PREDICTING IMPACT RESPONSE OF HUMAN FEMUR USING MATERIAL MAPPING STRATEGY

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Introduction

Material property mapping is a crucial step in developing quantitative computed tomography (QCT) based patient-specific finite element (PSFE) heterogeneous model of bone. However, its accuracy is highly dependent on several factors, such as density–modulus relationships (E-ρ) and the number of bone material sets. Significant moduli variation for both trabecular (80%) and cortical bone (40%) was observed using different E-ρ relationships previously reported in the literature [1]. This work aimed to investigate the influence of E-ρ relationships and the number of bone material sets on the prediction accuracy of the dynamic response of the human femur.

Methodology

A three-point bend test was performed from lateral to medial impact direction on the human femur (mid-diaphysis) at 1.42 m/s impact velocity, and its force-time response was recorded using a piezoelectric load cell. Before testing, the specimen was scanned using a QCT scanner (XtremeCT, Scanco, Inc., Switzerland). Heterogeneous PSFE models of bone were developed using Mimics (Materialise, Belgium) and Hypermesh (Altair Engineering, USA). Ten PSFE models with two types of E-ρ relationships i.e. linear (eq. 1) and power law (eq. 2) each with five different numbers of bone material sets (3, 10, 40, 100, and 300) were tested. The genetic algorithm-based inverse characterization method was used to optimize design variables (a and b) for both trabecular and cortical bone. Optimization was run to minimize the root mean square error (RMSE) between the force-time response of the experiment and PSFE models. PSFE simulations were made to run corresponding to the time when the fracture was observed in our experiment and peak impact force was recorded at that instant. The performance of every model was evaluated in terms of the von Mises stress (σ_{von}), maximum principal stress (σ_{mps}), and effective plastic strain (ε_{eps}) of elements at mid-diaphysis opposite to the impact (Fig. 1).

$$E = a\rho + b \qquad (1)$$
$$E = a\rho^b \qquad (2)$$

Results

Significant variation in peak force values was observed (Fig. 2 a) and power law (eq. 2) with 300 material sets best predicted the peak force (0.9% error). Predicted values of σ_{von}, σ_{mps}, and ε_{eps} of other models were compared to the most heterogeneous model i.e. model with 300 material sets as shown in Fig. 2 b, c, and d, respectively.

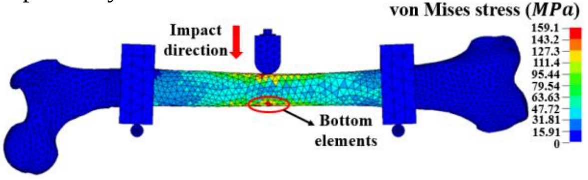

Figure 1: Bottom elements used for the evaluation of PSFE models.

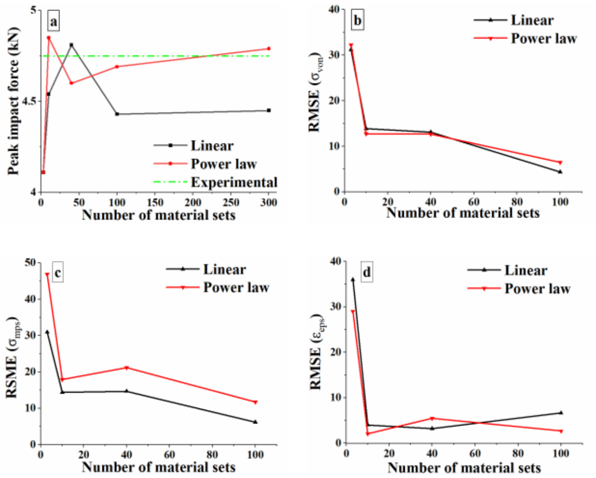

Figure 2: (a) Variation in predicted peak force. Variation in RSME values of (b) σ_{von} (c) σ_{mps} and (d) ε_{eps} at bottom elements.

Discussion

The prediction of the dynamic response of the human femur was dependent on both material mapping parameters [2]. Fig. 2a suggests that the E-ρ relationship significantly influences the prediction of peak force [3]. Fig. 2 b, c, and d indicate that the combination of material mapping parameters needs to be implemented for best prediction [1]. In this study force-times response was used from one experiment to obtain optimized PSFE models. Therefore, further validation is required with larger datasets to ensure reliable results.

References

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