Material characterization of subcutaneous adipose tissue and its application in injury prediction and prevention

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Abstract

Obesity is associated with increased fatality risk and altered distribution of occupant injuries relative to lower BMI occupants in automotive collisions [1-4]. This is partially because of the substantial effect that obesity has on occupant-restraint interaction. Restraining obese occupants is a challenge due to increased body mass, unfavorable belt placement [5], and increased forward excursion within the occupant compartment [6-7]. An increased depth of abdominal soft tissue, results in delayed and limited engagement of the lap belt with the pelvis and increases the risk of pelvis submarining under lap belt, exposing occupant's abdomen to belt loading [7].

Previous modeling studies have shown that pelvis submarining could not be replicated using existing obese human body models (HBMs), which is partially due to over stiffened shear response of flesh material model [8] (Gepner, 2018). Specifically, existing obese HBMs do not support large deformation due to both element formulation and material model limitations. They also cannot account for the differences in flesh material property due to increased amount of subcutaneous adipose tissue in obese occupants. After searching for existing literature, it was found that data for creating an adipose material model at automotive crash rates was lacking. Therefore, the objective of this study is to design a mechanical test fixture to characterize the mechanical properties of subcutaneous adipose tissue.

Test fixtures were designed to produce porcine adipose tissue specimens that have consistent dimensions and perform testing on the same specimen under both compression and shear loading. A cylindrical punch and a custom slicing device were designed to cut 10 mm tall cylindrical specimens. The tissue was glued to a pair of specimen plates with Loctite super glue. A pair of actuator plates was developed to interface with specimen plates and to allow for both compression and shear testing. Additionally, a pair of custom bridging plates was designed to attach to the specimen plates allowing for removal and transport of plate-specimen-plate complex. All specimen were tested in both compression and shear modes. For both compression and shear testing, preconditioning was performed for 10 cycles at 5% and10% strain level followed by ramp and hold loading.

Following testing, stress- strain curves were obtained. The material exhibited strong nonlinear behavior with strain hardening at higher strains. Also, stress relaxation effect could be clearly observed from each ramp and hold experiment, indicating viscoelasticity. An Ogden type hyperelastic-viscoelastic constitutive model was fitted to each specimen and then to all specimens combined by minimizing the sum of squared errors (SSE) between model response and experimental data. Sample variance was shown to be similar to previous experimental studies at different loading conditions [9]. The results indicated potential anisotropy of adipose tissue, which needs to be confirmed by medical imaging study and material testing in other loading orientations.

This is the first experimental study on subcutaneous adipose tissue aimed at modifications on existing HBMs to replicate submarining kinematics, which paves the way for its application in injury prediction and prevention using HBMs.

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