HASTE Sequence with Parallel Acquisition and T2 Decay Compensation: Application to Carotid Artery Imaging

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INTRODUCTION

T2-weighted carotid artery images acquired using the turbo spin echo (TSE) sequence often suffer from motion artifacts. Fast acquisition using the half Fourier single-shot TSE (HASTE) sequence [1] can reduce the motion artifacts to an unobservable level. However, the HASTE sequence readout is too long in comparison with the typical T2 relaxation times of neck tissues, causing severe blurring artifacts in the phase encoding direction. Combining HASTE with parallel imaging [pHASTE] can partially alleviate the blurring by decreasing the echo train length. Further reduction of image blurring can be achieved by compensating for the T2 decay in k-space before reconstruction. In our implementation of T2-compensated pHASTE, the aliasing due to undersampling was successfully resolved using KIPA reconstruction method [2] and Homodyne technique [3]. The feasibility of T2-compensated pHASTE imaging was evaluated via phantom and human carotid studies.

METHODS

Data acquisition: 1) The HASTE sequence without undersampling is used to acquire reference data for KIPA reconstruction. 2) HASTE data without phase encoding (PE) are acquired to construct the T2 decay compensation function. 3) HASTE with a reduction factor (R) of 2 or higher is used to acquire undersampled data.

Data processing: First, T2 decay is estimated from the data without PE ($S(k_x,k_y=0)$) by calculating the function: $D_j = Sum_{kx}(S_j(k_x,k_y=0))$, where j is the echo number along the echo train, and the summation is over k_x. The T2 decay compensation function is defined as $f_j= W_j*max(D_j)/D_j$, where W_j is an apodization function required to suppress noise amplification in high k-space data caused by small Dj values for the later echoes. For convenience we define $W_j =G_j(m,\sigma)$, a Gaussian function with mean m and standard deviation σ. The choice of σ value is a trade-off between T2 blurring suppression and SNR loss. The pHASTE data are corrected by multiplying with the compensation function. Second, the compensated pHASTE data are input to the KIPA algorithm to recover the missing PE views in the acquired half k-space. Finally, the fully sampled half Fourier data are reconstructed using ramp-weighted Homodyne to obtain the image corresponding to a complete k-space.

Studies: Both the phantom studies and the human carotid studies were performed on a 3 Tesla MRI scanner (Siemens Medical Solutions, Erlangen, Germany). The echo train length (ETL) was 136 for HASTE and 72 for pHASTE with R=2. Data with single average were acquired for the phantom studies. For the human studies 6 slices were scanned with 4 averages using a home-built 4-channel bilateral phased array carotid coil. Other parameters for the carotid studies were: imaging matrix of 256 x 256, in-plane resolution=0.5 x 0.5 mm^2, slice thickness=3 mm, and TE=74 ms. The readout time for the single echo train of the pHASTE sequence was 671 ms, scan time=26 s. For comparison, images from the same slices were acquired using a single-average TSE scan with the same resolution, ETL=7, TE=57 ms, TR=2000 ms, and scan time=1:53 min.

RESULTS

The typical results from the phantom studies are shown in Fig. 1. The conventional HASTE image (Fig. 1a) is noticeably blurred in the PE direction (horizontal). For pHASTE (R=2), the blurring artifact is reduced as shown in Fig. 1b. Application of T2 compensation to the HASTE data resulted in significant reduction of the blurring artifact (Fig. 1c). However, the image SNR is also decreased greatly due to the noise amplification by the T2 decay compensation function. The SNR problem is alleviated when the T2 compensation was applied to pHASTE data. Fig. 1d has better SNR than Fig. 1c, and less blurring than Fig. 1b. The carotid artery images acquired using conventional HASTE are severely blurred in the PE direction (vertical) as indicated by the arrow in Fig. 2a. The artery shape becomes normal in Fig. 2b. But the residual blurring is still apparent. Further reduction of the blurring artifact was achieved using the T2-compensated pHASTE (Fig. 2d), which is free of the motion artifacts present on the TSE image (Fig. 2c). However, the TSE image still has better vessel wall visibility. The carotid artery walls in Fig. 2c (arrows) are clearer than in Fig. 2d. Further work is needed to optimize T2-compensated pHASTE to achieve the carotid artery wall visibility comparable to that in TSE. The T2 compensated pHASTE image can be much better than the TSE image when the latter is severely corrupted by motion (Fig. 3).

