High Resolution Bilateral Hip Joint Imaging at 7 Tesla using Fast Multi-ROI B1 Shim methods

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INTRODUCTION. Recent advances in orthopedic surgery allow for successful treatment of subtle developmental hip joint abnormalities. Femoroacetabular impingement (FAI) typically causes labral tears and chondral lesions which, untreated, can lead to significant osteoarthritic changes [1]. The most important predictor for treatment success of FAI and labral tears is the integrity of the chondral articular surface. Assessing the latter with MR images requires both high resolution and high contrast/noise. Since these abnormalities frequently occur bilaterally, both hips must be imaged, yet an additional challenge requiring either a larger FOV or two single hip acquisitions. Clinical studies at 1.5 and 3 T typically consist in imaging a single hip, and make often use of intraarticular Gadolinium injections for contrast enhancement [2, 3].

In this preliminary study, we demonstrate that high resolution, high contrast/noise images of hip joints can be obtained at 7 T without contrast enhancement, both hips being imaged simultaneously despite of transmit B1 distortion at very high field. Key components for this success include the use of a transceiver RF coil array together with fast, low SAR B1+ shim methods, which could become standard components in 7T imaging protocols.

MATERIALS AND METHODS. Five healthy asymptomatic volunteers were scanned at 7 T (Magnex, Oxford, UK) with a Siemens console (Erlangen, Germany). A 16-Channel (Ch) Transceiver strip-line array [4] was used with 16 x 1kW CPC RF Amps (Brentwood, NY). Each Transmit (Tx) RF phase was set with a 16-Ch CPC control unit. **B1+ calibration**. 16 Estimated complex Transmit B1+ maps ($B1_k+$) were obtained using a fast, low SAR method [5] based on calibration data that consist of a series of 16 small flip angle GRE images, pulsing RF on a single Tx Ch (k) at a time (k:1→16). This acquisition (2min total time) was obtained in 3 axial slices crossing both femur heads. For each session the starting set of $B_{1,k}^+$ phases was geometrically predefined (+22.5⊕ per channel). The spatial targets for B1+ shim (i.e. ROI's used for B1+ optimization) were manually designed as 6 disk-like ROI's (left and right hips on each slice) encompassing (and expending ~1 cm beyond) the whole femoral head sections. The center part of these 6 ROI's was then excluded when it contained only inner bone tissues. **B1+ shim algorithm**. Non linear optimization (Matlab, Mathworks, Natick, MA) was used to either minimize a Inhomogeneous Coefficient (IC) or maximize an average RF efficiency (RFeff) through the 6 ROI's treated as a single target in matlab, with IC=std($|B_{1All}^+|$)/mean($|B_{1All}^+|$) and RFeff=$|B_{1All}^+|/\Sigma\ |B_{1,k}^+|$ [6, 7]. Here, the resulting B_1^+ field (B_{1All}^+) corresponds to the sum of the 16 complex $B_{1,k}^+$ maps: $B_{1All}^+ = \Sigma_k B_{1,k}^+$. **Hip Joint Imaging.** B1 shim success in the hips was evaluated on Turbo Spin Echo (TSE) images obtained before/after B1 shim at medium resolution (Fig. 1). To demonstrate High Resolution PD-TSE hip joint images, we then collected 7 coronal oblique slices with in-plane resolution of 0.5x0.5mm^2 (before interpolation) with 2mm thickness and a gap of 1mm (Fig.2) (TE=34ms, TR=3000ms, 2 averages, FOV=32cm).

