Self-Navigated Motion Compensation in Simultaneous $^{19}F/^{1}H$ 3D Radial Imaging using Golden Means Profile Interleaving

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Introduction

MR detection of low concentrations of imaging agents labeled with ^{19}F often requires long signal averaging times and therefore motion compensation is desirable. Simultaneous acquisition of ^{1}H and ^{19}F signal allows self-navigated motion tracking using the stronger ^{1}H signal [1]. In this work, 3D isotropic radial imaging has been combined with a profile acquisition order based on the 2D golden means [2,3]. Thereby, the intrinsic robustness of radial sequences against motion and undersampling can be combined with a flexible, motion-adaptive temporal frame rate. The technique is demonstrated in $^{19}F/^{1}H$ in-vivo scans with 1D translational motion and phantom scans with 3D rigid-body motion.

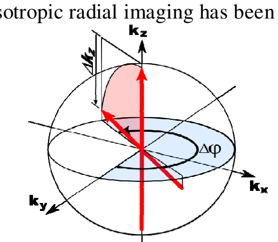
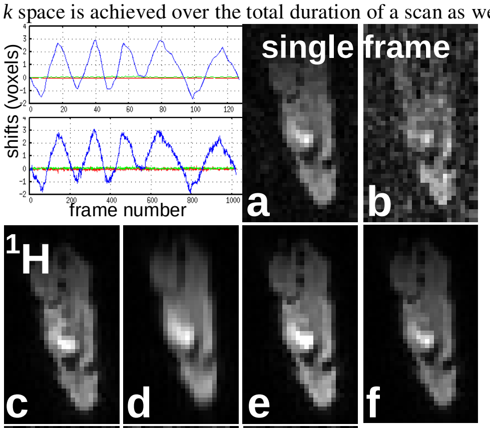


Figure 1: Golden section increments Δkz and Δφ between subsequent radial readouts.

Methods

A 3D radial echo sequence is applied [4]. Profile increments were derived from the 2D golden mean factors $\alpha = 0.4656$ and $\beta = 0.6823$ [5] to calculate increments $\Delta kz = 2\alpha$ and $\Delta\varphi = 2\pi\beta$ (Fig. 1). With this technique, a highly isotropic distribution of radial profiles in 3D *k* space is achieved over the total duration of a scan as well as over an arbitrary time window extracted for dynamic imaging. MR scans were performed on a modified clinical 3.0 T whole body scanner (Achieva 3.0T, Philips Medical Systems) using a dual-tuned $^{19}F/^{1}H$ T/R solenoid coil (∅ 7 cm) [1]. For simultaneous $^{19}F/^{1}H$ imaging, perfluoro-crown-ether nanoparticles were used as ^{19}F agents. To demonstrate dynamic imaging capabilities in in-vivo experiments, a few µl of nanoparticle emulsion were injected into sedated mice which were scanned with and without external 1D motion according to an institutionally approved animal protocol. Scan parameters were: FOV = 128 mm, isotropic matrix size 64^3, 131064 radial profiles, TE = 1.17 ms, repetition time TR = 3.6 ms, flip angle 8°, and total scan duration 7 min 52 s. The long acquisition time allowed detection of the ^{19}F-labeled tracers. For phantom experiments, 3D motion was performed by a volunteer's hand holding two vials, one filled with ^{1}H phantom fluid and one with ^{19}F nanoparticle emulsion. Scan parameters were: FOV = 80 mm, isotropic 80^3 matrix, 12800 profiles, TE/TR = 1.84/5.5 ms, flip angle 10°, total scan time 70 s. For motion tracking, *k* space data were retrospectively divided into the desired number of frames. All frames were reconstructed and the ^{1}H frames were used for motion registration. For 3D sub-pixel rigid-body tracking, an algorithm using multi-resolution processing as described in [6] was applied. The extracted motion information was used to correct the ^{19}F as well as the ^{1}H images.



