Biomechanics of hydrated soft tissues: effect of geometrical and constitutive parameters in harmonic nano-indentation tests.

Taffetani M.[a], Bertarelli E.[a,c], Gottardi R.[b], Landini E.[b], Raiteri R.[b] and Vena P[a,c].

[a] *Dipartimento di Ingegneria Strutturale, Laboratorio di Meccanica delle Strutture Biologiche (LaBS), Politecnico di Milano - Milano, Italy; e_mail: vena@stru.polimi.it*

[b] *Dipartimento di Ingegneria Elettronica e Biofisica, Università degli Studi di Genova, Genova - Italy*

[c] *IRCCS, Istituto Ortopedico Galeazzi, Via Galeazzi 4, 20161 Milano, Italy*

The biomechanics of hydrated soft tissues and of articular cartilage in particular, depends on their intrinsic composition, organization and bonding of their constituents as well as their interactions during the deformation process (Manking, et al. 2000). The articular cartilage is a complex material in which a solid porous matrix, composed by a collagen fibrils network and proteoglicans, is saturated with water. Due to constituents distribution, articular cartilage is inhomogeneous and anisotropic. Two main mechanisms can be used to describe the time and frequency dependent behaviour of this tissue: i) intrinsic viscoelasticity of the matrix constituents and of the bonding; ii) fluid flow through the porous medium. Viscoelasticity and poroelasticity are both time-dependent mechanisms, which contribute to the tissue overall response, through different mechanisms at different length scales.

Nanoindentation has been widely applied to the mechanical characterization of biological mineralized tissues exhibiting the capability to probe mechanical properties at different characteristic lengths. Whereas, for soft hydrated tissues – which exhibit non linear anisotropic stress strain relationship and time dependent response – the application of this technique is less established. Undoubtedly, dynamical mechanical analysis coupled with nanoindentation is an interesting approach through which the frequency dependent material response is studied by applying harmonic loading and sweeping a wide frequency range (Cheng, Ni and Cheng 2006).

This work aims at studying the mechanical response of a poroelastic medium subjected to harmonic forced oscillations in a spherical nanoindentation test. Through Finite Element simulations, a sensitivity analysis is carried out. The influence of both geometrical (tip radius and indentation depth) and constitutive parameters is investigated. In a transversely isotropic framework with constant permeability, the ratio between longitudinal and transversal Young moduli (α) and the out-of-plane Poisson's ratio are investigated.

Results have shown that material response is more sensitive to the tip radius than to the indentation depth. Axial to transverse elastic modulus ratio as well as the Poisson ratios affect the storage and loss moduli as well as the frequency at which the peak of loss modulus is found. The comparison between experimental numerical results allowed to determine the main mechanical parameters affecting the indentation response of such tissues.

Bibliografia

Cheng, Y.T., W. Ni, and C.M. Cheng. "Nonlinear analysis of oscillatory indentation in elastic and viscoelastic solid." *Physical Review Letters*, 2006.

Mankin H.J., Mow V.C., Buckwalter J.A., Iannotti J.P., Ratcliffe A. Articular cartilage structure, composition, and function. In: Buckwalter JA, Einhorn TA, Simon SR, editors. Orthopaedic Basic Science: Biology and Biomechanics of the Musculoskeletal System. Rosemont (IL): American Academy of Orthopaedic Surgeons Publishers; 2000. p. 443–70.