A Finite Element Analysis of Drop Tower Testing on Human Livers

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Introduction

The risk of abdominal injury is heightened in vehicle collisions. By understanding how the internal organs of the human body react to a given stimulus at high strain rates, a computational model can be developed to accurately predict injury. As with any Finite Element Model (FEM), there are significant benefits for using an accurate simplified model over an unnecessarily complex one. Determining that any liver characteristic does not provide a significant advantage in accurately capturing the liver's response would be advantageous.

Study Objective

The objective of this research is to perform a computational study to investigate how recognized material characteristics of the human liver influence the macroscopic response of the liver at large strain rates. These characteristics explored are:

- The anatomical geometry of the liver
- Nonlinear material properties
- Time dependent material properties
  - Viscoelasticity of the liver
  - Dynamic model analysis

Methods

Experimental Work

Conducted by Sparks et al. (2007)

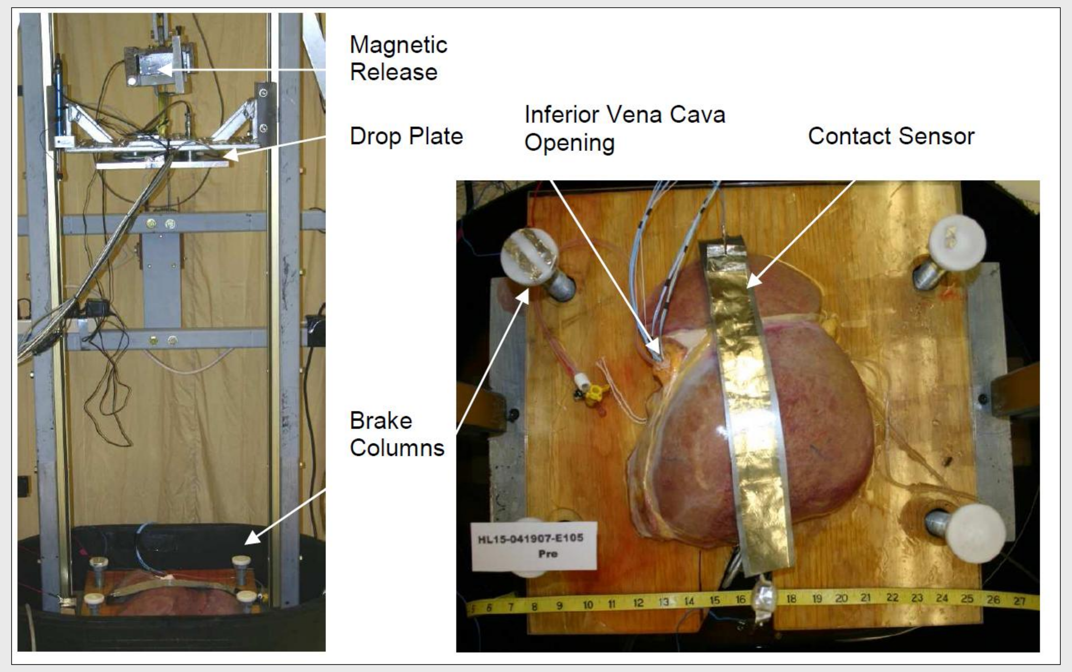

Figure 1: Experimental drop tower apparatus used by Sparks et al. (2007)

Experimental Procedure

A total of 14 livers were tested. Each tested liver was instrumented with Millar pressure sensors and perfused before and during each test run to create anatomical pressure conditions. Once placed in the drop tower, shown in Figure 1, the liver was compressed at a constant velocity a distance of 30% of the liver's initial height. Each liver was tested at a different strain rate (12.26 – 70.95 s^{-1}). The drop tower was instrumented with load cells, accelerometers, and LVDTs to capture force-displacement response of each liver.

Finite Element Analysis

Axisymmetric FEM

A liver FEM with simplified geometry was constructed using Abaqus Ver. 6.8-1 CAE. The reduced model was created using axisymmetry. The dimensions of the axisymmetric FEM are shown in Figure 2. Assuming that the liver's density is the same as water (1000 kg/m^3), the theoretical mass of the model is 4.067 kg. To reduce the number of active elements, bilinear, Fourier quadrilateral elements were used. Adaptive remeshing was also employed to assist convergence with the nonlinear geometry. The elastic modulus was iteratively determined to require agreement with experimental force-displacement data.

