Statistical Shape Analysis for Development of a Probabilistic Finite Element model of The Human Clavicle

Yuan-Chiao Lu, Costin Untaroiu PhD

Department of Mechanical and Aerospace Engineering, University of Virginia

ABSTRACT

Inherent variability exists in biological tissues in terms of geometrical shape and material properties. Statistical shape analysis has been shown to appropriately represent the geometric variability of bones, but it was limited to the applications of exterior bone surface and the human clavicle shape was investigated in only a few studies [1]. The main goal of this study is to enhance our knowledge regarding the shape of the human clavicle and distribution of cortical bone thickness along the shaft. As a result of this study, the first probabilistic finite element model of the clavicle would be developed by incorporating material data found in literature. The geometries of thirty-five clavicles were reconstructed from computerized tomography (CT) scans. The exterior and interior boundaries of cortical bone were obtained using polylines with different densities. Generalized Procrustes Analysis was implemented to register landmark configurations into optimal registration. Principal component analysis was employed to find the most important mode shapes. The length of the clavicle was shown to be the most significant shape mode and the first four principal modes accounted for 86.4% of anatomical variation. A batch file was developed in TrueGrid for automatic meshing of clavicles using hexahedral elements. Dynamic bending tests (1 m/s impactor rate) were simulated using similar pin-simply supported boundary conditions as those tested by Untaroiu et al. [2]. A 1000-trial Monte Carlo simulation was employed for the probabilistic analysis using various shapes and values of elastic modulus of cortical bone assumed to follow a log-normal distribution. The force-displacement test corridor obtained from testing was shown to be included in the corresponding corridor from simulation. This study is the first numerical investigation that combines bone shape variability and material properties of cortical bone. We hypothesize that using a probabilistic approach will help in better understanding variability observed in both data of component tests and injuries recorded in automotive accidents.