3D Density-Adapted Projection Reconstruction [23]Na-MRI with Anisotropic Resolution and Field-of-View

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Introduction

Three-dimensional radial imaging techniques are often used for short T_2^* imaging, such as sodium magnetic resonance imaging (^{23}Na-MRI) [1]. Usually, a spherical field-of-view (FOV) is sampled employing an isotropic spatial resolution. For some applications, such as, ^{23}Na-MRI of cartilage [2] or of skin [3], however, anisotropic spatial resolutions and FOVs prove to be more beneficial. Algorithms exist that allow for the design of anisotropic FOVs by non-uniformly sampling a set of cones or using a spiraling path on the surface of a sphere [4]. In this study, a 3-D density adapted projection reconstruction sequence sampling a cuboid (DA-3DPR-C) was implemented (Fig. 1). The manner by which the anisotropic spatial resolution and FOVs are obtained is analogous to rectangular Cartesian sampling.

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).

DA-3DPR trajectories, designed for spherical k-space sampling [5] were adequately scaled. The extremities of the trajectories were distributed on the surface of a cuboid (Fig. 1). The spacing between these extremities can be adjusted for the x-, y- and z- axes to adjust the FOV. The spatial resolution in each of these three dimensions can be altered by scaling the lengths of the cuboid's edges. The number of projections needed (N_{Nyq}) to fulfill the Nyquist criteria is derived by equation 1. The FOVs in the different directions are indicated by the number of pixels.

$$N_{Nyq}=2[(FOV_x-1)(FOV_y-1)+(FOV_x-1)(FOV_z-1)+(FOV_y-1)(FOV_z-1) + 1] \quad \text{(equation 1)}$$

Phantom-study: The newly implemented DA-3DPR-C sequence was evaluated using a resolution phantom (Fig. 2a). Subsequently, a comparison with a DA-3DPR sequence using spherical k-space sampling (DA-3DPR-S) was performed. A spherical k-space volume yields a 1.31-fold broader Full Width at Half Maximum (FWHM) of the Point Spread Function (PSF) compared with a cubical k-space volume (1.59 pixels vs. 1.21 pixels). This signifies an increase in spatial resolution by a factor of a 1.31 when compared with spherical k-space sampling. Parameters: TE/ TR = 0.35/ 20 ms; $\alpha = 43°$; readout duration $T_{RO} = 10$ ms. SNR was determined according to the National Electrical Manufacturers Association definition [6], using the magnitude signal of noise-only images. A normalization to the voxel size and to the square root of the measurement time was performed to ensure an adequate comparison.

In-vivo imaging: To demonstrate the benefits of higher in-plane resolution, ^{23}Na images of the human calf muscles and knee were obtained. DA-3DPR-C sequences with an isotropic resolution of $(5.1\ \text{mm})^3$ and a high in-plane resolution of $(3.3\ \text{mm})^2$ were applied to the image of the calf muscles. FOVs of $(64)^3$ voxels and (82x82x34) voxels were used to arrive at the same number of projections (23816) and acquisition time (13 min 54 s) for both sequences (TE/ TR = 0.55/ 35 ms; $\alpha = 51°$). To compare the performance of DA-3DPR-S and DA-3DPR-C sequences, 3-D data-sets of the human knee were acquired with isotropic resolution $(2.14\ \text{mm})^3$ and high in-plane resolution (1.8x2.7 mm^2) (slice thickness: 4.51 mm). Parameters: TE/ TR = 0.55/ 35 ms; $\alpha = 63°$; acquisition time: 18 min 26 s.

Results

Considering the differences in the FWHM, the DA-3DPR-C sequence shows a slightly higher normalized SNR compared with the spherical k-space sampling (Fig. 2 b-d). The in-plane resolution could be maintained by reducing the slice thickness and the FOV_z (Fig. 2d, e). By doing this, however, a slightly reduced normalized SNR was measured. Fig. 2f illustrates the effect of a one-dimensional resolution decrease. In elongated structures, such as, the human calf muscles, increasing the in-plane resolution at the expense of a lower slice resolution can considerably improve image quality (Fig. 3). For instance, the DA-3DPR-C sequences with isotropic resolution (Fig. 3a) and high in-plane resolution (Fig. 3b) exhibit similar SNR with the same acquisition time and similar voxel volume. Additionally, the DA-3DPR-C allows for a better resolution of knee cartilage than DA-3DPR-S imaging (Fig. 4).

