11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

ELASTOSTATIC, ACOUSTIC AND TIME-REVERSED SIMULATION OF BONES BY NON-STANDARD FICTITIOUS DOMAIN METHODS

E. Rank[1], S. Kollmannsberger[1], R. Seidl[1], H. Wille[1] and Z. Yang[1]

[1] Computation in Engineering, Technische Universität München, Arcisstr. 21, 80333 München, ernst.rank@tum.de, http://www.cie.bgu.tum.de

Key Words: *Biomechanics, fictitious domain methods, acoustic emission, time reversal*

In recent years, non-standard fictitious domain techniques [1] like the Finite Cell Method (FCM) have gained increasing interest in the context of high order methods or the integration of engineering design and numerical analysis [2]. One of the most important advantages of these methods compared to mesh-based finite element schemes is the possibility to circumvent any time-consuming mesh generation and to directly couple them to different types of geometric models. This feature yields the FCM particularly attractive for simulation of biomechanical structures, as these are often geometrically very complicated and thus difficult to mesh into finite elements. A very efficient implementation of the FCM is possible by pre-computation of (sub-)cell matrices, under the condition that material properties are constant in the corresponding geometric entities. As this is a natural assumption for each individual voxel of a geometric model obtained by e.g. quantitative Computer Tomography (qCT), the FCM has been successfully applied in a computational steering system for pre-operative planning, i.e. an integrated software to interactively simulate positioning of an artificial hip joint in a human femur.

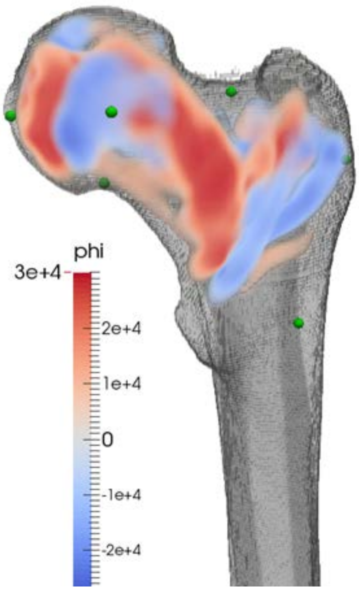

Figure 1: Compression wave propagating through a proximal human femur (snapshot from a forward simulation)

In this paper, a family of (*l*,*p*)-fictitious domain methods will be investigated, where *l* is the number of sub-cells in each spatial direction of one computational cell and *p* denotes the polynomial degree of the cell's shape functions. The classical voxel finite element method [3] with tri-linear shape functions is thus a (1,1)-fictitious domain method, and even certain finite difference schemes can be classified under this definition. The aforementioned FCM typically uses higher polynomial degrees and spatial resolutions, e.g. $l>4$ and $p>3$. Applying now classical explicit or implicit time stepping methods these elastostatic schemes can be generalized to dynamic methods, where again a comparison of the higher order methods with standard FEM simulation shows excellent accuracy. They can efficiently be applied to simulate acoustic emission techniques (AE), which have recently been applied to investigate failure processes in the human femur [4]. Combined with time-reversed methods, which have been used successfully e.g. in seismic analysis [5], dynamic fictitious domain methods open the door to identify the location of potential micro-cracks in bones. This paper will outline the developed numerical methods, the workflow from qCT over AE to the definition of the geometrical model and show first promising results of the numerical simulations.

REFERENCES

[1] A. Düster, J. Parvizian, Z. Yang, E. Rank, The Finite Cell Method for three-dimensional problems of solid mechanics. *Computer Methods in Applied Mechanics and Engineering,* 2008

[2] D. Schillinger, L. Dedè, M.A. Scott, J.A. Evans, M.J. Borden, E. Rank, T.J.R. Hughes, An Isogeometric Design-through-analysis Methodology based on Adaptive Hierarchical Refinement of NURBS, Immersed Boundary Methods, and T-spline CAD Surfaces *Computer Methods in Applied Mechanics and Engineering (HOFEIM special issue),* 2012, DOI: 10.1016/j.cma.2012.03.017

[3] M. Lengsfeld, J. Schmitt, P. Alter, J. Kaminsky, R. Leppek, Comparison of geometry-based and ct voxel-based finite element modelling and experimental validation, *Med. Eng. Phys.* 20(7) (1998) 515-522.

[4] F. Stark , F. Malm, E. Grande Garcia, P. Föhr, R. Burgkart, F. Reidl, C. Grosse, Investigation of failure processes in the human femur using signal-based acoustic emission techniques. In: *Proceedings 30th European conference on acoustic emission testing and 7th international conference on acoustic emission*, Granada, Spain, 12–15 September 2012, pp.175–184.

[5] M. Fink, Time-reversed acoustics, *Scientific American,* 281(11), 91–97, 1999