Ultrashort Echo Time (UTE) Bi-Component Analysis of Bound and Free Water in Cortical Bone - A Field Dependence Study

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INTRODUCTION

The existence of two distinct T2* components in cortical bone has been demonstrated in recent studies [1-3], where a bi-component model has proven to be superior to a single-component model in fitting ultrashort echo time (UTE) images of cortical bone with progressively increasing TEs. The two components have T2*s about 10 times different, corresponding to water bound to the organic matrix (the shorter T2* component) and water residing in the microscopic pores of cortical bone (the longer T2* component). However, all these studies were performed on a clinical 3T whole body scanner. The field dependence of UTE bi-component analysis of cortical bone has not been studied. In this study we investigated how cortical bone bound and free water T2*s and their relative fractions change at 1.5 T and 3 T.

MATERIALS AND METHODS

Three bovine tibial midshatft samples and three human tibial midshaft samples were harvested from cadaveric leg specimens. The bovine cortical bone samples were cleared of all soft tissue and were cut into segments with length×width×height~10×10×10 mm^3. The human cortical bone samples were cleared of external muscle and soft tissue. Bone marrow was removed with a scalpel. Cross-sectional human cortical bone segments with a thickness of 20-30 mm were prepared. All six cortical bone samples were examined with UTE imaging using a 1.5T and a 3T GE whole-body scanner, respectively. The non-slice selective 2D UTE sequence employed a short rectangular pulse (duration = 32 μs) for signal excitation [4], which together with radial ramp sampling and fast transmit/receive switching allowed the use of a very short nominal TE of 8 μs defined as the time between the end of RF excitation and start of free induction decay (FID) data acquisition. We used a short rectangular pulse for the non-slice selective 2D excitation in order to enhance SNR and to eliminate errors due to eddy currents associated with conventional half-pulse excitation. The 2D non-selective axial imaging plane was centered in the middle of each sample so that the UTE signal intensity represented the integrated signal across the whole bone axial thickness. The 2D UTE imaging protocol used the following parameters: TR = 200 ms, field of view (FOV) = 8 cm, matrix = 256×256, band width = 125 kHz, 20 TEs (0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6. 0.8, 1.0, 1.2, 1.4, 1.6, 2, 2.5, 3, 4, 5, 6, 7, 8 ms), 1.7 minutes per image. A home-build birdcage coil (~2.5 cm in diameter) was used for signal excitation and reception. Each bone sample was placed in a 20 ml syringe filled with PBS solution or perfluorooctyl bromide (PFOB) during MR imaging to maintain hydration and minimize susceptibility effects at air-bone junctions. A semi-automated matlab program was developed for UTE bi-component analysis, where only three fitting parameters (bound water T2*, free water T2*, bound or free water fraction) were subject to non-negative least-square curve fitting. Background noise was automatically estimated based on maximum likelihood estimation (MLE) distribution fitting of a partial histogram [5]. The bound and free water T2*s as well as their relative fractions were compared among the samples and between the two field strengths.

RESULTS and DISCUSSION

Figure 1 shows selected UTE images of a bovine segment at 1.5 T as well as single- and bi-component fitting. Single-component fitting of the UTE T2* decay curve from ROI drawn in cortical bone showed a short T2* of 0.98 ± 0.04 ms. However, there was systematic residual signal with errors of more than 11% around TEs of 2 to 6 ms, suggesting the existence of another water component with a longer T2*. Excellent fitting was achieved with the bi-component model, which demonstrated two distinct T2* components one with a short T2* of 0.33 ms, and the other with a longer T2* of 4.40 ms. The shorter T2* component accounted for 68.5% of the total UTE MR signal decay, and the longer T2* component accounted for the other 31.5% of the signal decay. The residual signal was reduced to less than 2%, demonstrating that the bi-component model accounted well for the UTE T2* decay behavior.

Figure 2 shows the same bovine bone sample studied at 3T. Similarly a bi-component model fitted the UTE images much better than a single-component model. Bound and water T2*s were reduced to 0.27 ms and 1.51 ms, respectively, but their relative water fractions remained unchanged at 69% and 31%, respectively.

