Quantitative 23-Sodium and 17-Oxygen MR Imaging in Human Brain at 9.4 Tesla Enhanced by Constrained k-Space Reconstruction

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Introduction:

The sensitivity of the 9.4 Tesla scanner for human brain imaging allows access to MR signals from 23-sodium and 17-oxygen nuclei in acquisition periods (< 10 minutes) and at spatial resolutions (< 8mm isotropic) with sufficient signal-to-noise for quantification of the data as metabolic concentration maps. Constrained k-space image reconstruction methods allow co-registered k-space data from a more sensitive nucleus (e.g., 23-Na) acquired at high spatial resolution to be combined with k-space data from less sensitive nucleus (e.g., 17-O) to form images of enhanced spatial resolution of the less sensitive nucleus [1]. To be useful as a method to enhance metabolic imaging, this reconstruction method must maintain the quantitative relationship of the MR signal to the metabolite concentration. We report that the accuracy of such constrained k-space image reconstruction techniques for signal quantification is preserved.

Methods:

Studies on human volunteers were performed under IRB supervision using the 9.4T 80 cm MR scanner described in [2]. 23-Na and 17-O imaging was performed using a modified version of the previously reported twisted projection imaging [3] and custom-built, single-tuned quadrature birdcage RF coils. These RF coils can be rapidly exchanged without disturbing the subject, enabling co-registered acquisitions across nuclei.

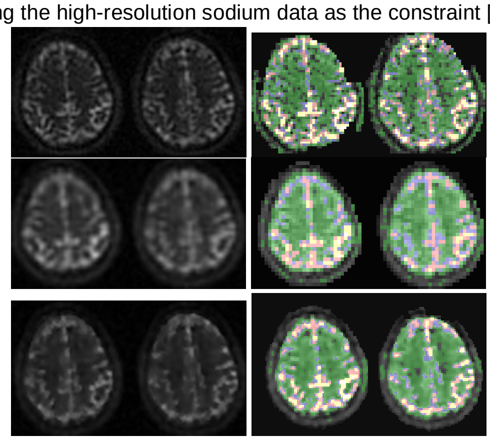
After shimming at the sodium frequency to a whole-head linewidth of 20-25 Hz, sodium imaging was performed with a spatial resolution of 3.125 x 3.125 x 3.125 mm^3 in 6 minutes and 36 seconds (TR=150 ms, TE=0.26 ms, F_R=0.20, 4 mT/m gradient amplitude) and with a spatial resolution of 5 x 5 x 5 mm^3 in 2 minute 44 seconds (TR=150 ms, TE=0.26 ms, F_R=0.20, 4 mT/m gradient amplitude). Natural abundance 17-O imaging was performed with a spatial resolution of 7.4 x 7.4 x 7.4 mm^3 in 7 minutes and 50 seconds (TR=100 ms, TE=0.360, F_R=0.35, 4 mT/m gradient amplitude, 4 averages). The specific absorption rate (SAR) was monitored in real-time during all acquisition and remained within FDA guidelines. Image reconstruction was performed using a conventional 3D gridding approach with a Kaiser-Bessel interpolation kernel. Constrained reconstruction was performed on the low-resolution sodium data and the oxygen data using the high-resolution sodium data as the constraint [1].

23-Na and 17-O imaging was repeated using the same acquisition parameters on multi-compartment calibration phantoms with known metabolite concentrations and with electrical and relaxation properties similar to a human head. These data were used to quantify the human measurements into metabolic concentration maps.

Results:

As expected, the spatial resolution of the low-resolution sodium and oxygen images was enhanced using the constrained k-space reconstruction methodology and, although blurred, the tissue sodium concentrations were still accurately registered. The tissue sodium concentration (TSC) maps shown in **Figure 1,** measured from equivalent locations through the brain covering multiple brain structures (white matter, gray matter, CSF) show equivalent values irrespective of whether the constrained k-space method was used. Linear calibration curves were maintained through the constrained k-space methodology.

The images for natural abundance 17-oxygen water in a human brain reconstructed with, and without, the constrained k-space technique using high-resolution sodium images are shown in **Figure 2**.



(a) Sodium images of the human brain at 9.4 Tesla and the derived TSC map at high resolution (3.125 mm isotropic) acquired in 6:36.

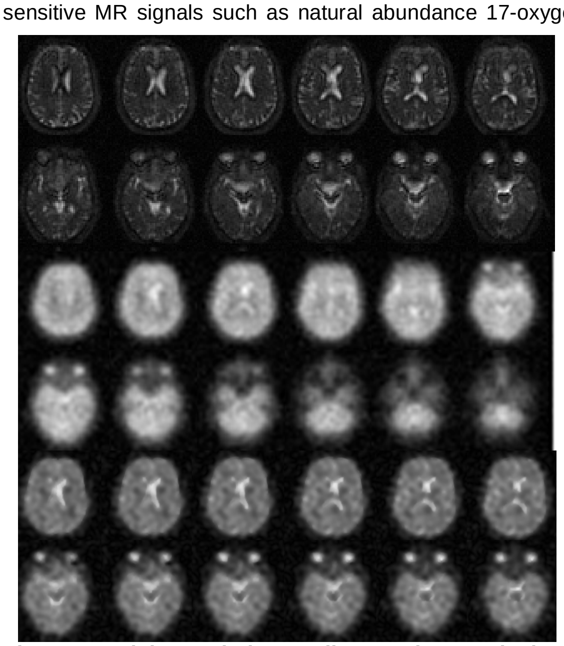
(b) Equivalent images and TSC map as in (a) but acquired at low resolution (5 mm isotropic) acquired in 2:44.

(c) Equivalent images and TSC map as in (b) using the constrained k-space reconstruction method to enhance resolution (<5 mm isotropic).

Figure 1: Sodium images and TSC maps (green=20-45 mM, blue=45-55 mM, red=55-70 mM, yellow=70-100 mM)

Conclusions:

The constrained k-space image reconstruction technique allows less sensitive MR signals such as natural abundance 17-oxygen to be produced at higher resolution images without loss of quantification of the metabolite concentration. This approach of enhanced image reconstruction combined with the improved sensitivity of high field broadens the human applications of metabolic MR imaging by minimizing otherwise long acquisition times to achieve adequate spatial resolution for the anatomy and SNR performance for quantification.



(a) Sodium images of the human brain at 9.4 Tesla at high resolution (3.125 mm isotropic) acquired in 7:45 minutes.

(b) 17-Oxygen water images of the human brain at 9.4Tesla at high resolution (7.4 mm isotropic) acquired in 7:50 minutes.

(c) 17-Oxygen water images from (b) enhanced using the constrained k-space reconstruction method (<7.4 mm isotropic).

Figure 2: High resolution sodium and natural abundance 17-O oxygen images

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