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Dynamic Mechanical Testing Techniques for Cortical and Cancellous Bone[1]

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Bone fracture typically occurs as an impact loading event (sporting accidents, vehicle collisions), the simulation of which requires in-depth understanding of dynamic bone behavior. Bone is a natural composite material with a complex multi length-scale hierarchical microstructure. At a macroscopic level, it is classified into hard/compact cortical bone and soft/spongy cancellous (trabecular) bone, though both are low-impedance materials relative to steels. Cortical bone is predominant in long bones, while in complex bone geometries (joints, flat bones) a cancellous bone core supports a thin cortical shell. Bone has primarily been studied at quasi-static strain rates ($\dot{\epsilon} < 1\,s^{-1}$), with some dynamic studies ($300\,s^{-1} < \dot{\epsilon} < 3000\,s^{-1}$), but rarely at intermediate strain rates (ISR) ($1\,s^{-1} < \dot{\epsilon} < 100\,s^{-1}$). The data shows bone to be viscoelastic, which suggests that more dynamic and ISR data is required. Furthermore, bone exhibits quasi-brittle failure, with interrupted quasi-static tests revealing a strong microstructure dependence. However, bone specimens are typically destroyed during dynamic tests, leading to a lack of dynamic microstructural damage investigations. In this paper, a short overview of dynamic bone testing is presented to give context to the challenges of testing low impedance, strain-rate dependent, non-linear, visco-elastic-brittle materials. Recent state-of-the-art experimental developments in dynamic bone testing are reviewed, with emphasis on pulse shaping, momentum trapping and ISR testing. These techniques allow for dynamic bone testing at small strains and near-constant strain rates with intact specimen recovery. The results are compared to those obtained with varying strain rate tests. Interrupted dynamic test results with microstructural analysis of the recovered specimens are presented and discussed. The paper concludes with a discussion of the experimental and modeling challenges that lie ahead in the field of dynamic bone behavior.

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