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Research paper

Role of damage mechanics in nanoindentation of lamellar bone at multiple sizes: Experiments and numerical modeling

Riccardo Lucchini[a,1], *Davide Carnelli*[a,b,1], *Matteo Ponzoni*[a], *Emanuele Bertarelli*[a,c], *Dario Gastaldi*[a], *Pasquale Vena*[a,c,*]

[a] *Laboratory of Biological Structure Mechanics (LaBS), Department of Structural Engineering, Politecnico di Milano, Milan, Italy*
[b] *Institute of Condensed Matter Physics (ICMP), Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland*
[c] *IRCCS, Istituto Ortopedico Galeazzi, Milan, Italy*

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ABSTRACT

The aim of this paper is to show that damage mechanisms can account for the response of lamellar bone to nanoindentation tests, with particular regards to the decrease of indentation stiffness with increasing penetration depth and to the loss of contact stiffness during the unloading phase of the test.

For this purpose, indentation experiments on bovine cortical bone samples along axial and transverse directions have been carried out at five penetration depths from 50 to 450 nm; furthermore, a continuum damage model has been implemented into finite element analyses, which are able to simulate indentation experiments.

Experiments along the axial direction have shown a decrease of about 20% of the indentation modulus with indentation depth; a similar trend was found along the transverse direction. All unloading branches of the force–displacement indentation curves exhibited relevant stiffness loss (curve concavity). The numerical model with damage was able to correctly predict the indentation stiffness and hardness at 300 nm penetration depth along both axial and transverse directions. Furthermore, stiffness loss during unloading was simulated with both qualitative and quantitative agreement with experiments. A final validation has been provided by simulating axial indentation experiments at the remaining penetration depths using the same set of constitutive parameters as those used to simulate the experiments at 300 nm depth.

These results support the hypothesis that damage plays a relevant role in the mechanics of lamellar bone and should be taken into account when studying bone mechanical properties at multiple scales.

* *Corresponding address:* Piazza Leonardo da Vinci, 32, 20133 Milano, Italy. Tel.: +39 02 2399 4236; fax: +39 02 2399 4220.
E-mail address: vena@stru.polimi.it (P. Vena).

[1] These authors equally contributed to the work.

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