MICRO-MECHANICAL FINITE ELEMENT ANALYSIS OF HUMAN BONE

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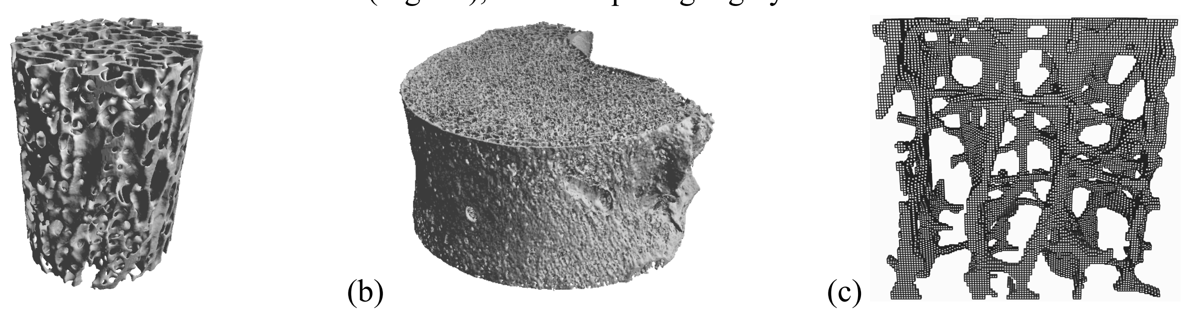
Osteoporotic fractures in the hip, spine, and wrist are increasingly common. In the US alone, osteoporosis affects an estimated 44 million Americans and generates health care costs in excess of $17 billion annually. Therefore, understanding the mechanisms that lead to failure in bones is of great clinical importance. The two types of bone tissue—cortical and trabecular bone—have the functional task of withstanding stresses that arise during daily activities, as well as those arising from non-habitual loading conditions such as a fall. Trabecular bone mechanical behavior presents a challenging problem due to its high-porosity—over 85% in the spine—and complex microstructural architecture (Fig. 1a & 1c), both of which vary substantially between anatomic sites and across individuals. A widely used tool is the micro-finite element (μFE) method, which uses high-resolution micro-CT (μCT) scans to obtain geometrically accurate FE models of trabecular bone [1]. These μFE models may consist of several million elements (Fig. 1b), hence requiring highly scalable efficient solvers for analyses.



(a) (b) (c)

Figure 1: (a) 22-μm resolution μCT scan of a femoral neck trabecular bone specimen (Ø: 8-mm, L: 15-mm) with 73% porosity. (b) μFE model of a whole vertebral body (T-10) containing 45 million 40-μm elements. (c) μFE mesh (5×5×2 mm) of vertebral trabecular bone (90% porosity) with 53,000 44-μm elements.

This work concerns some of the first applications of our parallel FE code *Athena* (built on the serial research code FEAP), and our implementation of a smoothed aggregation multigrid method in the linear solver package *Prometheus* [2]. Parallel supercomputers at Lawrence Livermore National Laboratory and San Diego Super Computing Center (available through NPACI) are used for the analyses. Results of linearly elastic analysis of vertebral bodies and large deformation μFE analyses of trabecular bone specimens will be presented. Also, scalability of our algebraic multigrid solver for these highly unstructured meshes will be discussed.

References

[1] E.F. Morgan, H.H. Bayraktar, and T.M. Keaveny, "Trabecular bone modulus-density relationships depend on anatomic site," *Journal of Biomechanics*, in press, 2003.
[2] M.F. Adams, "Evaluation of three unstructured multigrid methods on 3D finite element problems in solid mechanics," *International Journal for Numerical Methods in Engineering*, v.55, p. 519-534, 2002.