# **Development and validation of simulations and phantoms mimicking the viscoelastic properties of human liver**

##### *Investigator: Jingfeng Jiang, PhD*

Department of Biomedical Engineering, Michigan Tech University

##### BRIEF DESCRIPTION OF THE PROJECT:

Totally, three viscoelastic numerical models corresponding to three CIRS materials (E2297-AX, E2297-BX and E2297-CX) have been generated. Quasi-linear viscoelastic material properties and an acoustic pushing beam based on a published paper from Dr. Palmeri’s work [[1](#_ENREF_1)] have been assigned to each numerical model. Numerical models are compatible with an open-source finite element package, FEBio [[2](#_ENREF_2)], and will be used to investigate estimation of shear wave speed and shear wave dispersion. Those numerical models contain 1.0 – 1.5 million tetrahedral elements and take approximately 10 hours to solve for a high end multi-core workstation (12 cores, 64 GB memory, Linux OS) with a time-step size of 5.0 × 10-5 second.

**Approach:**

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| **Figure 1.** An illustration of Three-element Standard Linear Solid (SLS) model. A spring () and a dashpot (η) are first connected in series (Maxwell body). Then the Maxwell body is connected with a spring () in parallel. |

Viscoelasticity of soft tissues was taken into consideration by a quasi-linear viscoelastic material model[[3](#_ENREF_3)] implemented in FEBio[[2](#_ENREF_2)]. In the quasi-linear viscoelastic model, a relaxation function G(t) was used[[4](#_ENREF_4)] to simulate time dependent behaviors as follows,

|  |  |
| --- | --- |
|  | (1) |

where represents one of relaxation time values in the Prony series, and is the viscoelastic coefficient in the Prony series. In this study, N was set to be 1 and Eqn. (1) became a three-element Standard Linear Solid (SLS) model (see Fig. 1). Parameters of three CIRS materials (E2297-AX, E2297-BX and E2297-CX) suggested by Dr. Mark Palmeri have been fitted into the above-mentioned relaxation function (see Eqn. (1)).

The elastic contributions to the quasi-linear viscoelastic material model [[3](#_ENREF_3)] are being simulated using the well-known Mooney-Rivilin model [[5](#_ENREF_5)] to match respective for each model. The parameters shown in Table 1 below are tentative.

**Table 1**. Viscoelastic coefficients and relaxation times used in the FEA simulations

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| --- | --- | --- |
| **Component** | **Viscoelastic coefficient**  **()** | **Relaxation time () Unit: second** |
| E2297-AX | 4 | 0.278 |
| E2297-BX | 2.75 | 0.167 |
| E2297-CX | 4 | 0.083 |
|  |  |  |

**PLAN**

Currently, computer simulations are being analyzed and the final results will be provided **by August 23, 2015**. One numerical model is attached as a part of the deliverables for this interim report.

**References**

[1] M. L. Palmeri, M. H. Wang, J. J. Dahl, K. D. Frinkley, and K. R. Nightingale, "Quantifying hepatic shear modulus in vivo using acoustic radiation force," *Ultrasound Med Biol,* vol. 34, pp. 546-58, Apr 2008.

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[3] Y. C. Fung, *Biomechanics : mechanical properties of living tissues*, 2nd ed. New York: Springer-Verlag, 1993.

[4] A. Gerig, J. Zagzebski, and T. Varghese, "Statistics of ultrasonic scatterer size estimation with a reference phantom," *Journal of the Acoustical Society of America,* vol. 113, pp. 3430-3437, 2003.

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