Multi-Acquisition SSFP for In-vivo Measurements of Trabecular Bone Structure in the Proximal Femur

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Introduction

Quantitative high-resolution MRI (HR-MRI) is a useful technique, allowing in-vivo, noninvasive, three-dimensional structural assessment of trabecular bone micro-architecture for evaluation of bone quality in the context of osteoporosis. In the past, in vivo HR-MRI of bone was generally limited to imaging of the extremities, due to signal-to-noise constraints. For the first time, a study of in vivo quantitative HR-MRI at the proximal femur at 1.5T and 3T using fully balanced steady-state free precession (b-SSFP) imaging was recently presented by our group [1]. At 3T, susceptibility artifacts at the bone-bone marrow interface are more pronounced than at 1.5T. The sensitivity of balanced SSFP response to off-resonances which cause banding artifacts is well documented in the literature and multiple phase-cycled acquisitions can be employed to reduce the artifacts caused by off-resonance. However the improvement comes at a cost of imaging time. The focus of this study was to investigate the effect of number of multiple phase-cycled acquisitions (N) and the different techniques of combination of these datasets in reduction of local susceptibility artifacts in the bone-marrow. Furthermore SNR and SNR efficiency of the methods were also compared.

Material and Methods

Data from multiple phase-cycled b-SSFP acquisitions can be combined in various ways to eliminate b-SSFP banding artifact. In this work we employed an N=4 and N=2 3D b-SSFP sequence to obtain high resolution images of the proximal femur using the parameters in Table 1. The multiple-acquisition combination methods used differ only in reconstruction. As suggested by a previous publication [2] a sum-of-squares (SOS) reconstruction with N=4 phase cycles is expected to perform best in terms of artifact reduction and SNR efficiency. In order to reduce scan time, a comparison with N=2 phase cycle (SOS-SSFP) was conducted. Additionally images using maximum-intensity (MI) reconstruction were performed with N=2 phase cycles. Finally 3D b-SSFP scans applying only 1 phase cycle and dual-energy x-ray absorptiometry (DXA) measurements were conducted for comparison. All MRI measurements of the proximal femur were performed on 1.5T and 3T Signa systems (General Electric, Waukesha, WI) using a four-coil phased array for detecting the signal. Six volunteers (3 female and 3 male) were scanned with the above mentioned techniques. A low-pass filter (LPF)-based coil sensitivity correction was conducted on this local region to correct the spatial variations in the image caused by spatial variation in coil sensitivity. The next step included binarization of the trochanter into bone and marrow phases. Previously described methods [1] were used to compute the apparent trabecular structural parameters: bone-volume/total-volume fraction (app. BV/TV), separation (app.Tb.Sp), thickness (app.Tb.Th) and number (app.Tb.N). SNR and SNR efficiency was determined for each scan.

Parameters	3 Tesla			1.5 Tesla
Reconstruction / N	**SOS / 4**	**SOS / 2**	**MI / 2**	**N=1**
Imaging time	**26'4''**	**13'2''**	**13'2''**	**6'12''**
TR / TE / α	**11/ 3/ 60**	**11 / 3 / 60**	**11 / 3 / 60**	**10 /4 / 60**
Bandwidth	**31.25**	**31.25**	**31.25**	**41.7**
FOV / Slice / Matrix	**12 cm / 1.5 mm / (512 × 512 × 28)**			

Table 1: Pulse sequence parameters for 1.5 T and 3 T b-SSFP

Results

Resulting images from single SSFP acquisition (RF phase cycle=π) and 2-acquisition SSFP (RF phase cycle=π, 2π) at 3T are depicted in Figure 1. The susceptibility artifacts are clearly reduced in the latter case. A loss of signal in the marrow due to susceptibility artifacts is seen in these images (left image compared to the right image). Results for app.BV/TV and app.Tb.Th are shown in Table 2 for SOS-SSFP with N=4 and N=2 phase cycles and single acquisition (N=1) at 3T and single acquisition SSFP at 1.5T for comparison. The correlation of app.BV/TV with results from DXA measurements revealed values higher than R=0.83 for 5 volunteers for all MRI measurements. The correlation factor for BV/TV between SOS N=4 and SOS N=2 was R=0.95 for all volunteers. The resulting app.BV/TV and app.TbTh were significantly higher ($p<0.05$) for N=1 compared to N≥2. The higher field strength provided an increase in SNR of factor 1.6 (N=2) compared to SNR at 1.5 Tesla (N=1) but only factor 1.1 gain in SNR efficiency (imaging time increases linearly with N). Comparing SOS-SSFP at 3 T with different phase cycles, a gain of factor 1.5 in SNR was found for N=4 compared to N=2. SNR efficiency was similar for both techniques. MI-SSFP and SOS-SSFP revealed similar SNR and SNR efficiency behavior for equal number of phase cycles N.

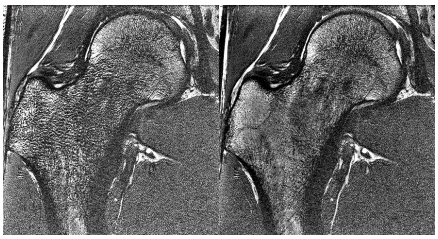

Figure 1: MRI images from the proximal femur acquired with N=1 phase cycle (left) and N=2 (right) at 3 Tesla

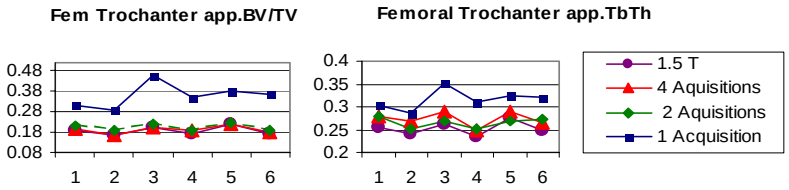

Table 2: App.BV/TV and app. TbTh measured at 1.5 T and 3 T with different phase cycles

Discussion

In this study we have compared different multiple-acquisition techniques and their feasibility for measurement of bone structural parameters at the proximal femur at 3T and compared the results with measurements at 1.5T and results from DXA. We have shown a clear improvement in local susceptibility reduction using N≥2 phase cycles at 3T (see Figure 1) which is also verified by smaller app.TbTh (Table 2), since the artifactual swelling of the trabeculae is clearly reduced. We also showed that SOS-SSFP with more than two phase-cycles (N≥2) perform equally in terms of depiction of trabecular structure and similar to results obtained at 1.5T (Table 2). We therefore conclude, that 2 phase cycle SSFP at 3T is the method of choice for characterizing the trabecular structure at the proximal femur. The higher SNR (compared to 1.5T) and the additional gain in imaging time (compared to N=4) can be used to increase in-plane resolution and/or decrease slice thickness - the next step in improving the accuracy and reproducibility of trabecular structure measurements.

References

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