TSE with Average Specific Phase Encoding Ordering for Motion Artifact Suppression

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Introduction

Turbo/fast spin echo (TSE/FSE) pulse sequences are widely used in clinical practice. In some cases when image SNR is low, scans with multiple averages can be used to attain acceptable image quality. However, multi-average scans have extended imaging time, making them more subject to motion artifacts. This project focuses on reducing image artifacts caused by sporadic motion during multi-average TSE scans. In multi-average TSE data, motion-corrupted echo trains can be detected by examining differences between k-space data of different averages. However, if each average has the same phase-encoding ordering, it is impossible to tell to which average the corrupt echo trains belong. To resolve this problem we have developed a new PE ordering scheme such that the same echo train in each average has a unique PE pattern (signature). This makes it possible to identify, not only the corrupted echo trains, but also the corrupted averages, which finally leads to automatic detection of motion corrupted PE views in the k-space datasets acquired by multi-average imaging with the TSE sequence.

Methods

For TSE sequences [1], the standard PE ordering of the i^{th} echo in the j^{th} echo train $l(i,j)$ is defined by

$$l(i,j) = nET * ETL/2 + (i - nET/2) + sign(i - nET/2) * j * nET/2 \quad (1)$$

where nET is the number of echo trains required to acquire the complete k-space, and ETL is the echo train length. Index i counts from 0 to nET-1, and j counts from 0 to ETL-1. This PE scheme continues to be used for the first average acquisition in our method. However, for the other averages, the PE orders of the 2nd and 3rd echoes of each echo train are changed. Assuming imaging a study with N averages, the m^{th} average will have its set of phase encodings for the 2nd and 3rd echoes circularly shifted by Δ_2 and Δ_3 echo trains, respectively, relative to their echo trains in the first average

$$\Delta_2 = (m-1) * \frac{nET}{N}, \quad \Delta_3 = \frac{1}{2} * \Delta_2 \quad (m = 2, ..., N) \quad (2)$$

One requirement for this modified PE ordering is $\Delta_2 >= 2$.

For two different averages with k-space data of $S_m(k_x, k_y)$ and $S_l(k_x, k_y)$ ($1 <= m, l <= N$), a k-space difference $\delta(k_y)$ can be calculated as

$$\delta_{ml}(k_y) = \sum_{k_x} \left| S_m(k_x, k_y) - S_l(k_x, k_y) \right| \quad (3)$$

If motion occurs during the scan of some average, then one or more echo trains in this average data will be corrupted. The plot of $\delta(k_y)$ will have peaks at k_y positions corresponding to the motion corrupted PE views. Comparing the peak positions with unique PE ordering for each average, the corrupted echo trains and the average in which motion occurred can be identified. This process is repeated for all pairwise combinations of N averages. In reconstruction, the corrupted PE views are replaced by the same PE views that are uncorrupted in the nearest-in-time average. If the same PE view is corrupt in all averages, then the mean value can be used. However, in cases when multiple coils are used for MR signal collection, generalized SMASH or POCSENSE can be applied to regenerate such PE views [2, 3]

Results

Phantom and brain imaging were performed on a 3T Siemens Trio scanner (Siemens Medical Solutions, Erlangen, Germany) using a TSE sequence with the new PE ordering. Phantom data were acquired with 4 averages and ETL=7. The position of the phantom was repeatedly changed from the baseline during acquisition of the second and third averages. The images reconstructed from the original k-space data have significant blurring and ghosting in the corresponding averages as shown in Fig. 1a. The plot of $\delta(k_y)$ for averages 1 and 3 is shown in Fig. 2. The motion corrupted echo train and the average in which the motion occurred is easily identifiable by the peaks at the corresponding k_y positions. After the corrupted PE views were replaced by uncorrupted data, the image quality noticeably improved (Fig. 1b). Fig. 4 displays the brain images acquired using the TSE sequence with 2 averages and ETL=7. The subject moved during the first average acquisition causing serious image quality degradation (Fig. 4a). The difference image between the averages demonstrates significant dissimilarities between the averages caused by motion. In this study, the gradient of $\delta(k_y)$ was used to detect the corrupted PE views (Fig. 3). After replacing the PE views, the motion artifact was significantly reduced (Fig. 4b).

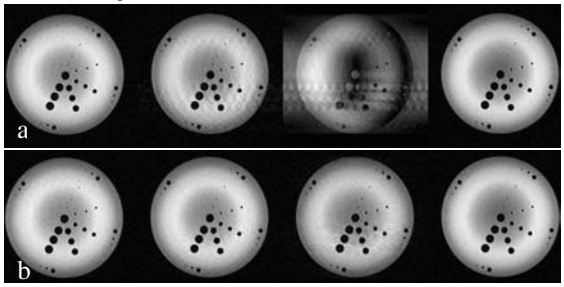

Fig. 1 Phantom images for average 1-4 reconstructed using **a:** the original k-space data; **b:** the k-space data constructed by identifying motion-corrupted PE views and replacing them by the corresponding uncorrupted data of the nearest in time average.

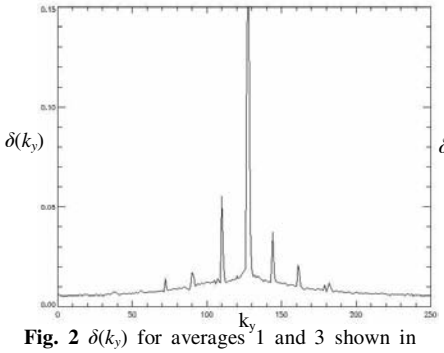

Fig. 2 $\delta(k_y)$ for averages 1 and 3 shown in Fig. 1

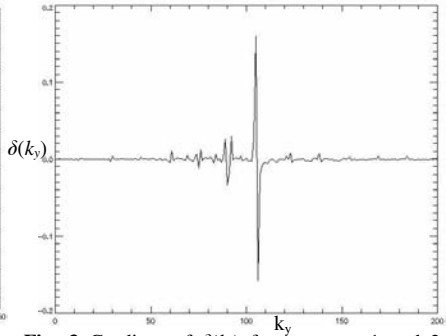

Fig. 3 Gradient of $\delta(k_y)$ for averages 1 and 2 shown in Fig. 4

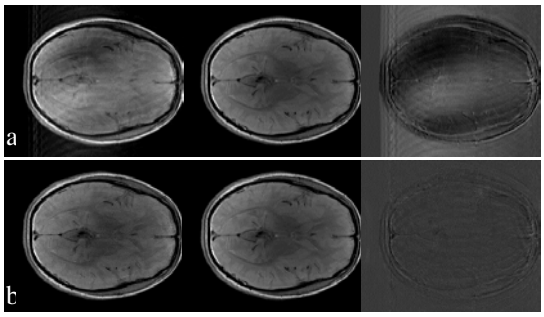

Fig. 4 Brain images for average 1 and 2 and difference between them reconstructed using **a:** the original k-space data; **b:** the k-space data constructed by identifying motion-corrupted PE views and replacing them by the corresponding uncorrupted data of the other average.

Conclusion

The developed phase encoding scheme for TSE sequences can be used to automatically detect sporadic motion during multi-average acquisitions. The corrupted PE views can be discarded and replaced by corresponding uncorrupted data to suppress motion artifacts. Both phantom and human studies have shown significant reduction in motion artifact.

Acknowledgment

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References: [1] Constable RT and Gore JC. MRM 1992;28:9-24. [2] Bydder M, et al. MRM 2002;47:677-86. [3] Samsonov AA, et al. ISMRM 2005, p. 690.