# Adiabatic inversion recovery prepared ultrashort echo time (IR-UTE) imaging of cortical bone: effects of inversion time and undersampling

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## INTRODUCTION

Efficient suppression of signals from surrounding long T2 tissues including muscle and fat is important in achieving high contrast imaging of cortical bone with ultarshort echo time (UTE) pulse sequences [1]. Adiabatic inversion recovery prepared UTE (IR-UTE) sequences were developed for this purpose. With IR-UTE sequences, an adiabatic fast passage inversion pulse is used to invert the longitudinal magnetization of long T2 water and fat. The longitudinal magnetization of cortical bone, which has a very short T2*, is not inverted but partially saturated during the long adiabatic inversion process [2]. The UTE acquisition is begun at a delay time (TI) designed to allow the inverted long T2 water and fat magnetization to approach or reach the null point. Appropriate selection of TI allows robust and efficient suppression of long T2 water and fat signals. In this study, the effect of TI on cortical bone imaging was evaluated using a 3-T clinical MR scanner with the IR-UTE pulse sequence. Signal-to-noise ratios (SNRs) and contrast-to-noise ratios (CNRs) were used to assess the effects of different TIs. In addition, we acquired data using fullsampling and different degrees of undersampling to investigate the possibility of scanning faster but maintaining image contrast.

## MATERIALS AND METHODS

Mature bovine tibial mid-shafts from freshly slaughtered animals were obtained from a local slaughterhouse. Bovine cortical bone was cut into segments with a thickness of 20-30 mm, and stored in phosphate buffered saline solution for 24 h prior to use.

An adiabatic IR-UTE pulse sequence was implemented on a 3T Signa HDx TwinSpeed scanner (GE Healthcare Technologies, Milwaukee,WI). The adiabatic IR-UTE pulse sequence was applied to the bovine cortical bone samples. The following imaging parameters were used: TR = 300 ms, TE = 10 μs/4.4 ms (the second echo was acquired to show the effect of long T2 signal suppression), FA =45°, Bandwidth = ±62.5 kHz, FOV=8cm, slice thickness=7mm, reconstruction matrix =256*256, NEX = 2, single slice. Seven different TIs (80, 90, 100, 110, 120, 130, and 140ms) were used. For the optimal TI, seven different sets of projections (805, 405, 205, 105, 55, 35 and 25) were acquired to investigate the effect of undersampling on UTE and IR-UTE image quality. A birdcage transmit/receive coil was employed to image the cortical specimens. Images corresponding to each TI were reconstructed from each group of projections through regridding of the raw data onto a Cartesian grid using Kaiser-Bessel kernel, following by inverse 2D fast Fourier transformation.

## RESULTS

Selected axial dual dcho 2D IR-UTE images of the bovine mid-shafts of the tibia are shown in the Figure 1, which demonstrates that the signal strength of cortical bone, muscle and fat all depend on the choice of TI. With TI=90ms, excellent suppression of long $T_2$ signals was achieved with a CNR of 13.49±0.67 between cortical bone and muscle (Figure 2a), and a CNR of 12.26±0.86 between cortical bone and marrow. However, there was some residual fat signal due to the difference in T1 values between fat and muscle, resulting in a CNR of 1.24±0.35 between muscle and marrow fat. As shown in Figure 2b, the varying TIs did not have a significant impact on the SNR of cortical bone. With TE=4.4ms there is little signal from cortical bone. As a result the SNR of the second echo is much lower than that of the first echo.

Another important observation is the great tolerance of IR-UTE images to angular undersampling. The streak artifacts are barely visible with 105 projections, which correspond to an acceleration factor of ~8. Noticeable streak artifacts are present in the images reconstructed with less than 105 projections. Cortical bone can be nicely identified with only 55 or 35 projectoins Figure 3). These results suggest that high contrast bone imaging can be achieved with vastly undersampled 2D and especially 3D IR-UTE sequences.

