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Discrete quasi-linear viscoelastic damping analysis of connective tissues, and the biomechanics of stretching

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Abstract

The time- and frequency-dependent properties of connective tissue define their physiological function, but are notoriously difficult to characterize. Well-established tools such as linear viscoelasticity and the Fung quasi-linear viscoelastic (QLV) model impose forms on responses that can mask true tissue behavior. Here, we applied a more general discrete quasi-linear viscoelastic (DQLV) model to identify the static and dynamic time- and frequency-dependent behavior of rabbit medial collateral ligaments. Unlike the Fung QLV approach, the DQLV approach revealed that energy dissipation is elevated at a loading period of ∼10 seconds. The fitting algorithm was applied to the entire loading history on each specimen, enabling accurate estimation of the material's viscoelastic relaxation spectrum from data gathered from transient rather than only steady states. The application of the DQLV method to cyclically loading regimens has broad applicability for the characterization of biological tissues, and the results suggest a mechanistic basis for the stretching regimens most favored by athletic trainers.

Keywords: Relaxation spectrum, storage and loss modulus, stress relaxation, ligament, quasi-linear viscoelasticity, discrete quasi-linear viscoelastic model

1. Introduction

"Stretching" is commonly performed by athletes for the purpose of optimizing body performance, but the mechanisms, optimal conditions, and efficacy of stretching are sources of debate. Stretching has been shown to enhance range of motion (Murphy et al., 2010), but to either decrease or not affect peak athletic performance (Molacek et al., 2010; Behm & Chaouachi, 2011). The time period and character (ramped, ballistic, sustained) of stretching appear to influence its efficacy, with ballistic stretching apparently less effecive than lower frequency dynamic stretching (Hough et al., 2009; Pearce et al., 2009; Unick et al., 2005; Behm & Chaouachi, 2011). The mechanisms underlying these effects are hypothesized to be some combination of connective tissue inelasticity, muscle plasticity, paracrine effects, and neural effects, the latter mediated by the Golgi tendon organ and the muscle spindle stretch receptor, and somewhat less long-lasting in effect (Cuissard

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