RESULTS AND DISCUSSION. **B1 shim:** Very strong improvements were consistently obtained when using B1+ shim, making it possible to image both hips simultaneously, as shown in Fig.1. Weak B1+ was often observed in the right hip with the geometric B1+ phase settings. Furthermore, we observed substantial variations of $B_{1,k}^+$ phase through different subjects, making it necessary to adjust B1 phases on an individual basis. Such $B_{1,k}^+$ phase variations through subjects has also been reported for B1 shim in the prostate at 7 T [7]. As can be seen in Fig.1, dark areas almost devoid of signal in the right hip became clearly visible after B1 shim. Furthermore, B1+ homogeneity substantially improved through both hips, although a precise quantification would require to directly measure |B1+| in the large flip angle regime in order to correct images for receive B1 bias. An intrinsic limitation of increasing B_1^+ homogeneity in a large volume is that such solutions can reduce average RF efficiency, yielding in turn larger RF power for a given flip angle. On the other hand, maximizing RFeff typically reduces RF power for a given flip angle but to the cost of less homogeneous B1+. In several cases, including the one shown in Figs. 1 and 2, B1+ homogeneity was still satisfactory after maximizing RFeff, resulting in lower RF power than when strictly minimizing IC. Importantly, high consistency between predicted results and experimental verification was always obtained. **Hip Imaging.** The TSE images shown in Fig.2 depict the femoral head within the acetabulum, with the labrocartilaginous junction also well depicted. Note that typical resolution used in hip joint imaging at 3T in our institution is about 0.8x0.6x3.5mm^3 for a single hip and about 1.2x0.7x4mm^3 for bilateral hip imaging. A qualitative comparison between these 7T images and typical 3T images strongly suggests that the high contrast/noise obtained at a higher spatial resolution (0.5 x 0.5 x 2mm) with non contrast enhanced hip joint MRI at 7T may allow for diagnostic evaluation of the cartilage covering the femoral head as well as the acetabulum (See Fig. 2 caption for more details). Further investigation will help to determine whether symptomatic patients would benefit from hip screening at 7T for femoroacetabular impingement (FAI) and other pathologies.

FIGURE 1

FIGURE 2   *Right Hip*   *Left hip*
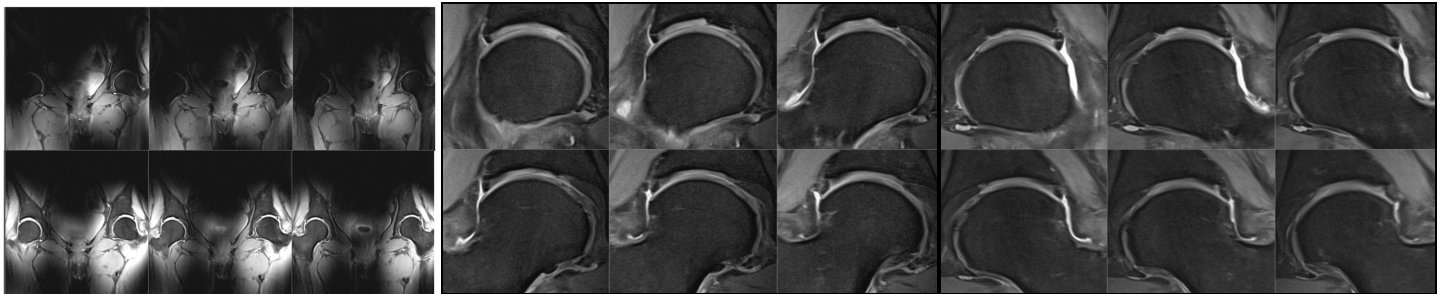
Fig. 1: Coronal TSE images before (upper row) and after (lower row) B1 shim, obtained with same RF power and shown with same grayscale window. Note the correction of multiple dark areas with B1 shim and the much improved signal homogeneity. **Fig. 2**: High resolution TSE images (6 out of 7 oblique coronal views) of normal femoral heads within the acetabulum. Left and right hips were imaged simultaneously. The cartilage (light gray) covering the femoral head as well as the acetabulum can be accurately delineated. The superolateral labrum and the labrocartilaginous junction are well seen, a normal amount of joint fluid is present. Voxel size in these fat saturated, bilateral hip images was 0.5x0.5x2mm^3, TR=3000ms, TE=34ms, 2avg

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