In vivo imaging of bound and pore water in tibia and femur using 3D Cones sequences

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INTRODUCTION

Recent studies have demonstrated that bound and pore water make different contributions to the mechanical properties of cortical bone [1,2], making it important to image and quantify the two water components to understand their effectson bone quality. Ultra-short echo time (UTE) imaging has the potentials to assess different water components in cortical bone in vivo[3]. However, regular 2D and 3D UTE sequences are relatively inefficient for imaging cortical bone, especially if quantification needed [4].Here we propose to study tibial and femoral cortical bone in healthy volunteers using 3D Cones and 3D IR-Cones sequences at 3T scanner, and to measure T1 and T2* of bound and pore water at both sites.

MATERIALS AND METHODS

The 3D Cones sequence employs a short rectangular pulse for signal excitation, followed by Cones trajectory sampling. An adiabatic inversion pulse (duration= 8.64 ms) was used to invert and null the long T2 signals from muscle and bone marrow, leaving bone to be selectively imaged. The 3D cones and IR-Cones sequences allow anisotropic FOVs and slice resolution (e.g., higher in-plane resolution, thicker slices) to increase SNR and reduce the total scan time. T2*s of bound and pore water were measured by bi-component fitting of interleaved multi-echo 3D Cones images. T2* of bound water was measured by single-component fitting of the IR-Cones images. The effective T1 of bound and pore water was measured by fitting 3D Cones images acquired at different TRs. T1 value of bound water was measured by fitting of IR-Cones images acquired at different TR/TI combinations (pore water was suppressed in each TR/TI combination)[5]. Typical imaging parameters included: FOV = 15 cm, number of slices = 10, slice thickness =9 mm, bandwidth = 125 kHz. Other imaging parameters are shown in Table 1. In total five healthy volunteers were recruited for this study. The femoral mid-shaft was imaged with a body phased array coil, andtibial midshaft was imaged with an 8-channel knee coil.

RESULTS AND DISCUSSION

Figure 1 shows selected 3D Cones and IR-Cones images of tibia and femur of a 32 year old healthy volunteer. High resolution imaging of the tibia (voxel size = 0.8×0.8×9 mm^3) can be achieved in 1.5 min using an 8-channel knee coil. High contrast imaging of the femur can be achieved with the same resolution using a cardiac phased-array coil.

Figure 2 shows T2* bi-component analysis of multi-echo 3D Cones images as well as single-component analysis of 3D IR-Cones images of the femoral and tibial mid-shaft of a healthy volunteer. Both bound and pore water T2*s and fractions can be measured for both the tibial and femoral midshafts. Femoral and tibial midshafts show different T2* values and pore water fractions.

Figure 3 shows T1 analysis of the femoral and tibial midshafts of a healthy volunteer. Both effective T1 of bound and pore water, and T1 of bound water are different for the tibial and femoral midsafts, further suggesting that bone properties at disparate sites are different.

Bone properties have been evaluated at various sites. Our study suggest that the femoral midshaft and tibial midshaft have different MR properties, including bound and pore water T2*s, relative fractions, effective T1 of both bound and pore water, and T1 of bound water. The next step is to investigate whether absolute bound and pore water contents are different between these two sites. Further investigation of other bone sites (e.g., ulna, radius, phalanges, humerus, spine, skull, etc) will also be performed. Ring artifacts were observed in 3D IR-Cones imaging of the femur, which were probably due to out-of-slab excitation and can be suppressed by using selective excitation and/or out-of-slab saturation, and will be further investigated.

CONCLUSIONS

Our study suggests that T1 and T2* of bound and pore water in cortical bone can be measured with 3D Cones and IR-Cones sequences in a time efficient way using a clinical scanner. Femoral and tibial midshafts show different MR relaxation times in healthy volunteers.

	Sequences	TR/TI/TE/TSR [ms]	Matrix	FA	Scan Time [min]
T1	3D CONES-TR	TR=5.8, 10, 15, 20, 40, 60	192x192	20	14
	3D CONES-TI	TR/TI=500/147;400/131;300/110;200/81;100/45	128x128	15	11
T2*	3D CONES	Dual TE=0.06/2.4;0.2/4.4;0.4/6.6;0.6/8.8;0.8/11	192x192	10	7
	IR-CONES	TE=0.06, 0.2, 0.4,.6	128x128	15	5

Table 1 MR protocol to image and quantify T2* and T1 of bound and pore water in the femoral and tibial midshafts of healthy volunteers using a clinical 3T scanner.

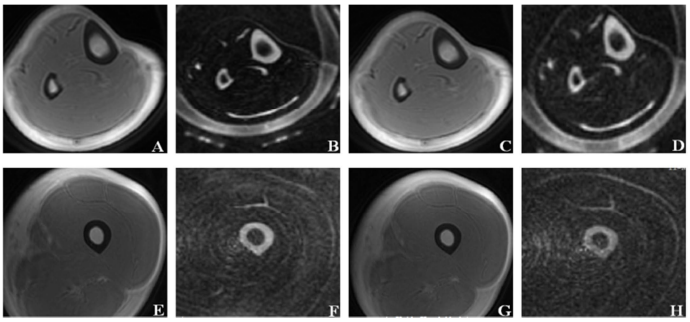

Fig 1 Axial tibiaimaging with 3D Cones-TR (A), 3D Cones-TI (B), 3D Cones (C) and IR-Cones (D); Axial femurimaging with 3D Cones-TR (E), 3D Cones-TI (F), 3D Cones (G) and IR-Cones (H) of a 32 yo volunteer.

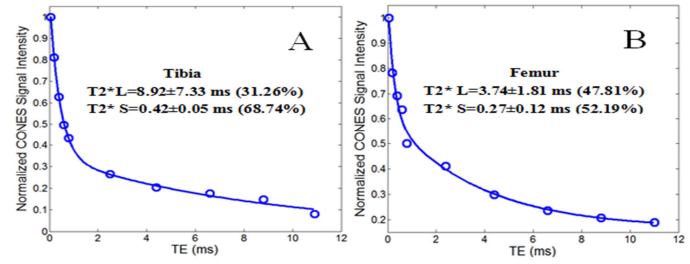

Fig 2 Bi-component T2* quantification of tibial (A) and femoral (B) midshaft of a healthy volunteer. Different T2* values and relative fractions were observed in tibial and femoral bone.

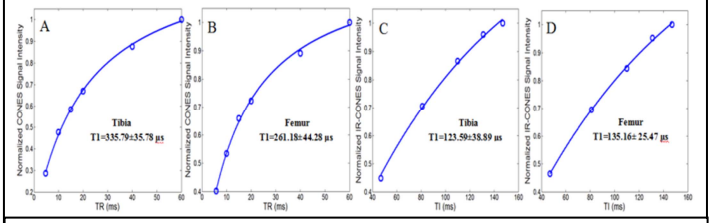

Fig 3 Effective T1 of bone water quantified using 3D Cones with variable TR for the tibial (A) and femoral (B) midshaft, as well as T1 of bound water quantified using 3D IR-Cones with different TR/TI combinations for tibial (C) and femoral (D) midshaft. Different T1 values were observed for tibia and femur.

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