Figure 3 shows a summary of bound and free water T2*s and their relative fractions at 1.5 T and 3 T for all bovine human cortical bone samples, respectively. Similar findings were found for bovine and human cortical bone samples, with slightly increased discrepancy for the latter probably due to increased fat signal contamination within human cortical bone.

CONCLUSIONS

There results demonstrate that UTE bi-component analysis can robustly estimate bound and free water T2*s and their relative fractions at 1.5 T and 3 T. It might be difficult to apply this technique at fields greater than 3T due to reduction in both bound and free water T2* values [6].

REFERENCES

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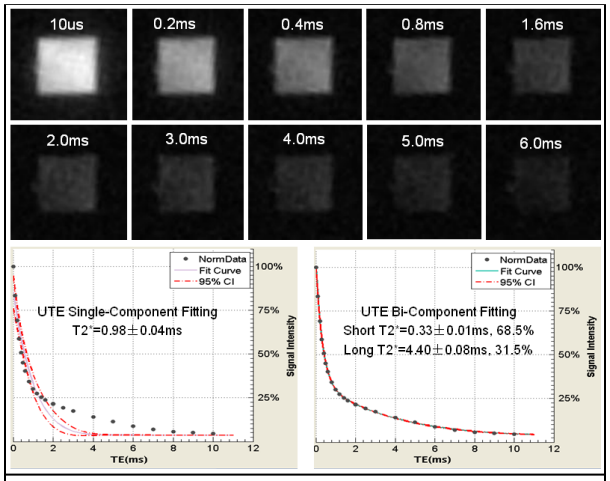

Fig 1 *Selected UTE images at 1.5 T, and the corresponding single- and bi-component fitting. The bi-component model provides better fitting than the single-component model, and shows a bound water T2* of 0.33 ms with a fraction of 68.5% and a free water T2* of 4.4 ms with a fraction of 31.5%.*

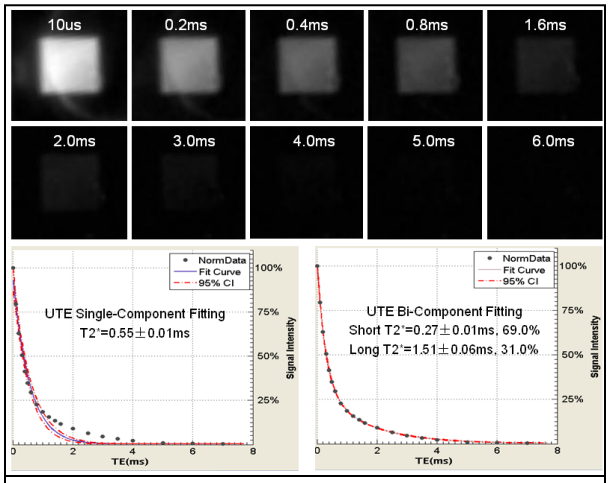

Fig 2 *The same bone in Fig 1 imaged at 3T, as well as the single- and bi-component fitting. The bi-component model provides better fitting than the single-component model, and shows a bound water T2* of 0.27ms with a fraction of 69% and a free water T2* of 1.51ms with a fraction of 31%.*

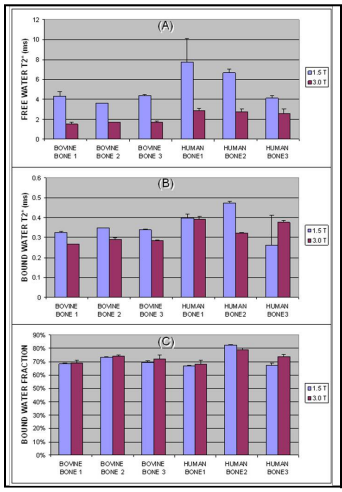

Fig 3 *Bi-component analyses of UTE images of three bovine bone samples and three human cortical bone samples acquired at 1.5 T and 3.0 T, respectively. This shows that both bound and free water T2* decrease with higher field strength. However, bound and free water fractions remain relatively constant for both bovine and human cortical bone samples, suggesting the field-independence of UTE bi-component analysis.*