Thesis title: Characterization of Long Bones under Dynamic Loading: A Subject-specific Integrated Experimental–Computational Approach

Abstract

Pedestrian–vehicle collisions frequently result in severe lower-limb injuries, with the tibia and femur being among the most commonly fractured long bones. Accurate prediction of long-bone response under impact loading is therefore essential for injury biomechanics and pedestrian safety applications. However, the predictive capability of existing finite element (FE) models is often limited by simplified constitutive formulations and the lack of specimen-specific representation of bone geometry and material heterogeneity. In particular, the combined incorporation of strain-rate dependency, anisotropy, tension–compression asymmetry, and specimen-specific modeling remains limited in the literature.

This thesis presents an integrated experimental–computational framework for the specimen-specific characterization of long bones under dynamic loading conditions. The framework combines quasi-static and dynamic three-point bending experiments, computed tomography (CT)-based specimen-specific finite element (SSFE) modeling, inverse FE characterization, and model validation. A two-stage inverse FE methodology was developed in which quasi-static material parameters were first identified and subsequently used to characterize strain-rate-dependent behavior using dynamic experimental responses.

The framework was initially developed and validated using goat tibia specimens incorporating an isotropic strain-rate-dependent constitutive model. The optimized FE model accurately reproduced experimental force–displacement, force–time, and strain–time responses, with characterization and validation errors below 9%. The framework was subsequently extended to human tibia specimens by incorporating anisotropic and tension–compression-asymmetric constitutive behavior. The developed model successfully captured the directional and asymmetric response of cortical bone, achieving prediction errors below 10% under both quasi-static and dynamic loading conditions. The same framework was further applied to human femur specimens, yielding quasi-static and dynamic responses with errors below 8.5%.

The successful application of the proposed framework to goat tibia, human tibia, and human femur specimens demonstrates its robustness and generalizability for characterizing long-bone behavior under impact loading. The developed methodology provides a validated approach for specimen-specific material characterization and dynamic response prediction, with potential applications in injury biomechanics and pedestrian safety assessment.