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Mathematical modeling approach to dynamic and impact testing of articular cartilage

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In recent years, a number of experimental studies have been conducted to investigate the mechanical behaviour, damage mechanisms, and viability of articular cartilage under dynamic and impact loading. While well-developed quasi-static indentation methods are suitable for many industrial applications, an enhanced indentation technique is needed for measuring time-dependent material properties of biological tissues, like articular cartilage, by taking into account dynamic effects. At present, there is the need of simple mathematical models, which allow comparing experimental results obtained in impact testing with impactors of different masses and incident velocities as well as in dynamic indentation tests with different indentation depths and loading times.

A variety of mathematical models were suggested to describe the stress-strain response of articular cartilage that represents a multiphasic, structurally complex material possessing time-dependent properties. In the present study, we develop viscoelastic models for dynamic indentation and impact problems capturing the main features of the indentation and impact tests recently suggested for assessing articular cartilage viability. It is assumed that the mechanical response of the articular cartilage layer can be described in the framework of viscoelastic model with time-independent Poisson's ratio such that the overall constitutive behaviour is expressed in terms of the complex modulus. Based on the elastic-viscoelastic correspondence principle, the governing integral equation of the associated dynamic contact problem is formulated, and closed-form analytical solutions for the integral characteristics of the indentation test are obtained. An asymptotic modeling approach is then applied for analyzing and interpreting the results of the dynamic indentation test in terms of the so-called incomplete storage modulus and the loss angle of the viscoelastic material. The behaviour of the dynamic and pulsatile indentation moduli has been studied in detail.