Nonlinear Shock Wave Propagation in Soft Tissues as a Mechanism of Injury

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ABSTRACT

The aim of this study is to investigate the propagation of shock waves and self-preserving waves in soft tissues such as aorta and brain as a mechanism of injury in high rate loading conditions as seen in blunt trauma and blast-induced trauma (BIT). It is shown that such phenomena can only be seen in nonlinear viscoelastic materials and the existing linear and quasi-linear models predict only decaying waves. Various attempts to explain the mechanisms of soft tissue injuries e.g., traumatic aortic rupture (TAR) and traumatic brain injury (TBI) as a result of car accidents and sports injuries have been reported over the past 3 decades. In recent years, with advances in protective gears, blast induced trauma (BIT) has also become a major concern. To date, the mechanisms of soft tissue injuries, especially at high-rate loadings, are still not clearly understood. As a blast wave enters a biological tissue, high-rate stress waves, which have longitudinal and shear components, develop in the tissue and such components can have devastating effects on the tissue based on the amplitudes of the waves and the orientation of tissue fibers. In this study, nonlinear viscoelastic wave propagation in soft tissues is studied and a criterion for the development of onedimensional shock waves has been proposed. It is shown that realistic jumps in the acceleration that may happen in blast or blunt trauma evolve to shock waves that result in large discontinuities in strain and stress that may lead to tissue failure. Results of this study show that when blast over-pressure is applied to the head resulting in 110 G acceleration, the nonlinear theory predicts significantly larger amplitudes in brain stress and strain after only a few milliseconds after the impact as compared to the linear viscoelastic theory. The generation of shock waves and self-preserving steady waves is a characteristic only applicable to non-linear viscoelastic materials when certain conditions in the material properties and initial conditions are met. Since the majority of the constitutive models developed in the literature for soft tissues are linear viscoelastic models and do not pay attention to the nature of the nonlinearity of the instantaneous elastic function, this study suggests that the development of discontinuous strain and stress as a mechanism of soft tissue injury, especially for the high-rate loading conditions observed in blunt and blast trauma, is overlooked.