Optimization and Reproducibility of In-vivo Trabecular Bone Microarchitecture Measurements in the Proximal Femur at 1.5T and 3T

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Introduction

Osteoporosis is a skeletal disease characterized by low bone mass density (BMD) and micro architectural deterioration of bone tissue leading to an increase in bone fragility and susceptibility to fractures. Osteoporotic fractures of the hip (proximal femur) are the greatest concern because of the associated medical expenditure and morbidity. Previous studies have demonstrated the important contribution of the microstructural distribution of trabecular bone to bone strength. Improved diagnostic tools for the non-invasive assessment of bone quality in the hip could provide better predictive measures of propensity to fracture as well as improved evaluation of the efficacy of treatment and preventative therapies. In a previous work [1] we showed that it is possible to determine structural bone parameters of the proximal femur using high resolution MRI at 1.5T and 3T. The focus of this work was to optimize high resolution MRI for evaluation of trabecular bone microarchitecture in the proximal femur in vivo and the evaluation of reproducibility of the measurements.

Material and Methods

MRI hip measurements of six volunteers (3 female and 3 male) were performed on 1.5T and 3T Signa systems (General Electric, Waukesha, WI) using a four-coil phased array receiver. A 3D fully balanced steady-state free precession (3D b-SSFP) sequence was applied at 1.5T and a phase-cycled 3D b-SSFP sequence with two alternating phase cycles to reduce susceptibility artifacts was used at 3T. Sequence parameters were optimized as shown in Table 1. Structural parameters analogous to standard bone histomorphometry were determined in the femoral head and trochanter regions of interest. The image analysis included an automated coil inhomogeneity correction, bone-marrow binarization and determination of structural parameters characterizing trabecular bone [2]. Bone mineral density (BMD) measurements were also obtained using dual-energy x-ray absorptiometry (DXA) for the femoral trochanter in the same subjects. Ten slices of a total of 28 acquired slices were used for analysis. The reproducibility of the measurements was determined scanning 3 volunteers 4 times on both systems. Additionally, coil placement and the graphical prescription of the imaging plane according to anatomic landmarks were optimized. The influence of different coil correction methods (regional and global correction), field of views and slice thicknesses were investigated as well as inter- and intra-operator (ROI placement) variability.

Parameter	*1.5 Tesla*	*3 Tesla*
TR/TE/Flip angle [ms]	**10.3 / 4.2 / 60**	**10.3 / 3.6 / 60**
Bandwidth [kHz]	**± 41.7**	**± 31.25**
Voxel [mm]	**0.234**	**0.234**
Imaging time	**6'12"**	**12'43"**

Table 1: Imaging parameters at 1.5T and 3T.

Results

Figure 1 shows a representative image of the proximal femur at 3T. Comparing the results in app.BV/TV at both field strengths, a correlation coefficient of R=0.86 was obtained for both femoral sites. Applying linear regression to the app.BV/TV values, a slope value of 1.0 was found for the femoral head between both field strengths whereas for the trochanter a value of 1.2 was determined. Values found for the trochanteric region differ clearly from values found for the femoral head at both field strengths. The app. BV/TV values were significantly ($p<0.05$) higher at 3T for the trochanter compared to 1.5T. Other structural parameters do not show a significant difference between the field strengths for either of the investigated sites at the proximal femur. In general, men had higher app. BV/TV at both femoral sites. Values for the coefficient of variation %CV were found to be between 2.0 % and 10 % for all structural parameters at both field strengths as shown in Table 2. Analyzing 3 measurements of the same subject, the inter-operator (2 operators independently) variability was between 2.5 % and 5.9 %. Intra-operator variation ranged between 1.5 % and 4 %. Values of %CV for different coil correction methods were found to lie in between 0.5 % and 1.25 %. Decreasing the slice thickness resulted in an increase in app.BV/TV and therefore in an increase in app.TbN and app.TbTh. SNR decayed linearly with the reduced slice thickness as expected.

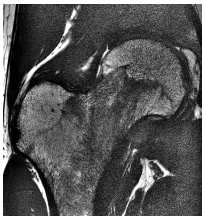

Figure 1: MR image acquired at 3 Tesla

Parameters	App.BV/TV	App.Tb.Th	App.Tb.Sp	App.Tb.N
1. 5T (total)	2.57	8.11	9.72	7.43
3T (total)	3.64	3.12	9.48	6.20
Inter-operator	5.90	4.55	5.89	2.54
Intra-operator	4.02	1.45	4.13	1.45
Coil-correction	1.04	0.75	1.25	0.52

Table 2: Coefficient of variation (%CV) measurements for the femoral trochanter.

Discussion

In a previous study [1] we have shown that it is possible to determine microstructural parameters of trabecular bone in the proximal femur from *in vivo* MR images. In this work we optimized our scan protocol for 3T MRI (b-SSFP). Several factors for variability in measurement were identified and investigated. We found that variation in coil correction methods had the least influence on reproducibility (< 1.5%). Variability between operators (definition of ROIs) was higher (up to 5.9 %) and can be primarily attributed to differences in placement of ROIs in the cortical shell in order to obtain the appropriate threshold for binarization. Scan-rescan tests on the same volunteer resulted in the highest %CV (10 %). We therefore conclude that consistent graphical prescription of the acquisition slice is crucial for improvement in reproducibility. Suitable anatomical landmarks (along the femoral neck) will have to be identified for slice prescription in a precise and reproducible manner. This, combined with image registration would enhance the reproducibility of the measurements considerably. Image registration was applied, but not yet very useful because of the limited number of acquired slices (scan time). This will be considered for future measurements.

References

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