Ultra-High-Resolution Skin Imaging at 7 T with Motion Correction and Fat/Water Separation

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Introduction: High-field systems and dedicated surface coils provide sufficient SNR to image the skin with very small voxel sizes [1-3]. However, motion can significantly degrade the images and limit the effective resolution in vivo [4-6]. Immobilization techniques have been used [1,4], but these squeeze the dermis [6] and limit the areas of the body that can be imaged. Another challenge of skin imaging at high-field strengths comes from frequency offsets due to chemical shift because the hypodermis is a fat layer. An interleaved multi-echo GRE sequence was previously used to achieve good fat/water separation in skin at 3 T [4] and 7 T [2]. In this work, we propose the integration of motion navigators to this sequence and demonstrate its effectiveness at 1.5 T. We then obtain images at 7 T with 100 μm isotropic resolution.

Methods: Pulse sequence: Our gradient-spoiled GRE sequence (Fig. 1) features three interleaved echo times (one per TR) corresponding to phase angles separated by $2\pi/3$ to resolve fat and water. Fractional echo was used to minimize the echo time and image the short-T_2 species of the dermis. Cartesian navigators with good temporal and spatial resolution were then added [7]. The time between the RF pulse and the navigator was fixed for the three echo times. To comply with the gradient duty cycle, the navigators were interleaved (Y-X-Y-Z), and 64 sampling points were used, with the navigator FOV equal to the image FOV.

Reconstruction: The individual images were first corrected for motion using standard processing [4,7]. For better accuracy, the Lucas-Kanade algorithm was used to obtain the shifts [8]. A homodyne-IDEAL method was then implemented to reconstruct a fat image and a water image [9].

Experiments: Experiments were performed on GE Excite 1.5 T and 7 T whole body scanners, with maximum gradient amplitude 40 mT/m and maximum slew rate 150 mT/m/ms. Two dedicated surface coils were used: a 1-inch-diameter receive-only coil at 1.5 T [4], and a 0.5-inch-diameter transmit-receive coil at 7 T (Fig. 2). The calves of healthy volunteers were imaged with the following parameters (1.5/7 T): TR = 28/50 ms, TE = 5/6 ms, flip angle = 20°, BW = ±32 kHz, FOV = 6x3x1.6/4x1.5x0.8 cm^3, matrix size = 512x256x16/400x150x80, scan time = 5:44/30:00 min:s. For each experiment, the subjects were supine and the coil placed beneath the calf.

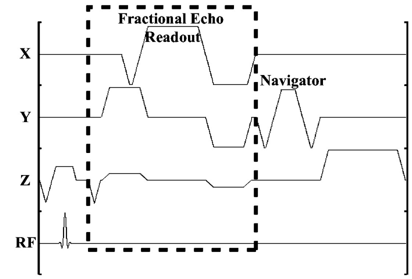

Figure 1: Pulse sequence. The dashed frame slides to obtain three different echo times (one per TR) for fat/water separation. The navigator (here on Y) is alternated among the three axes.

Figure 2: 0.5-inch-diameter transmit-receive surface coil used at 7T.

Results and Discussion: Figure 3 shows fat and water axial images with and without motion correction obtained at 1.5 T. Resolution is 117x117x1000 μm^3 (14 nL). Up to 1.1 mm of motion was detected, and significant blurring is removed upon correction. Figure 4 shows axial, sagittal, and coronal images of the 7 T dataset with isotropic 100 μm (1 nL) resolution. Up to 1.2 mm of motion was detected. The impact of motion correction is readily visible for the epidermis and the septae in the hypodermis. Note that the skin is a highly deformable structure [10] and our experimental set-up may therefore have allowed for non-rigid motion, not corrected here.

Conclusion: We have demonstrated that very high resolution can be achieved at 7 T with fat/water separation and rigid motion correction. 1-nL resolution skin images were presented. Our technique will likely be beneficial for other imaging applications.

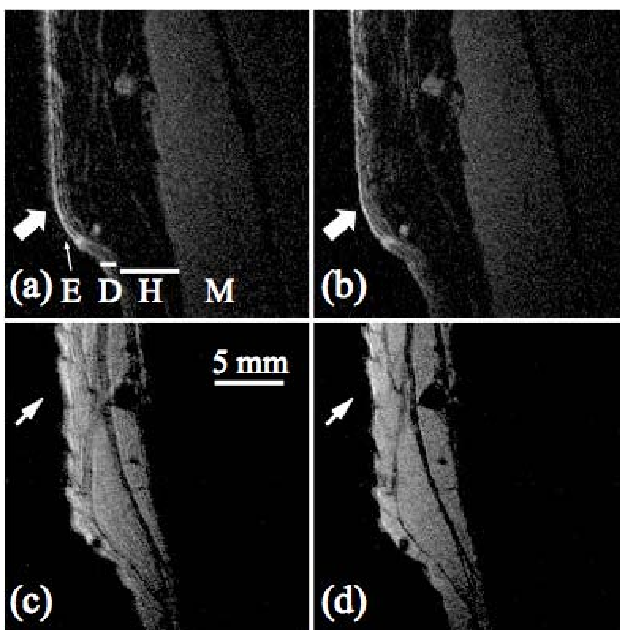

Figure 3: Water (a,b) and fat (c,d) 1.5-T images before (a,c) and after (b,d) motion correction. The different skin layers are easily distinguished. Epidermis (E), dermis (D), and muscle (M) appear in the water image, whereas the hypodermis (H) is mainly a fat layer. Correction removes significant blurring (arrows).

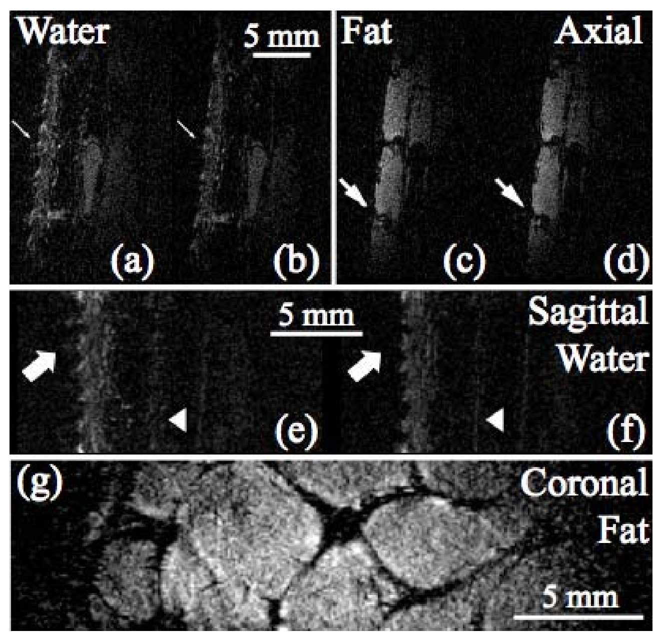

Figure 4: Water (a,b,e,f) and fat (c,d,g) 7-T images before (a,c,e) and after (b,d,f,g) motion correction. 100 μm isotropic resolution was achieved. The impact of motion correction is clearly visible for the epidermis and the septae of the hypodermis (arrows).

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