NON-INVASIVE ANALYSIS OF THE MECHANICAL PROPERTIES OF SKELETAL MUSCLE TISSUE *IN-VIVO*

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Introduction

Validation of constitutive models of living human skeletal muscle tissue requires non-invasive analysis methods. This abstract presents an advanced framework for the validation of such models. MRI based indentation experiments are proposed during which dynamic indentation force, 3D dynamic tissue deformation, tissue geometry and fibre architecture are recorded. Following inverse Finite Element Analysis (FEA) of the experimental boundary conditions the parameters of an appropriate constitutive law can be optimised. The framework presented allows for the first time for the non-invasive evaluation of detailed non-linear, anisotropic and viscoelastic material laws.

Methods

Using newly developed computer controlled MRI compatible soft tissue indentor, a cylindrical gel phantom (with known mechanical properties) and the upper arm region of a volunteer were subjected to transverse indentation (Fig.1A-C). Force was recorded with a custom made 100Hz optical force sensor. During indentation dynamic 3D tissue deformation is recorded through the application of novel dynamic tagged MRI methods (Fig.1C) (dynamically optimised version of [Moerman, 2011]) and fully automatic Gabor filtering based post-processing. Prior to indentation anatomical, and for the volunteer tests also diffusion tensor [Froeling, 2010], MRI were used to record the tissue geometry and muscle fibre architecture (Fig.1.E). Using custom made segmentation software these could be converted to detailed FEA models where for the volunteer skin, adipose and muscle are accounted for (bone is modelled via supported core nodes). The silicone gel phantom and human skin and adipose tissue are modelled as Ogden hyperelastic. Muscle was modelled using a novel constitutive model: the Gaussian modulated spherical fibre distribution Ogden hyperelastic.

Results

Fig.1B shows force displacement history curves for repeated indentations sampled at 100Hz which demonstrate tissue viscoelasticity. Fig.1D shows a dense (3mm grid, 3.6 Hz) tagged MRI derived dynamic 3D displacement field. Following segmentation of anatomical MRI accurate FEA models could be constructed and for the volunteer model (Fig1.F left) fibre directions could be mapped for each element. For the phantom model (Fig1.F right) preliminary results show appropriate material parameters can be derived following inverse FEA based optimisation of the experimental force and deformation boundary conditions.

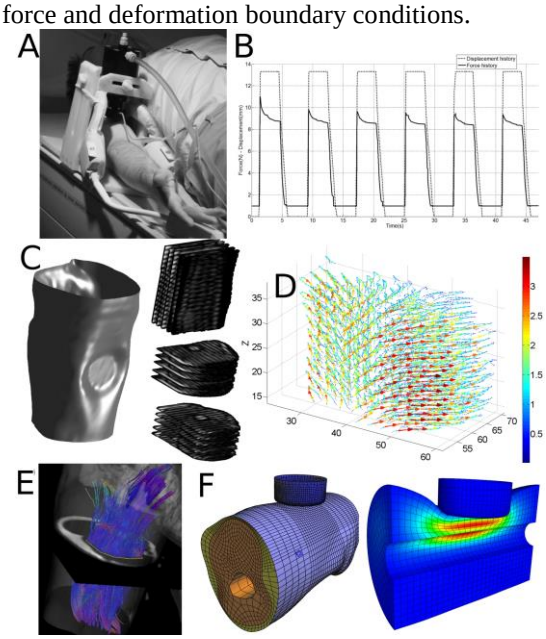

Figure 1: The non-invasive analysis framework

Discussion and Conclusions

An experimental and computational framework is presented consisting of the following unique features: *1) a novel computer controlled MRI compatible indentor, 2) a high speed (100Hz) optical force sensor, 3) high resolution (3mm) tagged MRI based dynamic (3.6Hz) 3D tissue deformation measurement* and *4) anatomical and diffusion tensor MRI based FEA model construction where fibre directions can be mapped for each element.* This framework allows, for the first time, for the non-invasive validation of detailed anisotropic, non-linear and viscoelastic constitutive laws. Preliminary results on a phantom demonstrate the use of the framework for inverse FEA based material parameter determination. Results for human inverse FEA will be presented.

References

Moerman *et al*, Med. Phys, 38(3),13, 2011.
Froeling *et al*, MRM, 64(4):1182-1190, 2010.