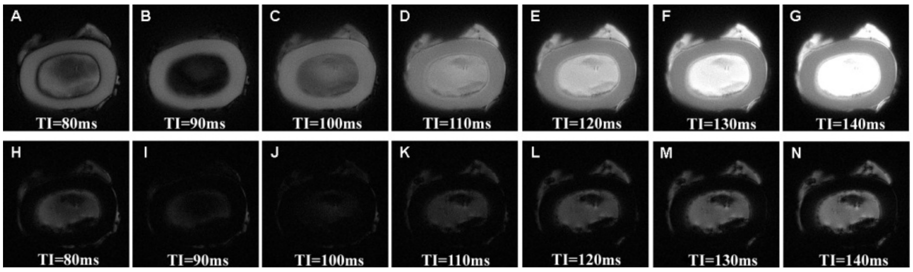


Figure 1. Images of a mature bovine tibial mid-shafts acquired with the adiabatic inversion UTE pulse sequence with different TIs, TEs of 10μs(1st row) and 4.4ms(2nd row).The second echo images depicts the signals from the long $T_2$ water and fat, reflecting long $T_2$ signal suppression effectiveness.

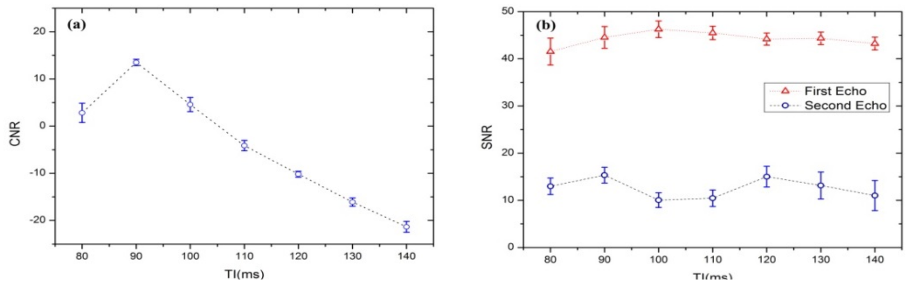


Figure 2. (a)TI versus CNR between cortical bone and muscle. (b)TI versus SNR of cortical bone for dual echos. Error bars indicate standard deviations.

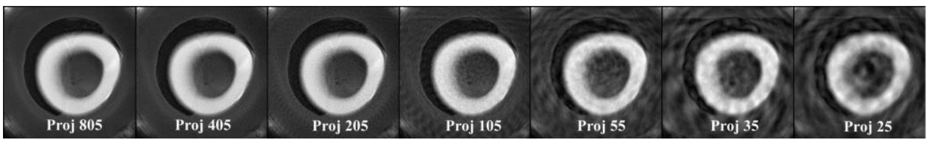


Figure 3. Images of mature bovine tibial mid-shafts reconstructed from fullsampling (805 projections) and undersampling(405,205,105,55,35,25projections) data.

## DISCUSSION

The 2D adiabatic inversion UTE sequence with a TI of 90 ms provided excellent qualitative depiction of bovine cortical bone. Due to the significant difference in T1 between muscle and fat at 3T, the inverted longitudinal magnetization of muscle and fat cannot reach the null point simultaneously [2]. As a result simultaneous reduction in long T2 water (such as muscle) and fat signals is complicated. However, this study shows that both fat and muscle signals can be reduced by more than 80% with an appropriate combination of TR and TI. While qualitative changes with underampling are readily seen, the quantitative analysis of the effects of different degrees of undersampling needs further study.

## REFERENCES

1.Du J, Bydder M, Takahashi AM, et al. Short T2 contrast with three-dimensional ultrashort echo time imaging. Magn Reson Imaging. 2011; 29(4):470-482.

2.Du J, Carl M, Bydder M, et al. Qualitative and quantitative ultrashort echo time (UTE) imaging of cortical bone. J Magn Reson. 2010; 207(2):304-311.