Anisotropic 3D Radial Sampling for Ultrashort TE Imaging

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Introduction

3D radial free-induction-decay (FID) sampling schemes are used in ultrashort echo-time imaging (UTE), which is a method to visualize short-T_2 components in tendons, ligaments, and the like [1-4]. 3D UTE techniques sample a spherical k space volume with isotropic angular resolution, leading to rather long scan durations and, especially in case of multicoil reception, large amounts of acquired data. For prolate objects, an ellipsoidal imaging volume can be used to reduce the number of necessary radial projections. This is achieved by introducing non-isotropic angular spacing of radial profiles, e.g., by thinning out profiles at the poles of the spherical k-space volume. To investigate the effect of anisotropic angular sampling, the 3D radial point-spread function (PSF) is calculated. Phantom and in-vivo scans are presented to demonstrate the benefits of this technique. Depending on object shape, reductions in scan duration of 25 % or more are possible.

Methods

To minimize TE, typical 3D UTE sequences apply a non-selective excitation pulse and radial FID sampling (Fig. 1a). Isotropic k-space coverage can be achieved by arranging radial profiles on a spiral path over the surface of a sphere [5] (Fig. 1b). In this case, k_z steps are equally spaced with increment Δk_{z0}, and the azimuthal angle is varied according to $\varphi = \sin^{-1}(k_z)\sqrt{N\pi}$, with N being the number of radial projections. An anisotropic 3D arrangement of radial profiles is derived from this sampling pattern: To obtain a reduced angular density in the polar regions of the spherical k-space volume, a variable k_z increment $\Delta k_z = \Delta k_{z0}/(1-\alpha \sin^2(\pi/2 k_z))$ is introduced, cf. Fig. 1(d). The constant α determines the degree of anisotropic undersampling. It can range from 0 (isotropic sampling) to almost 1 (massively anisotropic sampling). A larger value of α results in a larger reduction in number of radial profiles: for instance, $\alpha = 0.5$, corresponds to 25 % reduction (cf. Fig. 1(c)), whereas $\alpha = 0.75$ corresponds to 37.5 %. For a homogeneous distribution of profiles, azimuthal angle increments vary according to $\Delta\varphi = \sqrt{2\pi\Delta k_z}/\sqrt{1-k_z^2}$. In 2D radial imaging, a reduction in angular density in k_y direction reduces the aliasing-free imaging volume in the x direction of the resulting image [6]. Thus, in 3D, a reduction in angular density around the poles, i.e., in k_z direction, reduces the imaging volume in x and y direction. This is verified by comparing the PSFs for isotropic and anisotropic sampling for $\alpha = 0.5$ (Fig. 2). The isotropic PSF is calculated for full sampling of a field of view (FOV) that corresponds to the radius of the depicted dashed circles. For a given α, the sampling density at the poles is decreased by a factor $1/(1-\alpha)$, which results in an equatorial FOV reduction of $1/\sqrt{1-\alpha}$, e.g., $\sqrt{2}$ for $\alpha = 0.5$. Measurements have been conducted using 3D radial anisotropic sampling on a 1.5 T MRI scanner (Achieva, Philips Medical Systems). In phantom scans, a FOV of 320 mm was acquired and reconstructed to a 96^3 matrix. In-vivo UTE scans of the finger were performed on a healthy volunteer, whose informed consent was obtained beforehand. A FOV of 120 mm was acquired at TE = 50 µs and reconstructed to a 128^3 matrix.

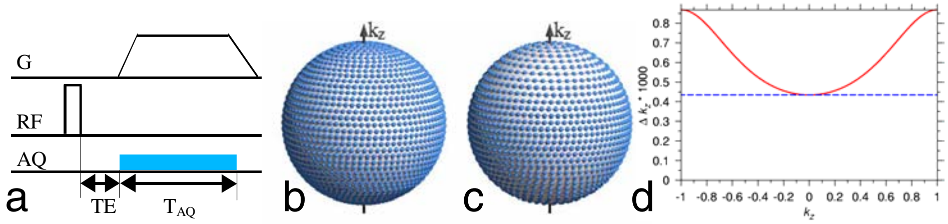

Figure 1: 3D Sampling. (a) 3D ultrashort TE sequence applying a non-selective excitation pulse and FID sampling. (b) Isotropic 3D sampling density. (c) Reduced density near the poles in k_z direction ($\alpha = 0.5$). (d) Corresponding k_z increments for isotropic (dashed) and anisotropic sampling with $\alpha = 0.5$ (solid line).

