Title

Editorial for “In Vivo Assessment of Age- and Loading Configuration-Related Changes in Multiscale Mechanical Behavior of the Human Proximal Femur Using MRI-Based Finite Element Analysis”

Journal

Journal of Magnetic Resonance Imaging, 53(3)

ISSN

1053-1807

Author

Bae, Won C

Publication Date

2021-03-01

DOI

10.1002/jmri.27427

Editorial for "In Vivo Assessment of Age- and Loading Configuration-Related Changes in Multiscale Mechanical Behavior of the Human Proximal Femur Using MRI-Based Finite Element Analysis"

Osteoporosis is a major risk factor for bone fracture. Imaging such as dual-energy X-ray absorptiometry (DXA) has been the tool of choice to assess osteoporosis, and to correlate the imaging findings of decreased bone mineral density (BMD) with increased fracture risk. As medicine became more personalized and with advancements in 3D imaging technologies, efforts began to determine an individual's structural and mechanical properties of bone from 3D images, using finite element analysis (FEA).

Quantitative computed tomography (CT) affords realistic assessment of cortical and trabecular bone structures,[1] and in turn, FEA of the bone using the local gray-scale information. In addition to improved fracture risk estimation compared to DXA,[2] FEA enables estimation of other biomechanical parameters such as stiffness, strength, and spatial distribution of vulnerable areas of the bone under a simulated loading condition.

Magnetic resonance imaging (MRI) implementation of bone FEA, while avoiding the use of the ionizing radiation of CT, has been challenging. Image noise and contrast is not always optimal for bone depiction, and varies with the pulse sequence used.[3] Spatial resolution is on par with CT but typical MR sequences prescribe nonisotropic voxels that provide sharp in-plane images at the expense of a thicker slice. High-resolution MR acquisition requires long scan times, up to 30 minutes, not amenable for routine use.

In this issue of JMRI, Zhang et al report on MRI-FEA of proximal femur of young vs. elderly Asian female subjects (n = 18) simulating standing and sideways fall. Imaging was performed at 3T, using a high-resolution sequence with a voxel size of $0.19 \times 0.19 \times 1.3$ mm^3. Each voxel within the proximal femur was assigned a variable elastic modulus value based on its grayscale value between that of the marrow and the bone. While this approach, also used by others,[4] is reasonable and straightforward computationally, it is unrealistic, in that bone tissue has similar elastic modulus throughout and varies in structure instead. Additionally, model-specific validation against biomechanical measurements in cadaveric samples[5] is seldom performed. Another consideration for an FEA study is a careful selection of loading conditions such as the location and magnitude of the applied force, and fixed locations of the bone. The authors found that, under the same loading conditions, the elderly had greater average and high-risk (within 10% of the peak strains) strains than the young, and the difference between the sideways fall and standing was also greater in the elderly. As demonstrated by this study, MRI-FEA provides useful means of comparing mechanical differences in cross-sectional cohorts, or in longitudinal follow-up after treatment.

Refinements in all fronts, including coil technology to increase signal,[3] pulse sequence to modulate bone contrast,[6] and image processing to deal with uneven contrast and low resolution,[7] could improve the accuracy and utility of MRI-FEA. Recent advancements in machine learning such as deep-learning noise reduction,[8] MR-to-CT synthesis,[9] and super resolution[10] could further complement existing techniques.

Conflict of Interest

None.

Won C. Bae, PhD
Department of Radiology
VA San Diego Healthcare System
San Diego, California, USA
Department of Radiology
University of California-San Diego
La Jolla, California, USA
Email: wbae@health.ucsd.edu

References

1. Danielson ME, Beck TJ, Karlamangla AS, et al. A comparison of DXA and CT based methods for estimating the strength of the femoral neck in post-menopausal women. Osteoporos Int. 2013;24(4):1379-1388.

2. Cody DD, Gross GJ, Hou FJ, Spencer HJ, Goldstein SA, Fyhrie DP. Femoral strength is better predicted by finite element models than QCT and DXA. J Biomech. 1999;32(10):1013-1020.
3. Chang G, Deniz CM, Honig S, et al. Feasibility of three-dimensional MRI of proximal femur microarchitecture at 3 Tesla using 26 receive elements without and with parallel imaging. J Magn Reson Imaging. 2014;40(1):229-238.
4. Hotca A, Rajapakse CS, Cheng C, et al. In vivo measurement reproducibility of femoral neck microarchitectural parameters derived from 3T MR images. J Magn Reson Imaging. 2015;42(5):1339-1345.
5. Rajapakse CS, Farid AR, Kargilis DC, et al. MRI-based assessment of proximal femur strength compared to mechanical testing. Bone. 2020; 133:115227.
6. Breighner RE, Endo Y, Konin GP, Gulotta LV, Koff MF, Potter HG. Technical developments: Zero echo time imaging of the shoulder: Enhanced osseous detail by using MR imaging. Radiology. 2018;286(3):960-966.
7. Folkesson J, Carballido-Gamio J, Eckstein F, Link TM, Majumdar S. Local bone enhancement fuzzy clustering for segmentation of MR trabecular bone images. Med Phys. 2010;37(1):295-302.
8. Kidoh M, Shinoda K, Kitajima M, et al. Deep learning based noise reduction for brain MR imaging: Tests on phantoms and healthy volunteers. Magn Reson Med Sci. 2020;19(3):195-206.
9. Lei Y, Shu HK, Tian S, et al. Magnetic resonance imaging-based pseudo computed tomography using anatomic signature and joint dictionary learning. J Med Imaging (Bellingham). 2018;5(3):034001.
10. Umehara K, Ota J, Ishida T. Application of super-resolution convolutional neural network for enhancing image resolution in chest CT. J Digit Imaging. 2018;31(4):441-450.

DOI: 10.1002/jmri.27427

Level of Evidence: 5 **Technical Efficacy Stage:** 1