Density-Adapted Spiral MRI sequence for ^{23}Na imaging

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Target Audience: Scientists and physicians interested in the field of non-proton MRI

Purpose

Three-dimensional radial imaging techniques are often used for short T_2^* imaging, such as sodium magnetic resonance imaging (^{23}Na-MRI).[1] Spiral sequences like Twisted Projection Imaging (TPI)[2] allow for shorter acquisition times, since there are fewer projections needed in order to fulfil the Nyquist criterion. However, there are restrictions to the applicability of this sequence due to the higher gradient slewrates required. In this study the original TPI sequence and 3-D density-adapted radial sampling (DAR)[3] were combined (DA-C-TPI). Thus, a lower radial fraction can be chosen. DA-C-TPI is compared to DAR and TPI.

Methods

^{23}Na-MRI was conducted on a 7-T whole body system (Magnetom 7-T, Siemens Healthcare, Erlangen, Germany) using a double-resonance (^{23}Na/ ^{1}H) quadrature birdcage coil (inner coil diameter: 26 cm; Rapid Biomed GmbH, Rimpar, Germany).

TPI trajectories, designed for spherical k-space sampling were used as a basis. The projections are distributed such that they lay on cones (Fig. 1), each characterized by its opening angle θ. The number of cones needed depends on the desired resolution Δx and the field of view FOV:

$$N_\theta = (\pi\ FOV)/(2\Delta x)$$

The number of projections required on the different cones depends on the radial fraction p, where spirals begin ($k_0 = p\ k_{max}$).

$$N_\varphi = 2\ N_\theta\, p\ \sin(\theta)$$

The cones exhibiting the smallest opening angle require the highest gradient slewrate. In order to prevent the slewrate from exceeding the limit of the MR scanner DASS modifies the projections on those inner cones (IC), for which the slewrate would be too high. Here, where θ is very small or almost π, the start of the spirals is separated from the density adaption (Fig. 2). In k-space the trajectories first move outwards radially until t_0, then continue density adapted radially until t_1 and finally move on in a spiral way, keeping density adaption.

<u>*SNR-evaluation:*</u> The newly implemented DA-C-TPI sequence was evaluated regarding the signal to noise ratio and a comparison with the DAR sequence was performed. The SNR was determined using a spherical container (Ø 17 cm) of 0.9% NaCl solution and applying the pseudo multiple replica method[4] in order to obtain an SNR map. K-space was oversampled in order to fulfil the Nyquist criterion and at the same time choose the same number of projections for all sequences. ($N_\theta = 168$, $\Sigma N_\varphi = N_{DAR} = 9440$, $t_0 = 530\mu s$, $t_1 = 950\mu s$, $T_E = 0.3ms$, $T_{RO} = 10ms$, $p = 0.26$)

<u>*In-vivo imaging:*</u> To demonstrate the quality of the DA-C-TPI sequence, ^{23}Na images of the human head were obtained and compared using different sequences. A FOV of 32cm and a nominal resolution of 4mm were chosen. This leads to $N_\theta = 126$ in case of TPI and DA-C-TPI. For DAR 20274 projections were taken. Each of those sequences was driven at its best efficiency, which means applying the smallest possible radial fraction. DAR: p = 0.15, TPI: p = 0.29, DA-C-TPI: p = 0.21. This leads to 5950 and 4314 projections needed for TPI and DA-C-TPI respectively, where the latter needed four IC. ($T_R = 100ms$, $T_E = 0.3ms$) A silicone-caoutchouc cushion filled with 2% agarose gel and different NaCl-concentrations (25-150mmol/L)[5] was used for quantification.

Results

<u>*SNR-evaluation:*</u> Both sequences, DAR and DA-C-TPI yield SNR values which lie within the error tolerances. DAR: 26.8 ± 1.9, DA-C-TPI: 28.9 ± 2.0

<u>*In-vivo imaging:*</u> All sequences yielded good image quality (Fig.3). DA-C-TPI enabled the shortest acquisition time.

Discussion

As expected, keeping all other parameters the same, the SNR of the newly implemented DA-C-TPI sequence agrees with the SNR reached by DAR. But DA-C-TPI enables imaging of a given FOV within shorter acquisition time. Still it does not yield the same radial fraction due to the higher gradient slewrates, which are at some point not only present at the inner cones. Compared to the TPI sequence, DA-C-TPI reaches lower p-values. This should reduce blurring due to fast transverse relaxation and enables slightly higher SNR efficiency and shorter acquisition times.

Conclusion

A density-adapted 3D spiral projection sequence, which combines density-adapted radial sampling and twisted projection imaging performs superior to TPI and DAR.

References

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4. Riffe et al. Proc Intl Soc Mag Reson Med 15 (2007): p. 1857
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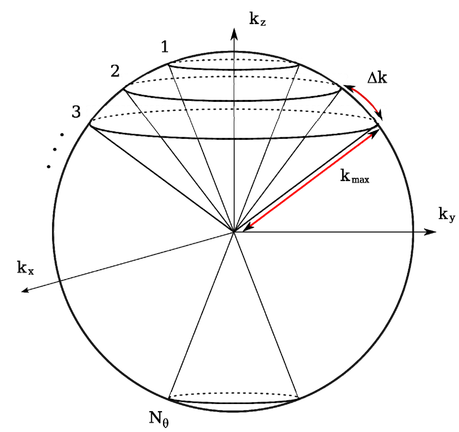

Fig. 1: Scheme used to distribute the radial projections. The trajectories start in the center of k-space and wind up on the surface of a sphere. The choice of the number of cones N_θ influences the ratio of resolution and FOV.

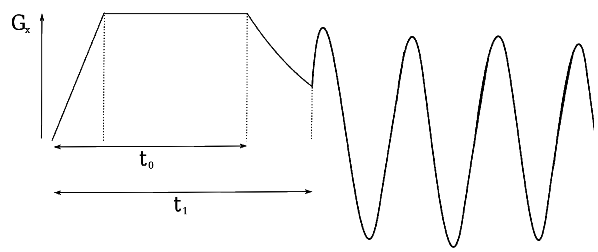

Fig. 2: Sketch of the magnetic field gradient in x direction: In case of the inner cones, where the slewrate in the beginning of the spiral part would be too high, the spiraling starts later, at t_1 instead of t_0, where the density adaption sets in.

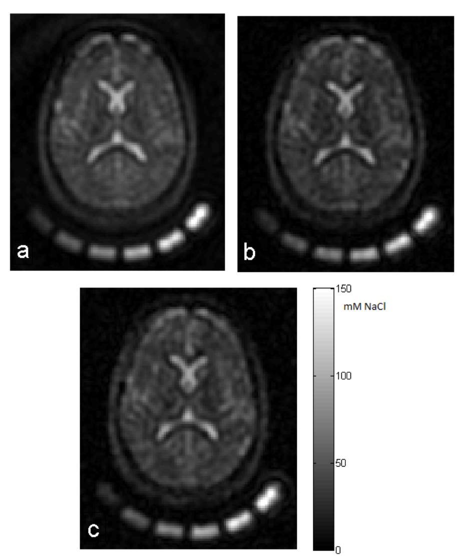

Fig. 3: Images of the human brain, lying on a reference cushion[5] with different sodium concentrations in it. It was chosen a spacial resolution of 4mm, 32cm FOV and 12.5ms readout duration, each sequence running at its optimal value of radial fraction. a) DAR: p = 0.15, 20274 Projections; b) TPI: $N_\theta = 126$, p = 0.29, 5950 Projections; c) DA-C-TPI: $N_\theta = 126$, p = 0.21, 4314 Projections