CONCLUSION

The HASTE sequence with parallel acquisition and T2 compensation has been developed for carotid artery imaging to achieve motion-free images with significantly reduced T2 blurring artifact and shorten scan time. The T2-compensated pHASTE data are reconstructed using KIPA plus Homodyne to produce images with invisible aliasing artifact for R=2. In our future effort to improve the carotid artery wall visibility, selective excitation as described in [4] will be combined with the proposed method to further shorten the ETL by reducing the FOV in the PE direction.

ACKNOWLEDGMENT

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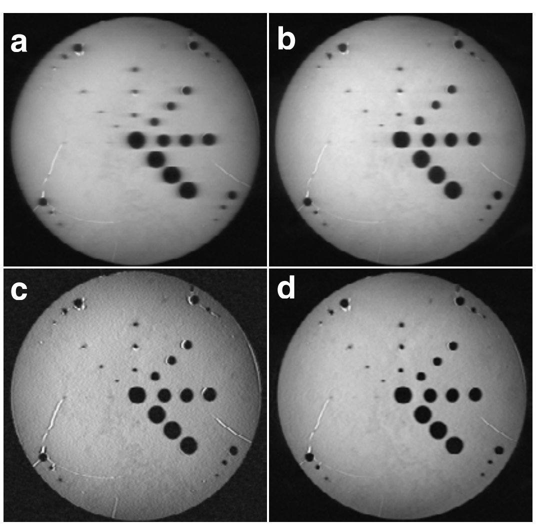

Fig. 1 Phantom images for **a:** HASTE without T2 compensation; **b:** pHASTE of R=2 without T2 compensation; **c:** HASTE with T2 compensation; **d:** pHASTE of R=2 with T2 compensation.

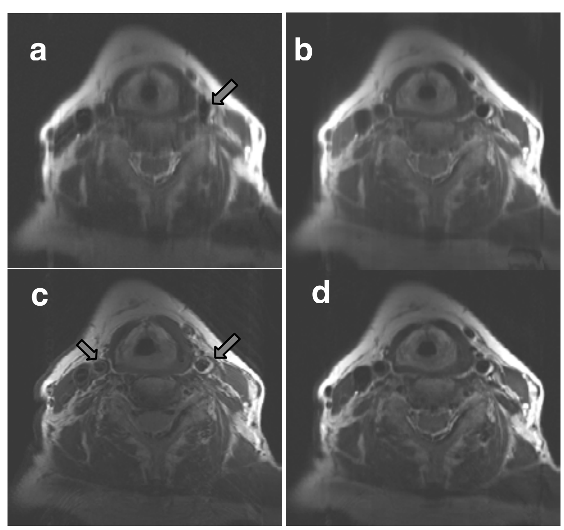

Fig. 2 Carotid artery images for **a:** HASTE without T2 compensation; **b:** pHASTE (R=2) without T2 compensation; **c:** TSE acquisition; **d:** pHASTE (R=2) with T2 compensation.

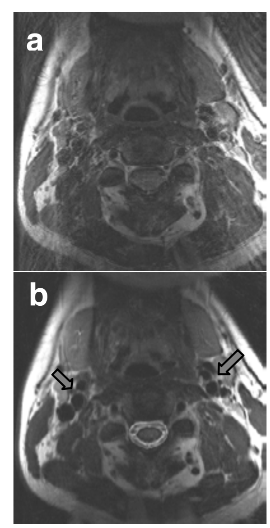

Fig. 3 Carotid artery images for **a:** TSE; **b:** pHASTE (R=2) with T2 compensation