Discussion and Conclusion

A density-adapted 3-D projection reconstruction sequence which samples a cuboid represents an intuitive and efficient approach for anisotropic resolution and FOV imaging.

References

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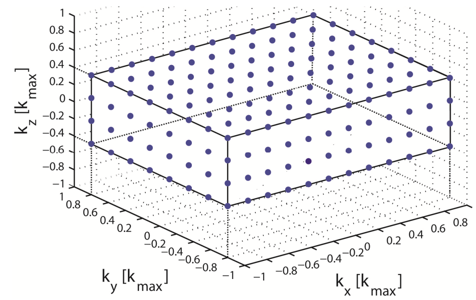

Fig. 1: Scheme used to distribute the radial projections. The trajectories start in the center of k-space and wind up on the surface of a cuboid. By distributing the extremities of the projections on the surface of the cuboid, the FOV and resolution can be adjusted in a manner resembling rectangular Cartesian sampling.

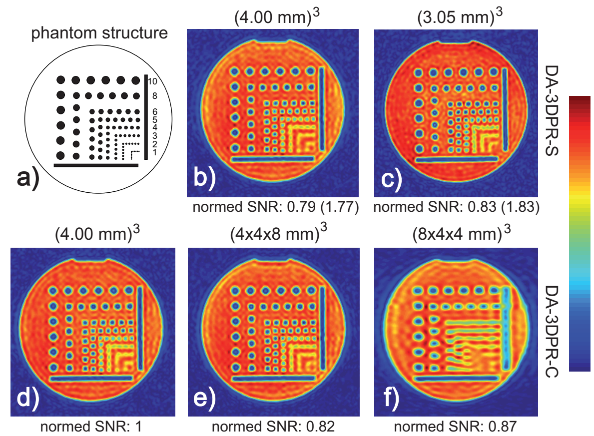

Fig. 2: Images of a resolution phantom (b-f). The sizes of the rods are given in millimeters (a). SNR was normalized to voxel size and the square root of the measurement time. For spherical k-space sampling, this value was scaled by a factor of $(1.31)^3$ to account for differences in the PSF. The original values are given in brackets.

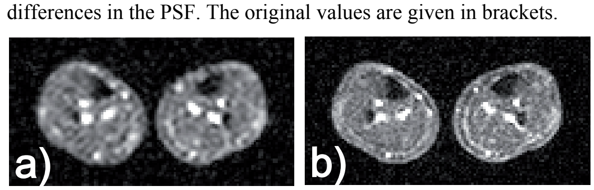

Fig. 3: Zoomed DA-3DPR-C images of the human calf muscle. a) Isotropic spatial resolution $(5.1\ \text{mm})^3$ (SNR = 8.2). b) In-plane resolution of 3.3x3.3 mm^2. Slice thickness: 12.7 mm. (SNR =8.7)

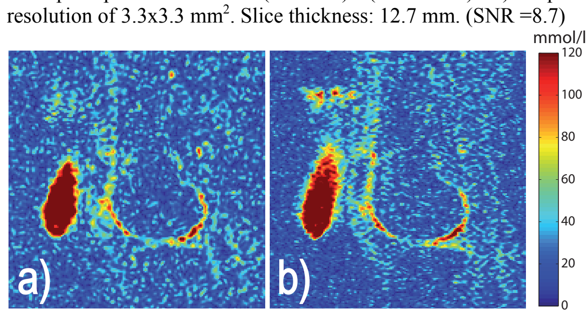

Fig. 4: Zoomed sagital images of the human knee. a) DA-3DPR-S sequence. $(2.14\ \text{mm})^3$. b) DA-3DPR-C sequence. In-plane resolution: 1.8x2.7 mm^2. Slice thickness: 12.7 mm.