Numerical Modeling of a Rabbit Cancellous Bone and Marrow using Fluid Structure Interaction by coupling Lattice Boltzmann and Smoothed Particles Hydrodynamics

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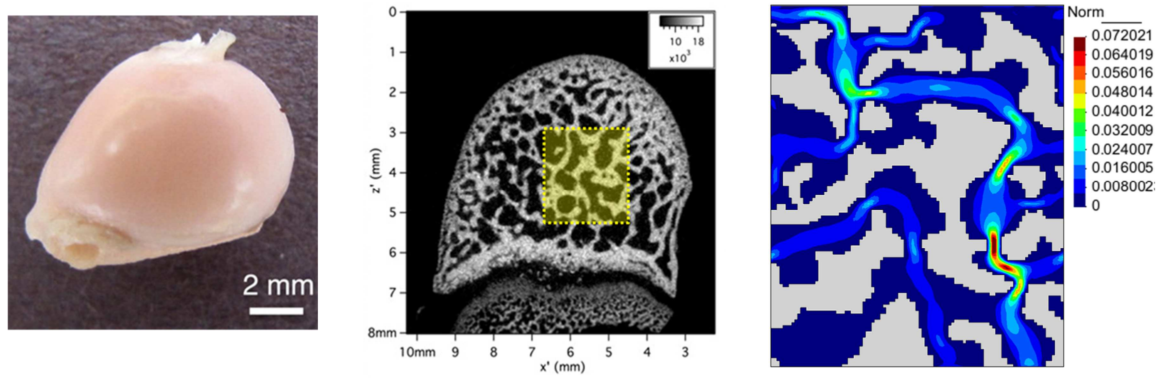
ABSTRACT

It has been shown through recent investigations in biomechanics, that marrow can play a critical role upon the cancellous bone behavior [1]. Besides its direct influence on the transport properties including pressure drop, shear dissipated energy and tortuosity of the bone geometry, the marrow is also responsible in transmitting and regulating the inter-lamellas pressure [2], due to external loading especially in case of impacts and crash accidents causing bone fracture. It is also worthy to notice, that for biological and clinical reasons such as bone remodeling, aging effects and drugs use, it is important to understand and quantify the mechanical behavior of cancellous bone in the presence of the marrow [3], [4].

A quick review in the biomechanics field shows an abundant literature related to the mechanical characterization of cancellous bone, yet only very few investigations have considered the influence of the marrow effects [1]-[4]. In the present investigation a new numerical procedure is proposed, to study the marrow effects on the mechanical behavior of the cancellous bone. The proposed approach is based on fluid-structure interactions using particles methods for the modeling of the trabecular bone and marrow environment. The Smoothed Particle Hydrodynamics method (SPH) is used for the modeling of the trabecular lamella while the Lattice-Boltzmann method (LBM) is used for the marrow flow modeling. Based on their previous work, the authors proposed an efficient shell-based SPH method which shows to be a real alternative to the conventional finite element, especially under large strains [5], [6]. This method has been adopted in the present investigation for the modeling of trabeculea using the Total Lagrangian Formulation.

The present approach has been validated in the modeling of the marrow flow through a cancellous bone of a rabbit femoral head sample [7] (Fig 1-a). At first, a two-dimensional slice of micro-CT image of *0.0185mm* resolution [7] has been used. A meso-scale rectangular area of $1.23\times 1mm^2$ has been extracted as a domain of study (Fig 1-b). The 2D-domain has been discretized using 123×100 particles, where Lattice particles have been used for the marrow areas and SPH particles for the bone trabeculea. For the boundary conditions, an imposed velocity flow of the marrow was imposed on the upper side (inlet), while free conditions were imposed on the two lateral edges. At the bottom side (outlet) no pressure variation was imposed. As a first attempt, the bone lamellas were assumed to be elastic isotropic (on the domain of study) and the marrow is considered as an incompressible fluid.

The numerical results obtained using the proposed FSI coupling approach between SPH and LBM (Fig 1-c), have been compared to those obtained using OpenFOAM® CFD software [8]. The preliminary comparisons show that the proposed approach is very promising and may constitute an efficient and elegant alternative to the conventional mesh based methods.



a) Rabbit femoral head sample [7] *b) 2D Micro-CT scan image* *c) Bone marrow flow modeling using FSI by coupling LB and SPH methods*

Fig 1: Rabbit cancellous Bone/Marrow modeling using FSI by coupling LBM and SPH methods

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