Quantifying Mechanical Properties of Liver Tissue Using Specimen-specific Finite-element Models and Optimization Techniques

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ABSTRACT

Human finite element (FE) models play an important role in understanding the injury mechanism and designing advanced restraint systems. However, the accuracy of FE models depends not only on geometrical properties, but also on assigned material models. While various experimental tissue tests of abdominal organs have been conducted, the specimen-specific FE modeling of abdominal organs has rarely been attempted in previous studies and the material models for FE simulation of abdominal tissues are still largely unknown [1-3]. Therefore, the goal of this study was to establish a standard procedure to develop FE material models for abdominal tissues utilizing specimen-specific FE models and optimization techniques. As a first step, the material properties of capsule and parenchyma of bovine liver were identified. Ten fresh adult bovine livers were obtained and the specimens were tested within 36 hours after slaughter. A custom blade assembly was used to obtain constant thickness slices (5mm) of liver samples [1, 2]. A custom stamp and a stamping base were used to obtain "dog-bone" shaped specimens (length: 45.5 mm, middle width: 7 mm) commonly used for uniaxial tension testing [1, 2]. All samples were then immersed in a bath of physiological (0.9%) saline at 24°C to maintain specimen hydration until test. The specimens were divided into three categories which were tested until failure at the following strain rates: $0.01~s^{-1}$, $0.1~s^{-1}$, and $1.0~s^{-1}$. One end of the specimens was fixed, and the time history recorded during testing was prescribed to the opposite side. The initial geometries of specimens were recorded using a FARO Laser Scanner (Beringen, Switzerland) and then used to develop the specimen-specific FE models. Several visco-hyperelastic material models were assigned to the specimens, and the tension tests were simulated in LS-DYNA software. The square root error between the time histories of force recorded in testing and simulations were defined as objective function and heuristic optimization algorithms (e.g. genetic algorithm) were used to identify the values of material coefficients. The material models were validated by comparing the specimen-specific surface strain during testing, quantified using a high-speed camera and a grid defined over the specimen, to the corresponding data calculated during the FE simulations. It is believed that the methodology developed in this study will be extended to human organs in the future to develop more accurate material models of abdominal organs, which consequently will result in more accurate FE human models.