Bilateral Hip MRI using Dual-Band Excitation with Slab-Phase Modulation

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Introduction: High-resolution MRI of the hip has shown great promise for the assessment of joint and bone diseases such as osteoarthritis and osteoporosis. Because of the relatively large distance between the two hips, only one site is usually imaged at a time. However, bilateral hip imaging would allow more accurate diagnosis of pathology in both hips, and would be also beneficial for dynamic contrast-enhanced MRI for measuring bone marrow perfusion [1]. In this work, we propose a time-efficient sagittal bilateral hip imaging technique using dual-slab excitation [2] incorporating slab-phase modulation [3]. This method was implemented and validated with both a 3D RF-spoiled gradient-echo (SPGR) and a 3D balanced steady-state free precession (bSSFP) sequence.

Method: For bilateral excitation of the two hips, we combined a minimum-phase RF pulse with a maximum-phase RF pulse to excite two slabs, which results in negligible increase of the peak RF amplitude over that of each RF pulse [2]. Each RF pulse was designed using the Shinnar-Le Roux (SLR) algorithm for a time-bandwidth product of 12 and 1.2 ms pulse duration [4], and then frequency-modulated based on the slab locations (Fig. 1a). Tipping of the magnetization occurs at 0.1 ms by the maximum-phase pulse and at 1.1 ms by the minimum-phase pulse after starting the pulse, which would yield an echo time difference of 1 ms between the two slabs. To avoid encoding of the empty space between the two slabs, a different linear phase with k_z number was added to each pulse for each sequence repetition [3] before combining the two pulses. The refocusing gradient area was set to half of the slab-select gradient area, resulting in four cycles of phase twist within each slab (Fig. 1b). This phase only causes signal loss of 1.5% when there are 48 sections within one slab.

The composite RF pulse was incorporated to both standard SPGR and bSSFP sequences. Three volunteers were scanned with the two imaging sequences on a GE 3T Excite scanner (GE Healthcare, Waukasha, WI) using an eight-channel phased-array cardiac coil. Scan parameters used were 24 x 24 cm^2 FOV (in-plane), 256 x 256 imaging matrix size, 48 sections for each slab (total 96 sections), and 2.2 mm section thickness, 20° flip angle, ±31.25 kHz bandwidth, TR of 16 ms (SPGR) or 11 ms (bSSFP), and an average TE of 3.8 ms. To reduce banding artifacts in bSSFP, two phase-cycled acquisitions were performed and combined using maximum intensity projection [5]. The scan times for both imaging sequences were 6.5 mins and 8.9 mins.

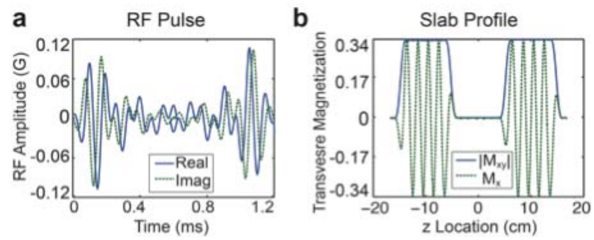

Fig. 1. (a) 20° RF pulse that excites two slabs at ±10 cm by combining a minimum-phase pulse and a maximum-phase pulse after frequency modulation. (b) shows the slab profile after refocusing slab-select gradient.

Results: Figure 2 shows one representative in-vivo exam**.** The two prescribed slabs are denoted in (a) with the pulses used to excite them. Bilateral hip images from SPGR and two-acquisition bSSFP are shown in (b-d) and (e-g), respectively. From both SPGR and bSSFP sequences, the two hips are imaged equally well, delineating the femoral head cartilage. With bSSFP, fluid signal is enhanced due to T_2/T_1 contrast (solid pink arrows). By combining two bSSFP acquisitions, severe banding artifacts are not observed even though there are minor ripples across the two slabs. When comparing the right and left slabs, the appearance of chemical shift artifacts at the interface of water and fat differs (dashed orange arrows in (c-d)) due to different phase shifts between the two species, caused by the actual TE difference.

Discussion: Dual-slab excitation from the composite RF pulse combined with slab-phase modulation allows efficient, simultaneous imaging of both hips. This bilateral imaging technique can reduce scan time by 30-35% compared with one single-slab bilateral imaging, and provide increased SNR compared with sequential unilateral hip imaging. We demonstrate its application to SPGR and bSSFP imaging, where SPGR is considered the standard for morphologic imaging of cartilage [6] and bSSFP is also a highly promising sequence for imaging cartilage as well as bone structure [7]. The residual banding artifacts from bSSFP shown in our images can be further removed by reducing the TR or increasing the flip angle. The echo time difference between the two slabs can yield different amount of T_2* decay and different appearance of chemical shift artifacts over the two slabs; however, these effects would be reduced when fat suppression is incorporated.

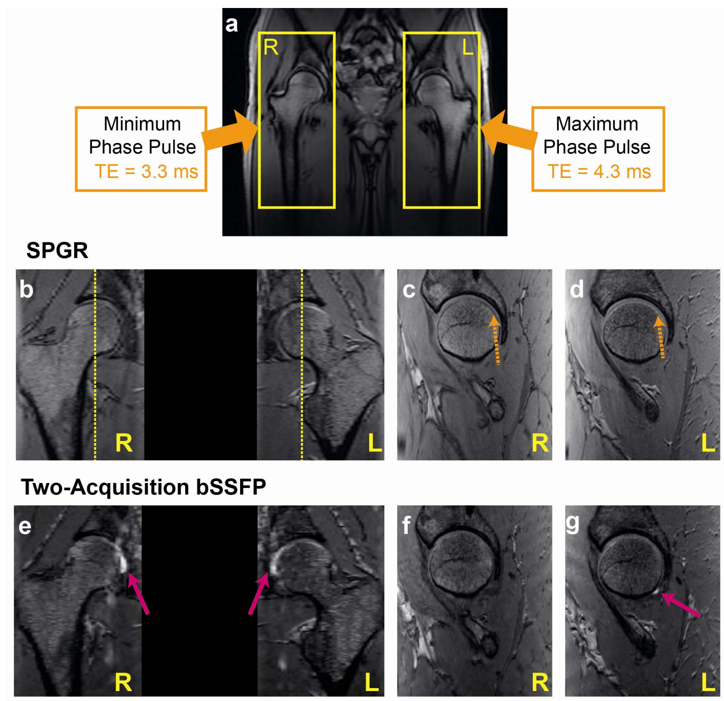

Fig. 2. Representative bilateral hip imaging. (a) denotes the two prescribed slabs. (b-g) show a coronally reformatted slice and two sagittal slices (locations denoted in b) by SPGR (b-d) and two-acquisition bSSFP (e-g). For both sequences, the two hips are imaged equally well. The dashed orange arrow in (d) depicts chemical shift displacement artifacts in the form of a bright border at the interface of the cartilage and the femur. These are not seen in (c) due to a bigger phase difference between water and fat.

References
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