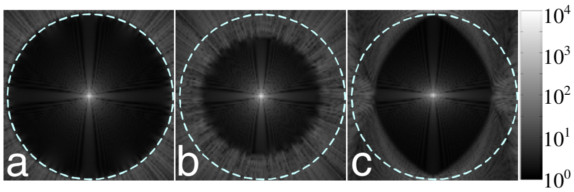

Figure 2: Logarithmic plot of PSFs. (a) Isotropic sampling. (b,c) Anisotropic sampling with $\alpha = 0.5$: (b) xy plane, (c) xz plane.

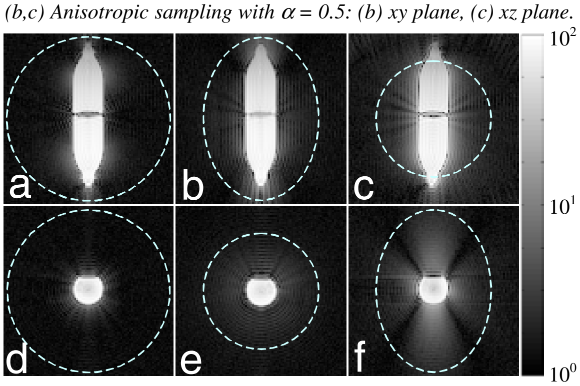

Figure 3: Phantom measurements in logarithmic representation. Dashed lines indicate the extension of the aliasing-free imaging volume. (a,d) Isotropic sampling. (b,e) Anisotropic sampling with $\alpha = 0.5$ and the long imaging volume axis aligned with phantoms. (c,f) Anisotropic sampling with the long axis perpendicular to phantom orientation.

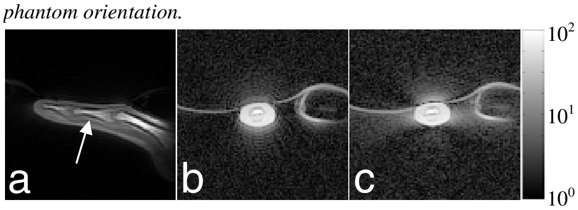

Figure 4: 3D UTE finger image at TE = 50 µs. (a) Anisotropic sampling with $\alpha = 0.5$, finger aligned with imaging volume. High signal from the flexor tendon (arrow) is obtained. (b) Transverse slice of the same data set in logarithmic scale. (Plastic coil covers are visible.) (c) Misalignment leads to a higher aliasing level.

Results

Figure 3(a,d) show two perpendicular slices of an isotropic 3D data set using a logarithmic intensity scale. 27648 radial profiles were acquired for full sampling. Figure 3(b,e) show the same phantom using undersampling with $\alpha = 0.5$ in the direction of the long object extension, which reduces the number of profiles to 20736. Figure 3(c,f) show a scan with the same parameters, but with undersampling applied perpendicular to the long object axis.

Figure 4(a) shows a sagittal slice of an anisotropically sampled data set ($\alpha = 0.5$) of the finger, aligned with the long imaging volume axis. Fig. 4(b,c) compares transverse slices using a logarithmic plot for parallel (b) and orthogonal alignment (c). 36865 radial profiles were acquired.

Discussion

By aligning the long axis of the anisotropic imaging volume with the long axis of a prolate object, the number of acquired profiles can be reduced with only minor losses in image quality (cf. Fig. 3(a,d) vs. 3(b,e)). However, failure to align imaging volume and object properly can increase the level of radial streaking artifacts in the image (cf. Fig. 3(b,e) vs 3(c,f), and Fig. 4(b) vs. 4(c)). Using correct alignment of imaging volume and object, for anisotropic objects such as extremities, the number of necessary profiles can be reduced considerably. This method can also be used in other 3D radial imaging applications, such as angiography [7] or cardiac imaging [8].

Conclusion

Anisotropic 3D radial sampling is a method to reduce scan duration and data size in 3D UTE imaging and other 3D radial applications. It can be applied to imaging of anisotropic objects, e.g. extremities. A scan time reduction in the order of 25% can be achieved without significant loss in image quality.

References

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