain regime of tissues in vitro. Here, we hypothesised that application of static pre-strain would increase the shear modulus in a non-linear manner. We begin by testing this hypothesis using in vitro tissue samples in which the strain field can be precisely controlled.

2. Methods

2.1. Specimen preparation and compression apparatus

Fresh bovine livers were obtained immediately after death from a local abattoir. This tissue collection method was performed in accordance with local animal welfare regulations and ethical guidelines. Livers were transported on ice

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