Indirect Measurement of Echo Peak Shift for Half Echo Ultrashort TE (UTE) Imaging with Radial Sampling

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Introduction: Ultra short TE (UTE) sequence, based on radial sampling, acquires an echo signal from central to outer parts of k-space with ramp sampling [1]. UTE is very sensitive to small k-space trajectory errors. Many kind of gradient waveform approximation were developed for correcting these k-space trajectory errors [2-4]. We have developed a robust UTE correction method consists of an approximation of the gradient waveform shape that makes it possible to estimate gradient waveform distortion and to correct k-space trajectory errors during image reconstruction [5]. We found that the UTE sequence is very sensitive to an echo peak shift after applying the gradient waveform approximation. The echo peak position can be detected if the complete echo signal is used, but for the UTE sequence only half the echo signal is acquired. Because it is difficult to detect the echo peak position directly, we developed indirect echo peak detection algorithm dedicated for half echo signal by using pre-scan.

Subject and Method: In the pre-scan, a reference full echo *S(t)* and a reference UTE echo *U(t)* are recorded. The reference full echo signal is acquired by using a readout dephasing gradient pulse. The echo peak shift is detected according to the flow diagram shown in Fig.1; (Step 1) Cut *S(t)* in half to make a pseudo UTE echo signal $S_{half}(t)$, (Step 2) Set the initial shift value Δtd, (Step 3) Shift $S_{half}(t)$ by the amount Δtd to get $S_{half}(t+\Delta td)$, (Step 4) Calculate the correlation value between $S_{half}(t+\Delta td)$ and $U(t)$, (Step 5) Change the shift value Δtd, (Step 6) Repeat steps 3 to 5 until the correlation value measured in step 4 is maximized. The shift value with maximum correlation value is defined as the resulting "best" echo peak shift value. This echo peak shift values are determined separately for each physical axis and are used in the gridding step to estimate the k-space trajectory. Only one reference echo signal and one UTE echo signal are acquired on each physical axis (X/Y/Z). Scan parameters of the pre-scan are set to same FOV, FA, TR, thickness and sampling points as that of UTE main scan. A 1.5T MRI (Hitachi Medical Corp., Tokyo, Japan), with a gradient system of 33 mT/m maximum amplitude and a maximum slew rate of 150 T/m/s, and a transmit whole body coil (diameter of 600 mm) and dedicated receiver knee coil (diameter of 200 mm) were used in the evaluation of image quality.

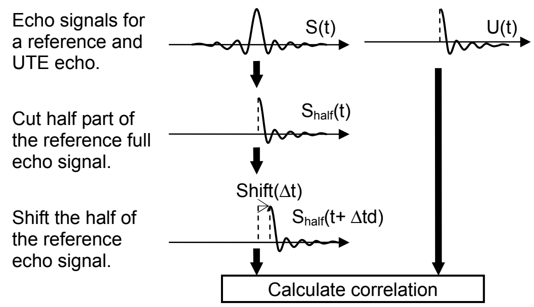

Figure 1 Diagram of the indirect echo peak shift detection for UTE sequence. Reference data acquired in pre-scan S(t) and UTE data U(t) were used for calculation.

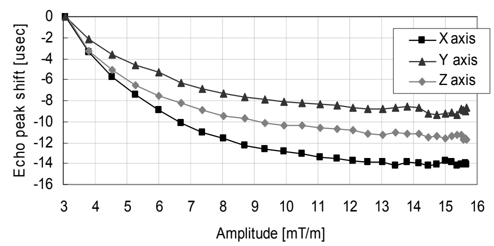

Figure 2 Echo peak shifts vs. gradient amplitude on each physical axis (X/Y/Z).

Results and Discussion: The echo peak shift value varies with the gradient amplitude used for the imaging and with the physical axis in the actual gradient system (Fig. 2). Figures 3 show the images of a structural phantom made from data acquired by the UTE sequence. The UTE data were reconstructed by using four kinds of k-space trajectories. The images that include the echo peak shift show serious image distortion (Fig. 3a, b). By applying indirect echo peak correction, image quality is drastically improved but a double edge is observed in the resulting image (Fig. 3c). Further improvement in image quality was achieved by applying the gradient waveform approximation (Fig. 3d).

The gradient amplitudes used depend on the parameters used such as FOV, BW, and oblique imaging angles for the clinical examples. In this study, we investigated the relationship between gradient output and gradient amplitude, and found that the gradient system performance varied with gradient amplitude. After correction for gradient waveform problems, we concentrated on a method for detecting and correcting time shift errors. Because the UTE sequence is very sensitive to the echo peak shift, we developed a pre-scan method for detecting echo peak timing errors. The echo peak shift value can be detected by searching the echo peak position if the complete echo signal is used. However, the UTE sequence acquires only half the echo signal, so a new algorithm for detecting the echo peak is required. In this study, we used complete echo signals as calibration data acquired in the pre-scan and the correlation algorithm to estimate the echo peak shift value for the UTE sequence that acquires only half echo signals. We note that the echo peak position is shifted depending on the gradient waveform that is used for gridding process. Our final pre-scan method detects the echo peak shift after applying the gradient waveform approximation. Because this is a pure timing measurement, remaining errors in timing caused by limitations of the gradient waveform approximation are automatically measured and compensated. Our goal in choosing this pre-scan method for detecting final echo peak timing errors was to "clean up" whatever timing errors were left after applying corrections based on the gradient waveform estimates.

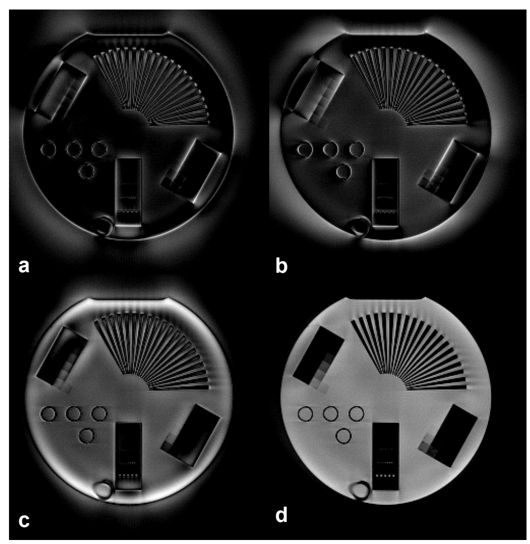

Figure 3 Transverse UTE image of structural phantom reconstructed by using four kinds of k-space trajectories that were calculated: **a:** without any correction: **b:** with correction by gradient waveform approximation only: **c:** with the indirect echo peak correction only: **d:** with the indirect echo peak correction and gradient waveform approximation.

Conclusion: Indirect echo peak detection works well. Our echo peak shift correction using this makes it possible to effectively minimize the error in the k-space trajectory caused by imperfect gradient system performance. The additional scan time needed for the pre-scan was about 10 seconds, a time that is small compared to the total examination time for a clinical scan. As a result, we achieved a practical UTE method that is robust under changing imaging conditions and variable parameters for a general oblique imaging plane.

References: *[1] Robson MD et al.; NMR in Biomedicine **19**; 765-780 (2006), [2] Peters DC et al.; Magn. Reson. Med. **50**; 1-6 (2003), [3] Cho SH et al.; Proc. Intl. Soc. Mag. Respn. Med. **16**; 1156 (2008), [4] Duyn JH et al.; J. Magn. Reson. **132**; 150-153 (1998), [5] Takizawa M et al. ; Proc Intl. Soc. Mag. Reson. Med. **19**; 4385 (2011)*