Reduction of truncation artifact in spectroscopic images using a dual-density spiral k-space trajectory

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Introduction

In proton CSI of the human brain, artifacts due to k-space truncation are particularly problematic since the intense extra-cranial lipid signal from subcutaneous fat can detrimentally contaminate the spectroscopic signals in the brain. Realizing that substantial signal contamination due to truncation arises mainly from areas having strong signals, a strategy for reducing contamination from these regions based on variable k-space coverage was developed [1]. The original implementation, which was based on variable data averaging, was feasible for one-dimensional experiments. To achieve variable coverage in 2-D spectroscopic imaging, a hybrid technique combining phase-encoded CSI and fast echo-planar spectroscopic imaging was introduced [2]. This sampling strategy can be more efficiently implemented using variable density spiral k-space trajectories in a manner similar to that used for acquisition based k-space apodization [3]. However, in the present work, we use a dual density spiral trajectory to selectively increase the spatial resolution of the lipid regions while preserving the SNR of metabolites.

Method

The reconstructed spatial image for a circularly symmetric truncation can be expressed as

$$\overline{M}_0(l\Delta t,\vec{r}) = \int_{\vec{k}=-\infty}^{\infty} M_0(l\Delta t,\vec{k})\,\mathrm{circ}\left(|\vec{k}|/|\vec{k}|_{\max}\right)\exp(j2\pi\vec{r}\vec{k})\,d^2\vec{k},$$

$\overline{M}_0(l\Delta t,\vec{r})$ is a blurred version of the ideal $M_0(l\Delta t,\vec{r})$ because of the circularly symmetric truncation of $\vec{k}$ -space.

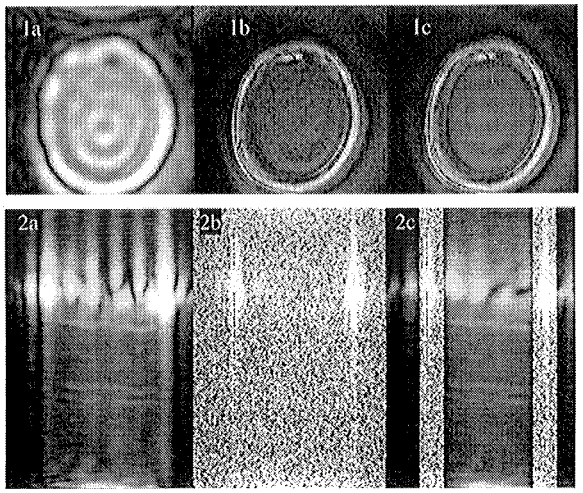
$\overline{M}_0(l\Delta t,\vec{r}) = M_0(l\Delta t,\vec{r}) \otimes\otimes |\vec{k}|_{\max} J_1(2\pi|\vec{r}||\vec{k}|_{\max})/|\vec{r}|$, where $J_1(|\vec{r}|)$ is the first order Bessel function. The basic strategy is to selectively increase k_{max} for the high intensity extra-cranial lipid regions, which causes the truncation artifact, within an acceptable increase in measurement time. In this strategy a larger region of the k-space is covered, with the low k-space points sampled using a high sampling density to achieve adequate SNR as required by metabolites and the high k-space points sampled using a low sampling density determined by the Nyquist sampling requirements. A dual density spiral trajectory is used to achieve this strategy such that the low k-space is sampled slowly because of high sampling density, whereas the high k-space is sampled rapidly at the Nyquist sampling density. The rapidly sampled high k-space data, being low in SNR, contain sufficient information for the high intensity areas, which contribute most significantly to the truncation artifact. Consequently, an extended region of the k-space is covered with a slight increase in measurement time.

A dual-density spiral k-space trajectory is designed using the theory and numerical design procedure outlined in [4]. In the present implementation, the trajectory is designed such that the sampling density in a lower portion of the k-space with a circular diameter of 18 pixels is 8 times that of the rest of the k-space, which extends to a diameter of 120 pixels. The gradients are designed for an FOV of 240 mm and a maximum gradient of 20 mT/m and a rise time of 600 μs. In this design, 64 k-space interleaves and 2 temporal interleaves are used. Spin-echoes are acquired using a TR/TE of 2000/135 ms. Each gradient segment is repeated 256 times after each excitation to encode the spectral dimension resulting in a spectral bandwidth of 575 Hz with a spectral resolution of 1.12 Hz. The pulse sequence is implemented on a 1.5T SIEMENS Magnetom Vision scanner. The total scan time for obtaining a data set with a single average is 4 min 16 s. A slice thickness of 10 mm was used and four averages were acquired to improve the SNR.

The measured k-space data along the spiral trajectories were compensated for density weighting, convolved with an optimal Kaiser-Bessel window, and re-sampled onto a Cartesian grid. Spatial location of the extra-cranial lipid is used as a mask in a spatially selective reconstruction technique [1]. The entire k-space data, including the low SNR high k-space data, are used to reconstruct the extra-cranial lipid regions, whereas only the high SNR low k-space data are used to reconstruct the brain tissue containing the metabolites of interest.

Results and Discussions

Lipid images obtained by integrating the spectral dimension around the lipid resonance are shown in Fig. 1. Fig. 1(a) shows the lipid image obtained from a circularly truncated k-space of diameter of 18 pixels and zero-filled to a diameter of 120 pixels. A spatial spectral slice of Fig. 1(a) is shown in Fig. 2(a). These figures exhibit severe bleeding of the lipid signals into the brain tissue regions. Figure 1(b) shows the lipid image using the entire k-space data of 120 pixels in diameter and the corresponding spatial-spectral slice in Fig. 2(b). These figures illustrate significant reduction in the truncation artifacts due to the improved spatial resolution of lipid pixels. However the SNR will not be sufficient to detect metabolite resonances. Fig. 1(c) shows the lipid image after performing the selective reconstruction and Fig. 2(c) shows the corresponding spatial-spectral slice. These images illustrate how the SNR of metabolites in the brain regions are preserved and the truncation artifacts reduced. Residual bleeding is minimal, and is similar in Figs. 2(b) and 2(c) which suggests it is most likely due to the truncation of k-space to 120 pixels.



Conclusion

A technique for reduction of truncation artifact using a dual-density spiral k-space trajectory was implemented and demonstrated to be successful in reducing the bleeding of extracranial lipid signals. This method for lipid removal will be very useful for spectroscopic imaging studies with smaller TE.

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References

1. Hu X et al, J Magn Reson, B 103:30-38 (1995)
2. Metzger G et al, Magn Reson Imag 17:435-443 (1999)
3. Adalsteinsson E et al, Magn Reson Med 42:314-323 (1999)
4. Spielman D M et al, Magn Reson Med 34:388-394 (1995)