Anatomical Geometry FEM

To construct a FEM with an anatomical liver geometry, a contrasting technique was used on CT scans to create a CAD model of the liver. The CAD model was imported into Abaqus Ver. 6.8-1 CAE to conduct the FEM analysis. Figure 3 shows a top view of the anatomical FEM. An automatic scheme was used to mesh the CAD solid, using 4-node linear tetrahedron elements. The same material properties as the axisymmetric model were used.

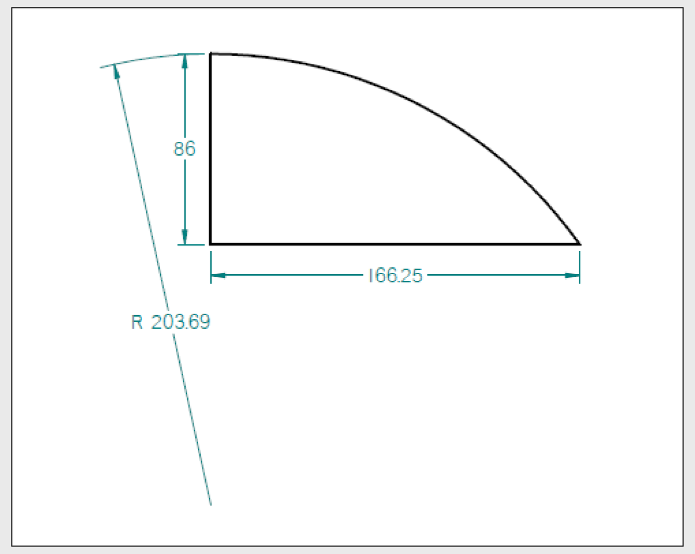

Figure 2: Dimensions of the Axisymmetric FEM

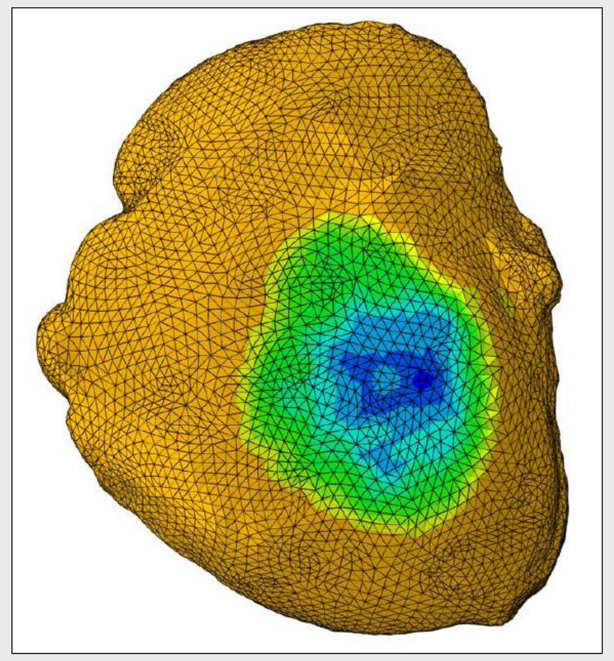

Figure 3: Top view of the Anatomical FEM

Results

Validation Criteria

To validate the results that were generated from each FEM, two experimental criterion were used. The experimental force-displacement data was used as primary validation. Secondary validation comes from localized pressure measurements captured with the Millar pressure sensors. Stress contours between the two FEMs are also examined for likenesses.

