Development of a material model to simulate through-the-thickness transmission of vibration in the adult human skull

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Abstract

Brain injury resulting from exposure to blast continues to be a significant problem in the military community, often leading to death or long term disability. The presence of high frequency energy content in pressure waves generated in explosive blasts necessitates understanding the transmissibility and damping characteristics of skull bone, through which these waves must pass before reaching the brain. Current finite element models (FEM) of the skull do not include material damping and therefore fail to capture the correct attenuation spectrum or rate dependency of skull bone. This study uses a simple lumped mass model that is representative of the human skull to obtain material parameters for use in the skull FEM.

Cylindrical through-the-thickness specimens (cores) of skull bone, approximately 18 mm diameter, were obtained from ten regions of the right calvarium of ten adult (55 ± 10 years old) male post-mortem human surrogates. A test apparatus was developed to apply cyclic loading to potted cores at frequencies ranging from 1 to 50 kHz using a piezoelectric shaker. High bandwidth transducers were used to record accelerations and forces at the boundary. A lumped mass model was developed and optimized to match the recorded boundary conditions. Due to large specimen to specimen variation of response, the model parameters were dependent on core geometry and histology. A micro computed tomography (μCT) study of the cores was performed prior to testing in order to characterize the geometry and histology. The lumped masses in the model are calculated from actual measured total mass of cores and spatial distributions from μCT and can be used as mass density parameters in FE. The stiffness and damping parameters in the model are used to develop material parameters in the FEM.

In the uncoupled mode, when the inner cortical table is traction free, the model exhibits damped resonance at ~32 kHz due to compliance and damping in the trabecular region. The vibration amplification at this frequency is ~15 dB. At frequencies beyond this first resonance, the vibration attenuation increases at ~30 dB/decade. The cortical shells resonate at ~300 kHz beyond which attenuation increases rapidly at 120 dB/decade. Confidence intervals for the model parameters are developed and reported in this paper. Previous researchers have tested pure cortical bone under cyclic loading and have reported very small loss due to material damping. Data regarding damping in trabecular bone does not exist in current literature. This model replicates the composite response of the skull as a whole. The dynamic compression response of the model has been validated against tests conducted on the same cores. This model is suitable for implementation in an FEM of the head whose response has been verified in

scenarios involving high frequency cyclic loading such as during explosive blast.