A particle model for prediction of cement infiltration in osteoporotic femoral augmentation– PARTICLES 2017

Ramos-Infante S.J.* and Pérez-Ansón M.A.

* M2BE-Multiscale in Mechanical and Biological Engineering
University of Zaragoza
Campus Río Ebro, 50018 Zaragoza, Spain
e-mail: sramos@unizar.es; angeles@unizar.es, web page: http:// m2be.unizar.es/

ABSTRACT

The prevention of fractures is a desirable goal to reduce morbidity, mortality, and socio-economic burden, especially given the growing incidence of osteoporosis, its susceptibility to fractures, and the dramatic rise in fracture incidence and the associated costs [1]. Augmentation of osteoporotic femur using PMMA bone cement has been shown in biomechanical studies as a preventive treatment to reduce the risk of fracture. Therefore, the main goal of this work is the development of a discrete diffusion model that allows a patient-specific planning of the technique. A correct planning and execution involve the development of an accurate method for predicting the diffusion of the cement through the porous medium of osteoporotic cancellous bone.

The proposed discrete model is based on the random-walk theory [2]. It takes into account the cement viscosity and volume injected, pressure of injection and direction of injection. There is a fixed 3D grid that cement particles can occupy. A cement particle is presumed to be surrounded by 26 locations. Cement particles are allowed to move through different positions as a stochastic process. They are not allowed to remain in their initial positions. Movement can be isotropic or anisotropic defining a preferential direction of movement. On the other hand, bone trabeculae is also modelled as fixed positions that cement particles cannot occupy. At every time step, particles move checking the availability of free positions. Once the cement injection is simulated, a voxel mesh is generated that represents the augmented bone (bone plus cement). Additionally, the computational model has been validated with experiments. We carried out injections in several open-cell structures (Sawbones, Malmö, Sweden) with different volume fraction (porosity). Three different cement types were injected that corresponded to three different cement viscosities. The open-cell structures were cut in blocks of approximately 65x65x40 mm^3. Each block was tightly enclosed in a Plexiglas shell of 5 mm thickness acting as a cortical shell. Cement was injected through a drilled hole of 3 mm on the different block faces. Cement injection was recorded and cement flux was followed using image techniques. Once the cement was solidified, we performed compressive mechanical tests in order to quantify the improvement of the specimen mechanical properties.

The cement injection pattern was successfully predicted in all the simulated cases. All the augmented specimens increased their mechanical properties. As the cement injection increases, the mechanical properties also improved. In fact, it was observed that specimens with lower volume fractions showed a considerable increase in the mechanical properties (61.16%).

Therefore, our proposed discrete cement diffusion model will allow us to plan and improve cement augmentation in a patient-specific model. Femoroplasty significantly increased fracture load when osteoporotic femora were loaded and cement filling may have an important role in the extent to which femoroplasty affects mechanical strength of the proximal femur.

REFERENCES

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