Simplified vs. Anatomical Geometry

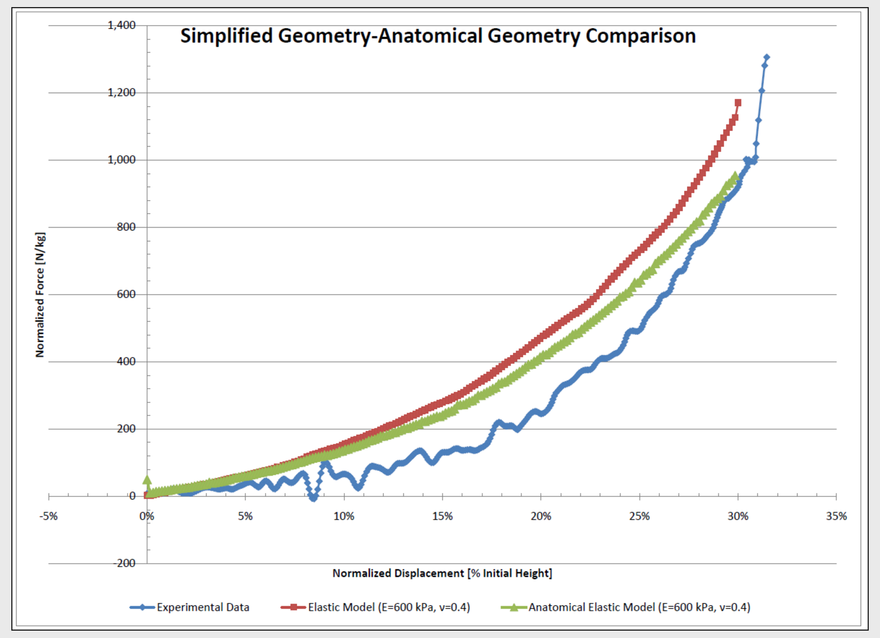

Figure 4: Force-Displacement Comparison of the two FEMs.

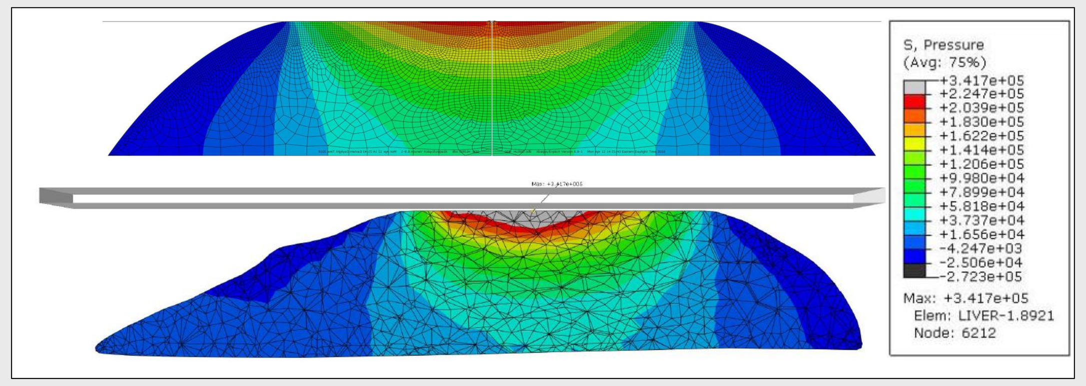

Figure 5: Pressure Contour Comparison of the two FEMs.

