Motion-free Carotid Artery Imaging with a Reduced-FOV Parallel HASTE Sequence

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INTRODUCTION

MRI with multiple contrasts (PDw, T1w, and T2w) is widely used to study carotid artery lumen and wall morphology [1] in evaluation of carotid artery diseases. Although these images are obtained with turbo (fast) spin echo (TSE/FSE) pulse sequences, the scan time for each sequence is still relatively long, making them sensitive to physiological motions, such as breathing, swallowing, and pulsation of the arteries due to pulsatile blood flow. We have developed an imaging protocol based on the Half Fourier acquisition single-shot TSE (HASTE) sequence [2] to acquire T2 weighted images of the carotid arteries with substantially reduced motion artifacts. We have tested this sequence on phantoms and human volunteers to verify 1) the reduction of motion artifacts on individual images, 2) the increased noise in individual images due to the small number of measurements used, 3) the potential for image averaging in conjunction with image registration to regain SNR

METHODS

The HASTE sequence acquires a complete k-space dataset in one shot. For such a short scan time, most physiological motions can be considered frozen making the pulse sequence a valid candidate for carotid artery imaging. However, the long echo train length (ETL) of HASTE makes it less useful for imaging of tissues with short T2 values such as vessel wall. The HASTE echo train should be significantly reduced to be applicable for carotid imaging. Because the region immediately around the carotid arteries is most important, reduced phase FOV and parallel imaging can be used to greatly reduce the ETL. In our experiment, the base resolution was 256. With phase FOV of 28.3% and parallel imaging with reduction factor, R, of 2, ETL was reduced to 25. The main problem with this imaging scheme is low signal to noise ration (SNR). To resolve this problem, the spatial resolution was reduced and multiple averages were acquired for each slice.

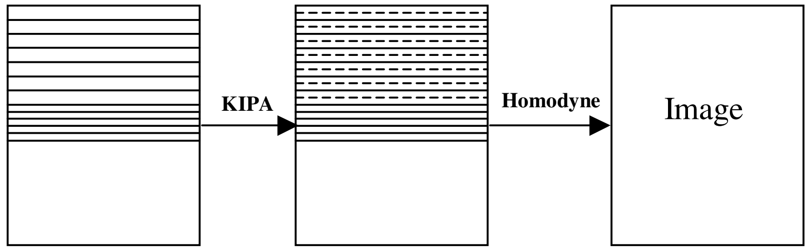


Fig. 1 Data processing scheme for HASTE sequence with R=2. The sampling pattern of acquired k-space is shown in the left of the figure. After applying KIPA, the missing PE views are generated which were represented as the dashed lines in the middle of the figure. Final image is reconstructed using Homodyne reconstruction.

Imaging was performed with a 3 Tesla MRI scanner (Siemens Medical Solutions, Erlangen, Germany) using our home built four-element bilateral phased array carotid coil. The reduction factor was limited to 2 by the coil characteristics. To avoid wrap-around artifact due to phase FOV reduction, magnetization outside the desired phase FOV was suppressed by saturation pulses. To enhance SNR, spatial resolution was reduced to 1 x 1 x 4 mm^3. With this protocol, HASTE readout duration was reduced to 279 msec. 24 slices were acquired in interleaved mode with 49 averages per slice in 5:30 min. Application of KIPA requires reference data with full sampling in the half Fourier space. For the reference scan, we only acquired 4 averages. With a TR of 431 msec, the reference scan only took about 35 sec.

Image reconstruction was implemented as shown in Fig. 1. First, the missing PE views are recovered using the KIPA algorithm [3]. Then, the image is obtained from the half Fourier data by homodyne reconstruction [4]. KIPA can provide better image quality (higher SNR, no aliasing artifacts) than GRAPPA as shown by the phantom study images in Fig. 2. Images from HASTE with R=1, 2, 3, and 4 were reconstructed by GRAPPA (Fig. 2a) and KIPA (Fig. 2b) resulting in improved image quality.

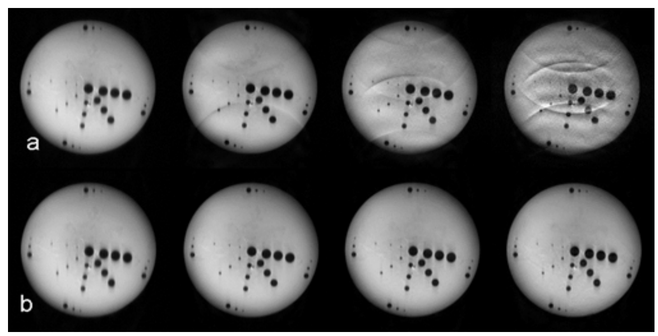
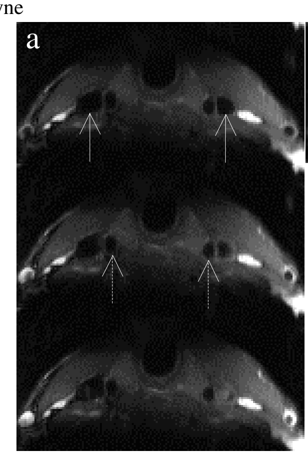


Fig. 2 Phantom images acquired by HASTE with R=1, 2, 3, 4 (from left to right) and reconstructed by **a:** GRAPPA and Homodyne; **b:** KIPA and Homodyne

RESULTS

The reconstructed image of each slice for each average was free of pulsation artifact. However, a cine view of the 49 images of each slice, showed the pulsating movement of carotid arteries and jugular veins throughout the 49 averages. By averaging images with similar motion status, high SNR carotid images at different phases of the cardiac cycle were constructed. Fig. 3a shows images of one of the 24 slices at three phases. There is still some residual wrap-around artifact due to imperfect saturation of unwanted regions. However, the wrap-around observed in Fig. 3 does not cross the regions near the carotid arteries. The pulsating of jugular veins is very obvious. The movement of carotid arteries is much smaller. But the slight shape change and vessel narrowing of carotid arteries from top to bottom in Fig. 3a is still visible. As a comparison, the same slice after averaging over all 49 images is shown in Fig. 3b. Notice that the right carotid artery has deformed to a square like shape and the left carotid artery has a small hole on the top of its vessel wall. This means that if TSE sequence is used to acquire carotid images, the effect of vessel pulsation will not only create ghosting artifact, but also lead to inaccurate information of carotid wall morphology.



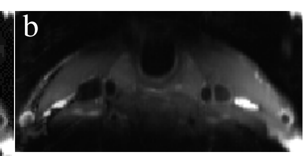


Fig. 3 a: Images of the same slice at three different phases of the cardiac cycle showing phase dependent changes in the carotid arteries (dashed arrows) and jugular veins (solid arrows). **b:** image of the same slice averaged over all 49 images.

CONCLUSION

The HASTE sequence with reduced phase FOV and parallel imaging was applied to acquire carotid arteries images with significantly suppressed motion artifact caused by breathing and blood pulsation. The combination of KIPA algorithm and Homodyne reconstruction gives acceptable images of individual averages from which vessel pulsation can be detected. Further research involves gating the scan with cardiac cycle and/or respiratory cycle, increasing SNR and spatial resolution without introducing motion artifact and better implementation of reduced FOV to decrease the wrap-around artifact. An improved RF coil with more elements will allow a greater reduction factor, a shorter echo train, and more efficient acquisition.

ACKNOWLEDGEMENT

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