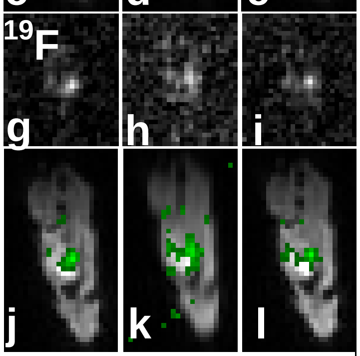


Figure 2: In-vivo motion tracking on 3D ^{1}H data and correction of simultaneously acquired ^{19}F data. Data without 1D shift motion (c,g,j) and with motion (d,h,k). Dividing data (d) into 128 frames of duration 3.7 s allows extraction of translational motion (upper graph). (e,i,l) Motion-corrected ^{1}H signal, ^{19}F signal, and overlay. (a) Single ^{1}H frame used for registration. Dividing data (d) into 1024 frames increases temporal resolution to 0.46 s (lower graph). (b) Single frame. (f) Motion corrected image from 1024 frames.

Results and Discussion

Figure 2 shows a slice of 3D $^{19}F/^{1}H$ in-vivo data acquired using the golden means technique. For reference, (c,g,j) show the ^{1}H, ^{19}F, and overlay images of a scan without motion. The respective images under the influence of 1D motion are blurred (d,h,k). Subdivision of the data into 128 frames allows extraction of 1D motion (upper graph) and removal of blurring in the corrected images (e,i,l). Comparison of the ^{19}F signal shows that the ^{1}H-based motion correction is able to transform the motion blurred signal (h) into an almost unblurred signal (i), closely resembling the motion-free image (g). A single frame has duration 3.7 s and shows high SNR (a), principally enabling a higher frame rate and temporal resolution. Therefore, the same scan is divided into 1024 frames, leading to frame duration 0.46 s, associated with more noise in the single frame image (b). Registration then also becomes noisier (lower graph), but the motion corrected image displayed in (f) is comparable to (e) while enabling a higher frame rate.

Figure 3 shows a slice of the hand holding two vials. Motion-free reference data is displayed in (a) and (e), while (b) and (f) show the respective ^{1}H and ^{19}F data with 3D motion. Division of *k*-space data into 70 frames allows extraction of motion from the ^{1}H data with a temporal resolution of 1.0 s. Extracted displacements and rotation angles are shown in the graphs. Application of the motion information to the ^{1}H data (b) and ^{19}F data (f) allows deblurring of the images (c,g) and therefore reconstruction of the true signal intensities, which are important for ^{19}F quantification. Image quality of single ^{1}H and ^{19}F frames are shown in (d,h). Obviously, registration can only be performed on the ^{1}H channel.

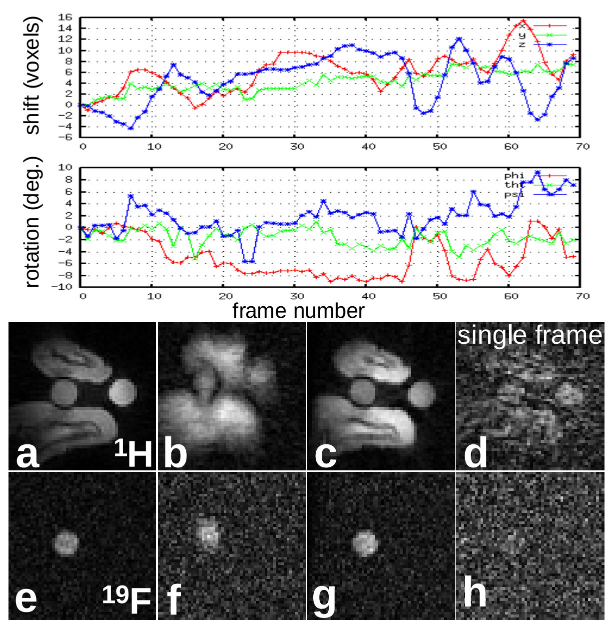


Figure 3: Motion tracking on 3D ^{1}H data and correction of ^{19}F signal. Data without motion (a,e) and with 3D rigid body motion (b,f). Dividing data (a) into 70 frames of duration 1.0 s allows extraction of translational and rotational motion (graphs). (c) Motion corrected ^{1}H image. (g) Corrected ^{19}F image using ^{1}H motion information. (d) Single ^{1}H frame. (h) Single ^{19}F frame.

Conclusion

3D isotropic undersampled radial imaging using golden means interleaving of profiles allows flexible true 3D motion compensation by self-navigation. Frame rates on the order of 0.2-2 Hz are feasible at reasonable resolution. Application to simultaneous $^{19}F/^{1}H$ imaging has been shown, but the achieved frame rates make the approach useful for compensation of breathing motion in abdominal or cardiac imaging as well. In the future, frame rates can possibly be increased by combination with sliding window and more intelligent reconstruction techniques.

References

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