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Computational modelling of articular cartilage

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Abstract: The mechanics of articular cartilage has been intensively studied in the last four decades. Early studies were mainly experimental with limited development in constitutive modelling. There has been rapidly increasing modelling work since the initial biphasic model was born. Researchers then tried over two decades to understand why the early versions of the biphasic models could not capture the great transient load response that had been observed in experiments. Another long-standing argument was over which mechanism dominates the transient response of articular cartilage: the fluid pressure or the inherent viscoelasticity of the solid matrix? A recent focus seems to be modelling the cell mechanics of articular cartilage by using continuum mechanics. The purpose of this chapter is to introduce fundamental theories and address some common issues in the mechanical modelling of articular cartilage.

Key words: articular cartilage mechanics, biphasic model, fibril-reinforced model, poromechanical behaviour, strain-rate dependence, viscoelasticity.

7.1 Introduction

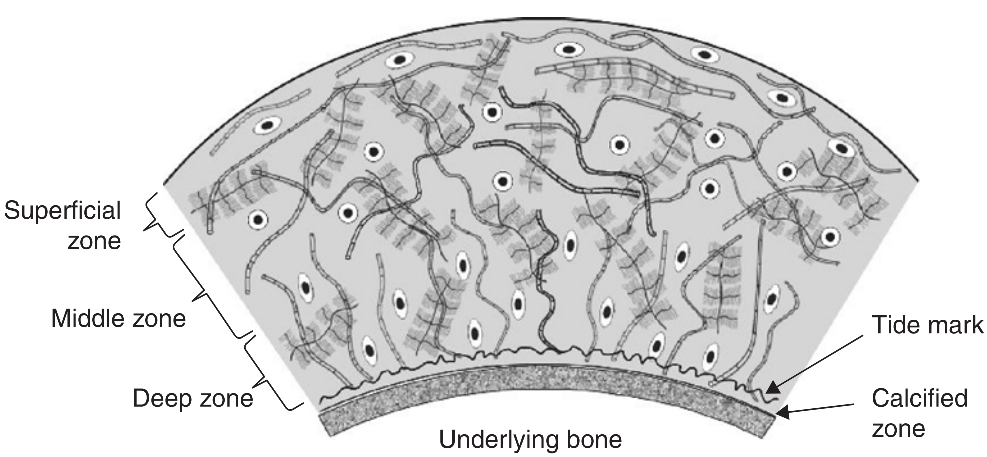
Articular cartilage plays a crucial role in the mechanical function of a diarthrodial joint in which it is located. The mechanical role of articular cartilage is determined not only by its structural compositions and material properties, but also by the contact conditions of the joint. Some background information on the mechanical structure and function of articular cartilage is briefly introduced in this section, followed by a review of major difficulties in cartilage mechanical modelling.

7.1.1 Mechanical structure and properties of articular cartilage

Articular cartilage is a soft connective tissue mostly found in diarthrodial joints. It is also called hyaline cartilage because of its glass-like appearance.

The other two types of cartilage are elastic cartilage and fibrocartilage. Cartilage consists of a porous extracellular matrix saturated with a fluid. The extracellular matrix is composed of proteoglycans and collagen fibres. It also contains elastin fibres except in articular cartilage. The elastic cartilage possesses higher amounts of elastin fibres, whereas fibrocartilage contains more collagen fibres which are stiffer than elastin fibres. Articular cartilage consists of fewer collagen fibres and more proteoglycans as compared to fibrocartilage. Articular cartilage absorbs fluid into its porous matrix due to the negatively charged proteoglycans. The only cells in articular cartilage are chondrocytes which are surrounded by the pericellular matrix. Articular cartilage is avascular in nature, that is, there is no blood supply in the tissue, which limits the cartilage capabilities in self-repairing when damaged. The mechanical loading that the cells experience largely determines their activity in production or degradation of extracellular matrix (Grodzinsky *et al.*, 2000).

Articular cartilage is highly inhomogeneous and anisotropic (Fig. 7.1). First, the mechanical properties vary along the tissue depth, often characterized by three distinct zones, superficial, middle and deep zones (Kempson *et al.*, 1973; Schenk *et al.*, 1986; Muehleman *et al.*, 2004). The depth of the superficial zone is reported to be 10–20% of the total thickness of the tissue; the collagen fibres are arranged tangentially to the articular surface in this zone. The middle zone usually occupies 40–60% of the tissue thickness with randomly oriented collagen fibres. The deep zone is adjacent to the underlying bone, which makes up 20–50% of cartilage thickness, with fibres being oriented perpendicular to the cartilage–bone interface (Mow *et al.*, 2005). The compressive modulus of articular cartilage is small in the



7.1 A schematic representation of a section of articular cartilage, showing the three zones with collagen fibres, proteoglycans and chondrocytes. The fibre orientation, cell shape and other properties vary continuously with the tissue depth.

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