Registration of MR trabecular bone images of the proximal femur in a longitudinal study

J. Blumenfeld[1], J. Carballido-Gamio[2], J. Folkesson[2], D. Carpenter[2], T. M. Link[2], and S. Majumdar[1,2]

[1]Bioengineering, UC-Berkeley/UC-San Francisco, San Francisco, CA, United States, [2]Radiology, UC-San Francisco, San Francisco, CA, United States

Introduction

The proximal femur is the most important site for osteoporotic fractures[1]. Due to advances in MR pulse sequence and coil development as well as higher magnetic field strength (3 Tesla), recent studies have been conducted which investigate the feasibility of using high-spatial resolution MRI to evaluate trabecular bone structure of the proximal femur and have shown promising results[2]. In reproducibility studies, primary sources of error for MR-derived trabecular bone parameters have previously identified as involuntary patient motion and failure to accurately match the analysis volumes[3]. In the proximal femur, consistent positioning between baseline and follow-up scans is challenging due to its complex shape. Additionally, the inherent regional variations within this anatomic site have an impact on trabecular bone structure quantification[4]. Despite the complex femoral shape, the same region must be consistently scanned and analyzed between baseline and follow-up image acquisition in repeat studies for improved trabecular bone structure measurement accuracy. Automatic image registration in the proximal femur has been shown to be accurate within 1 degree and 1 pixel and is able to ensure consistent volume of interest (VOI) selection for analysis baseline and follow-up images[4]. This study demonstrates the feasibility of using the same automatic image registration technique to ensure accurate VOI placement in a longitudinal study investigating changes in trabecular bone structure in postmenopausal women.

Methods

Coronal images of the proximal femur of 24 post-menopausal women (age 55 $\pm$ 3 years) were obtained using a 3T (GE Signa) MRI scanner with a four-element phased array coil, using a modified version of generalized autocalibrating partially parallel acquisition (GRAPPA), with an acceleration factor of two[5]. Scans were acquired with a 512x384 matrix, 12cm FOV, 60º flip angle, TR/TE 10.3/3.6 ms, 1 mm slice thickness, a total of 74 slices and a scan time of approximately 10 minutes. A follow-up image was acquired one year after the baseline image. Image registration was performed using a mutual information registration algorithm (based on ITK)[6] with a gradient decent optimizer and linear interpolator to determine the translation and rotation required to align the follow-up image to the baseline image[4]. The transform which aligned the follow-up image to the baseline image was applied to the follow-up image with a Bspline approximator. Bspline approximation was previously shown to maintain the integrity of the bone parameters[4]. A volumetric region of interest (VOI) which included only trabecular bone and bone marrow, consisted of ten slices and was manually defined on a slice-by-slice basis using a graphics cursor (Fig. 1). The same VOI was used on the baseline and registered follow-up images. An image intensity histogram based thresholding technique was used to binarize the VOI into trabecular bone and marrow phases. Previously described methods[7] were then used to compute the apparent trabecular bone structural parameters: App.BV/TV, App.Tb.Sp., App.Tb.Th., and App.Tb.N.

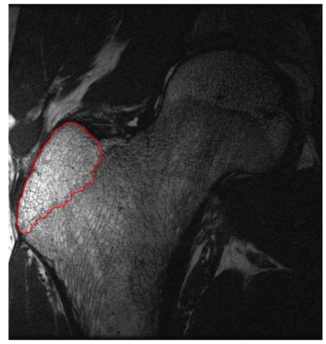


Figure 1. Example high resolution MR image of the proximal femur (0.234x0.234x1 mm^3) with region of interest outlined in red.

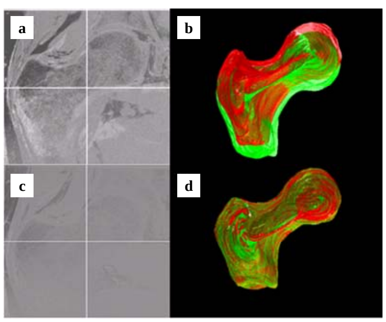
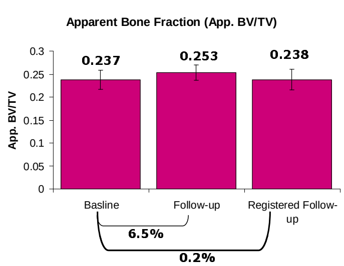
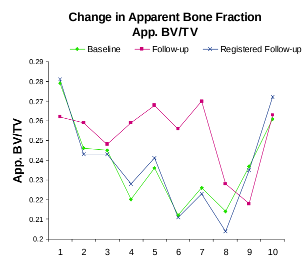


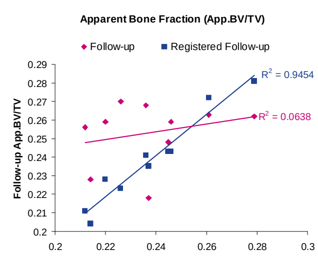
Figure 2 . Comparison of follow-up with registration versus follow-up without registration (a) Subtraction of baseline and follow-up without registration. (b) 3D rendering of non-registered proximal femur surfaces (c) Subtraction of baseline and registered follow-up (d) 3D rendering of registered proximal femur surfaces (green= baseline, red= follow-up)

Results

Twenty of the twenty-four sets of images successfully registered (Fig 2). The average outputs from the registration of the 20 femurs were: X rotation = 1.02 $\pm$6.68^o, Y rotation = -1.69$\pm$3.55^o, Z rotation = 0.25$\pm$2.93^o, X translation = -1.06$\pm$3.1mm, Y translation = -0.92$\pm$5.00mm, and Z translation = -0.98$\pm$1.65mm. Four of the images sets failed to register due poor image quality. Bone parameters were successfully calculated for baseline and follow-up images using the same VOI.







For one of the femora, the improved accuracy of App.BV/TV measurement in the registered follow-up image can be seen in the figures above. There is an improvement of 6.3% in the measurement of App.BV/TV between the follow-up with and without registration (Fig 3 -left graph). Registration is able to improve measurement accuracy by ensuring that the same slices are analyzed in the baseline and follow-up image (Fig 4- middle graph). A comparison of the follow-up with and without registration with baseline measurements shows that registration ensures that the analysis regions between baseline and follow-up images are well aligned reducing the error in the trendline when comparing the measurements (Fig 5 -right graph).

Discussion

The study of the progression of a disease or the efficacy of a treatment based on proximal femur MRI requires the proper analysis of corresponding regions of interest in the baseline and follow-up images. This work is the first time that automatic image registration has been implemented in a longitudinal study investigating changes in MR-derived trabecular bone structure. In this work we have demonstrated the feasibility of using a mutual information based method to accurately register longitudinal MR images of the proximal femur. Results suggest that this algorithm is robust enough to be used routinely in longitudinal studies of trabecular bone in other musculoskeletal sites, such as the tibia and wrist, as well as the proximal femur.

References

1. S. R. Cummings and L. J. Melton, Lancet 359, 1761-1767 (2002)
2. R. Krug et al. Osteoporos Int 16, 1307-1314 (2005)
3. B. R. Gomberg et al. Bone 35, 266-276 (2004).
4. Blumenfeld J et al. Med Phys. 2008 Oct;35(10):4630-9.
5. S. Banerjee et al. Magn Reson Med 56, 1075-1084 (2006)
6. http://www.itk.org
7. D. C. Newitt,et al. Osteoporos Int 13, 278-287 (2002)

Supported by: Merck & Co.; NIH ROI-AG017762; ARCS and Evnin-Wright Fellowships