Elastic vs. Hyperelastic Material Model

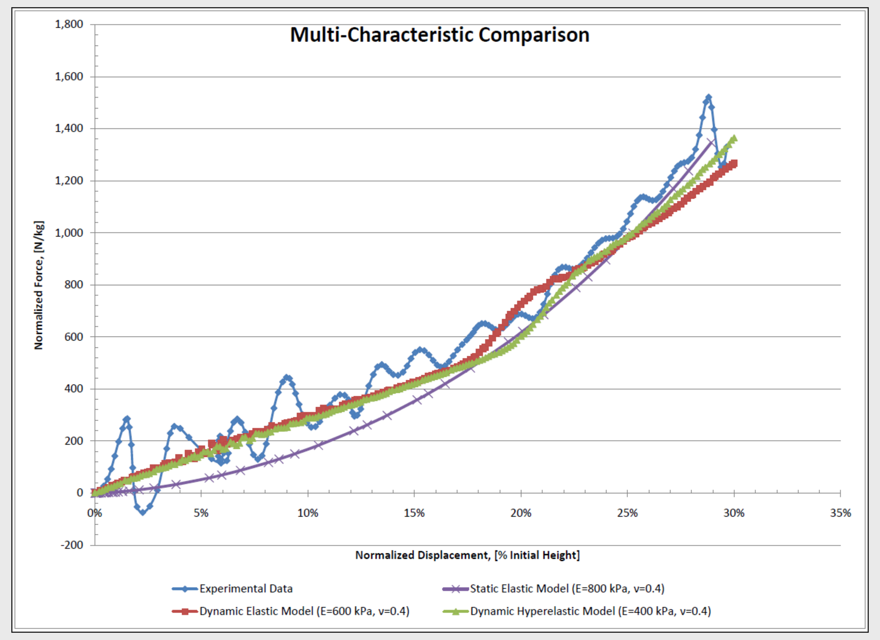

Figure 6: Multi-Characteristic Force-Displacement Comparison

Dynamic vs. Static Analysis

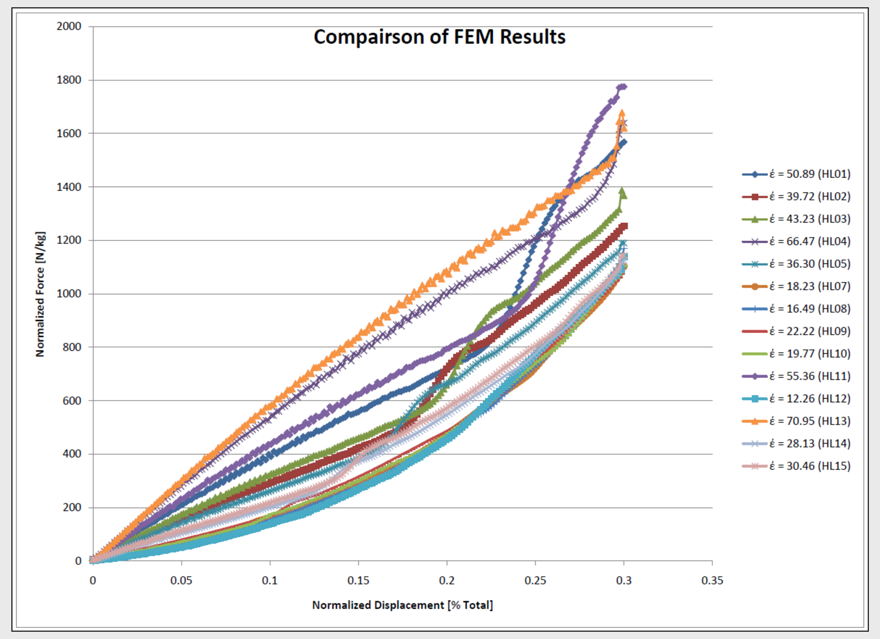

Figure 7: Dynamic FEM Force-Displacement Curves for each tested liver.

Excluding vs. Including Viscoelasticity

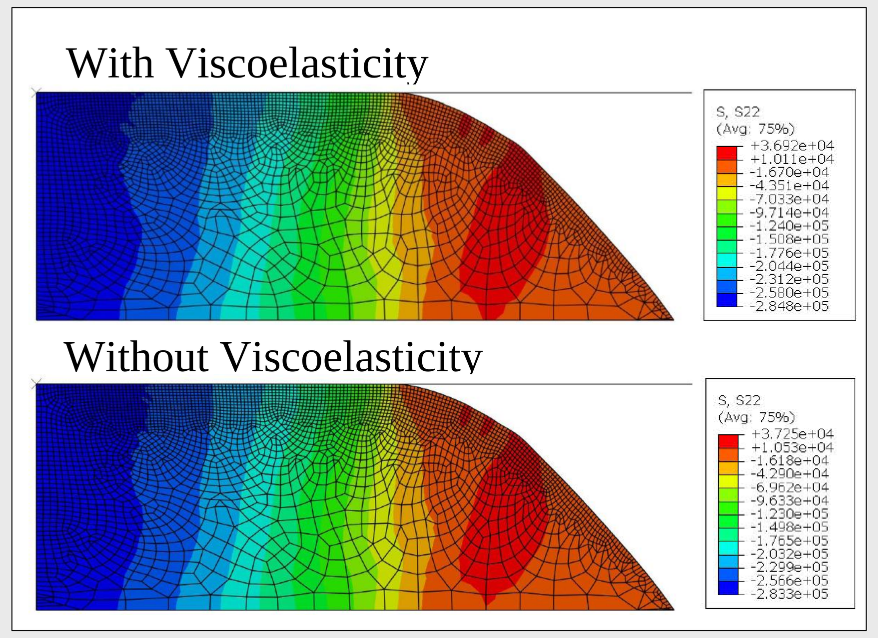

Figure 8: Stress contour plots comparing FEM results with and without visoelasticity.

Discussion & Conclusions

The results generated from the finite model analyses strongly agree with the experimental data. There is also agreement between the FEMs. The FEM geometry comparison, shown in Figure 4, shows that there is no significant benefit of using the anatomical liver geometry, since both models demonstrate the same trends. Figure 5 supports this conclusion, by illustrating only minor differences between the two FEM pressure contours. Figure 6 indicates that both elastic and hyperelastic material models can capture the experimental data. Figure 6 also shows a static analysis compared to a dynamic analysis. The benefit of using a dynamic analysis is shown in Figure 7. Strain rate dependence is evidenced in a dynamic analysis, where as a static analysis produces the same force-displacement results using different loading times. Finally, Figure 8 shows that viscoelasticity does not significantly change the response of the liver at the experienced strain rates.