

## SOFT TISSUE MODELING AND MECHANICS

Amy E. Kerdok<sup>1,2</sup>, Simona Socrate<sup>1,3</sup>, Robert D. Howe<sup>1,2</sup>

<sup>1</sup>Harvard/MIT Division of Health Sciences and Technology, Cambridge, MA

<sup>2</sup>Biorobotics Laboratory, Harvard University Division of Engineering and Applied Sciences, Cambridge, MA

<sup>3</sup>Massachusetts Institute of Technology Dept. of Mechanical Engineering, Cambridge, MA  
E-mail: kerdok@fas.harvard.edu

### INTRODUCTION

Although most soft tissues do not have load-bearing functions, understanding their mechanical behavior is of great interest to the medical simulation, diagnostic, and tissue engineering fields. Obtaining these properties is a formidable challenge due to soft tissue's mechanical and geometric nonlinearities, multi constituent heterogeneity, viscoelastic nature and poorly defined boundary conditions.

It has been shown that the mechanical response of soft tissues drastically change when removed from their natural environment (Brown et al. 2003; Ottensmeyer et al. 2004). It is necessary to measure the tissue's mechanical response under *in vivo* conditions. Several groups have made measurements *in vivo* (Brown et al. 2003; Ottensmeyer 2001), but the interpretation of these results remain to be understood because of the inability to control boundary conditions and other testing parameters.

Using a method to maintain a nearly *in vivo* environment for *ex vivo* tests, we have measured the force-displacement characteristics of whole porcine liver using a motorized indenter. The results of these tests are to be interpreted using inverse finite element modeling. The material parameters will be determined from a constitutive model

developed for cervical tissue (Febvay 2003) and adapted for the liver.

### METHODS

To obtain nearly *in vivo* conditions in an *ex vivo* state, a perfusion apparatus developed by Ottensmeyer et al. (2004) was used. Pigs used were systemically heparinized, their livers were harvested and flushed of blood, placed on ice for transport to the lab, and connected via the portal vein and the hepatic artery to a perfusion apparatus within 90 minutes post sacrifice that maintained nonpulsatile physiologic pressure (9 mmHg and 100 mmHg respectively) and temperature (39°C).

Tests were performed to capture the viscoelastic nature of the tissue using the motorized "ViscoElastic Soft tissue Property Indenter" (VESPI). As a preliminary step to guide the device development large strain (~50%) creep tests were performed. The thickness of the tissue was measured prior to each load (to determine nominal strain), and the tissue was allowed to recover to its initial state before repeating the test in each location. Future tests will be performed to capture the complete viscoelastic tissue response including large strain stress relaxation tests and cyclic loading/unloading tests at varied strain rates.

An axisymmetric finite element model to analyze the indentation of soft tissue is being

developed using commercial finite-element software (ABAQUS 6.4, HKS, Rhode Island). This model will incorporate the constitutive model for liver tissue. The constitutive model reflects the tissue structure, as the global tissue response is controlled by the cooperative contributions of its major constituents. The response is modeled by the association in parallel of a nonlinear elastic 8-chain model network, accounting for the role of the interlobular septa, and a viscoelastic component, representing the hydrated ground substance. The transient effects associated with fluid flow are accounted for in terms of a linear Darcy's law. The complete three-dimensional model resulting from these components is implemented as a user material subroutine for ABAQUS 6.4.

The results of the VESPI tests and testing conditions will be used as inputs to the FEM containing the adapted constitutive model for liver tissue. An iterative process will ensue to determine the material parameters that uniquely identify the mechanical characteristics of the liver.

## RESULTS AND DISCUSSION

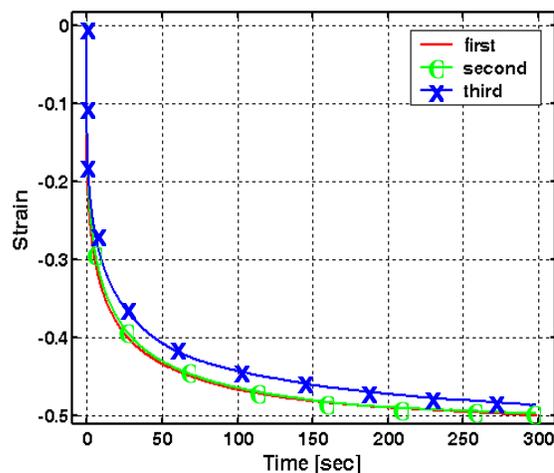
Results from the preliminary large strain creep indentation tests using perfused *ex vivo* whole porcine livers are shown in Figure 1. These tests qualitatively reveal repeatable results within location over time, and a clear creep response where a steady state was achieved within 5 minutes.

The VESPI is currently being modified to operate under position control so that stress relaxation and ramp tests can be performed.

## SUMMARY

This work presents preliminary results from large strain creep tests performed on *ex vivo* whole liver tissue using a perfusion system

that mimics *in vivo* conditions. A description of the proposed constitutive model was also given. Future tests will obtain stress relaxation and hysteresis results as inputs for a finite element model that will be used to identify the mechanical parameters of the liver.



**Figure 1:** VESPI 100g-creep response on a 27kg perfused pig liver at the same location. The second and third indentations were taken 20 and 48 minutes after the first.

## REFERENCES

- Brown, J. D., Rosen, J., et al. (2003). *Proceedings of Medicine Meets Virtual Reality*.
- Febvay, S. (2003). Massachusetts Institute of Technology. Master of Science.
- Ottensmeyer, M. P. (2001). *Proceedings of Medical Image Computing and Computer-Assisted Intervention - MICCAI*.
- Ottensmeyer, M. P., Kerdok, A. E., et al. (2004, accepted). *Proceedings of Second International Symposium on Medical Simulation*.

## ACKNOWLEDGEMENTS

Supported by a grant from the US Army, under contract number DAMD 17-01-1-0677. The ideas and opinions presented in this paper represent the views of the authors and do not, necessarily, represent the views of the Department of Defense.