CINE Turbo Spin Echo Imaging

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INTRODUCTION

While high resolution TSE images have demonstrated important details of carotid artery morphology, it is evident that pulsatile blood and wall motion related to the cardiac cycle are still significant sources of image degradation. Although ECG gating can reduce artifacts due to cardiac induced pulsations, gating is rarely used because it lengthens the acquisition time and can cause image degradation due to non-constant TR. This work introduces a relatively simple method of converting a conventional TSE acquisition into a retrospectively ECG correlated image sequence (cineTSE). The cineTSE sequence generates a full sequence of ECG correlated images at each slice location throughout the cardiac cycle in the same scan time that is conventionally used by standard TSE sequences to produce a single image at each slice location.

THEORY

Information about the patient's cardiac cycle is recorded during the MR scan utilizing a pulse oximeter. The acquired k-space data lines are sorted into N_t temporal bins according to the time elapsed since the last systolic trigger. The undersampled images are reconstructed by simultaneously considering information encoded by the coil sensitivities as well as applying a temporal constraint. This is accomplished by minimizing the following objective function:

$$G = \left\| W(k_x, k_y, t) \cdot \Im_{xy}\left[s_n(x,y) \cdot m(x,y,t) \right] - d_n(k_x, k_y, t) \right\|_2^2 + \left\| \lambda(x,y) \cdot \nabla_t \left[m(x,y,t) \right] \right\|_2^2$$

where t is the time (bin number) in the cardiac cycle, $W(k_x,k_y,t)$ is a weight function specifying which lines in k-space have been acquired in each bin, $\Im_{xy}()$ is the 2D Fourier transform along the spatial coordinates, $s_n(x,y)$ is the coil sensitivity of the n^{th} coil, $d_n(k_x,k_y,t)$ is the actual data acquired from the n^{th} coil in a given bin, $\lambda(x,y)$ specifies the level of temporal constraint and $\nabla_t()$ is a temporal gradient.

METHOD

All studies were performed on a Siemens Trio 3T MRI scanner with custom designed 4 or 16 element phased array surface coils with a modified TSE sequence. To help ensure that each temporal data bin contains a sufficient number of lines near the center of k-space (where most of the image energy is found), the product TSE sequence was modified to more frequently sample the center of k-space and to record the patient's cardiac cycle utilizing a pulse oximeter. To prevent an increase in scan time, this is accomplished at the cost of missing varying lines near the edge of k-space in each average. Every line of k-space is sampled at least once during the entire acquisition (typically 2 averages).

RESULTS

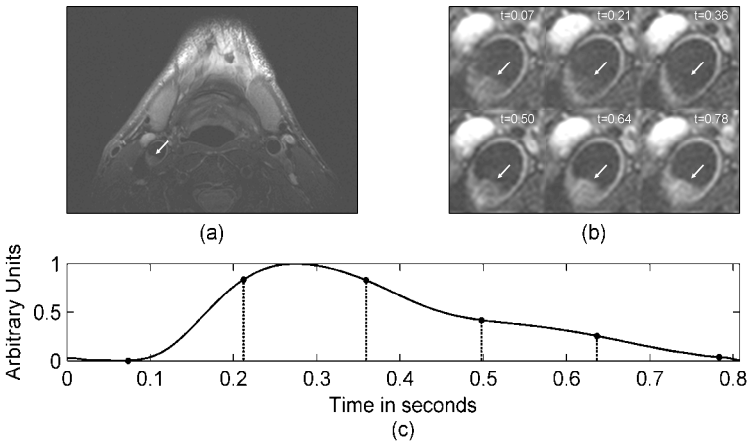

Figure 1. Flow artifact identification using a T2 weighted cineTSE reconstruction (4 channel receive coil and 2 data averages). The standard TSE image (a) exhibits a flow artifact indicated by the arrow. Six equally spaced images in the cardiac cycle (of 12 total images) from the cineTSE reconstruction are shown in (b). The time (in seconds) of each of the 6 images relative to the systolic trigger is indicated by the text on each image (b) as well as the dashed lines on the average pressure pulse waveform shown in (c).

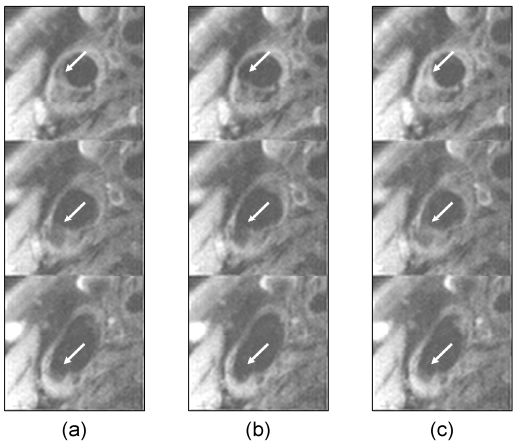

Figure 2. T1 weighted cineTSE images of carotid disease (16 channel receive coil, 2 averages). Each column contains the same three consecutive slices. Standard TSE images are shown in (a), systolic cineTSE images in (b) and diastolic cineTSE images in (c). The cineTSE images are from the same data set as the standard TSE image.

DISCUSSION AND CONCLUSION

In Fig. 1 it is evident that flow artifacts in the standard TSE images can be resolved using the dynamic information available with cineTSE. Figure 2 shows how the geometry of an ulcerated carotid plaque can be better visualized using the cineTSE sequence. In many neck TSE protocols, two or more averages are acquired to reduce motion effects and to increase image SNR. In these cases, the cineTSE generates a full sequence of ECG correlated images at each slice location throughout the cardiac cycle in the same scan time that is conventionally used by standard TSE sequences to produce a single image at each slice location. Because cineTSE acquisition is asynchronous with the cardiac cycle, it does not have the problems caused by non-constant TR periods of gated sequences. CineTSE can more accurately identify and allow for measurements of carotid artery plaque components by improving tissue visualization, allowing for identification and exclusion of artifacts and enhancing image quality.