

Characterization of Human Long Bones Using Experiments, Imaging and Inverse Finite Element Techniques.

Mike W.J. Arun*, Sudipto Mukherjee^{#@}, Anoop Chawla[#], Girish Sharma⁺, Parthiv Shah⁺, Christophe Ageorges⁺

I. INTRODUCTION

Human body kinematics in a crash is influenced by long bone behaviour. The objective of this work is to derive a finite element material model for long bones, which can predict both mechanical response as well as the different fracture types over a wide range of loading conditions.

II. METHODS

Experimental Testing

Twelve cadaveric humeri (four right and eight left) from human subjects in the age group 40-60 years were tested in dynamic three-point bending. The bones were impacted by a 31 kg mass with velocities of 3.23 m/s, 4.43 m/s and 5.42 m/s in the anterior-posterior direction until failure and the force exerted by the impactor was recorded.

Computational Modeling

Before testing, a detailed FE mesh of the specimen was obtained using CT scans. In order to capture the non-homogeneity of the material, the mesh was divided into twenty material sets based on Hounsfield Number from CT Scans and material properties were assigned to them. Long bones are seen to exhibit strain-rate dependency in stiffness as well as in failure. Therefore, it was concluded that rate-dependency has to be captured for an accurate structural and failure characterization of the bones. Data from the experiments have therefore been utilized in understanding bone behaviour under impact and capturing the same using computer simulations.

A user-defined material model was developed that incorporates the rate dependency of stiffness, yielding and failure. A logarithmic relation was used to model strain-rate dependency of elastic modulus, yield and damage initiation. A Drucker-Prager plastic model was chosen as it captures dilation of bone and asymmetry in yielding. A phenomenological damage model was chosen to capture the shear failure mechanism. The sums of the errors between the simulation and the experimental result for the three drop heights were minimized using constrained Genetic Algorithm.

III. FINDINGS

Oblique fractures were observed in all the experiments. The average peak load at failure was observed to be 1.6 kN, 2 kN and 2.7 kN for the 3.23 m/s, 4.43 m/s and 5.42 m/s impacts, respectively. The average fracture initiation time was 0.9 ms, 0.61 and 0.45 ms after impact. The initial slope of the force time curve was observed to be the highest (20.1kN/ms) in the 5.42 m/s case while the 3.23 m/s impact recorded the lowest (10.4 kN/ms).

By using the proposed computational method, fracture types observed in the experiments were reproduced in most of the cases, including those which were not predicted by earlier models. A single material model was thus obtained that well predicts the result (correlation >0.8) in all cases. The quasistatic modulus of bone is found to vary between 0.7 and 6 Gpa for cancellous and between 7 and 19 Gpa for cortical bone. For bone with Hounsfield Number of 1600 the modulus is found to vary from 19 to 50 Gpa as strain rate varies from 0.001 to 300/s.

IV. CONCLUSION

The outcome of this work would contribute significantly in evolving biofidelic FE human models to protect both occupants and vulnerable road users (VRU).

* PhD student in the Department of Mechanical Engineering, Indian Institute of Technology, New Delhi.

Professor in the Department of Mechanical Engineering, Indian Institute of Technology, New Delhi.

+ Mercedes-Benz Research and Development, India.

@ Corresponding author ((tel: +91 11 26591138, sudipto@mech.iitd.ac.in).