Imaging of the Spine with Metal Implants Using High-Bandwidth RF Pulses from a Local Tx/Rx Coil

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Introduction

Spinal fusion is among the ten mostly conducted surgeries in the USA[1] and often remains symptomatic, i.e. it requires follow-ups. MRI suffers from distortion due to differences in susceptibility between metal and the surrounding tissue. While in-plane distortions can be efficiently suppressed by a high readout bandwidth and VAT[2], through-plane distortions of the excited slice profile are more difficult to address, since the applicable radiofrequency (RF) bandwidth is limited and other approaches, such as SEMAC[3], are very time-consuming. A recent publication has shown that the use of high-bandwidth (HiBW) RF pulses can reduce distortion by exploiting the high B1 of a local transmit knee coil[4]. For screws and plates of titanium, which feature little distortion compared to full joint replacements of alloys like CoCr, this approach makes time-consuming advanced methods, which correct distortion through-plane, redundant. This work analyzes the effect of HiBW RF pulses on a titanium structure applied by a local Tx/Rx spine coil, a planar structure with a loop-butterfly antenna combination[5].

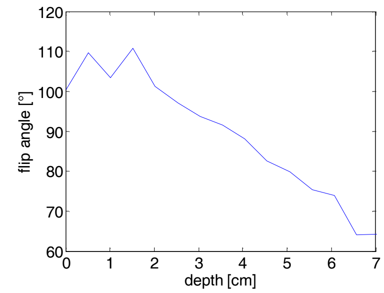

Fig. 1: Flip angle variation along the axis perpendicular to the planar coil.

Methods

Differences in magnetic susceptibility due to metal result in distorted spatial encoding. The geometric distortion of the excited slice profile $\Delta z = dz \cdot \Delta f / f_{BW}$ scales linearly with the slice thickness dz and the off-resonance Δf, while an increased bandwidth f_{BW} of the RF pulses decreases distortion. This work aims to minimize distortion through-plane. While thinner slices can increase acquisition time, since more slices are required to cover the anatomy, the downside of HiBW RF pulses is the specific absorption rate (SAR) and hardware limitations. In contrast to the body coil, local Tx coils potentially enable higher B1, which can be used for HiBW RF pulses. In this work, a clinical 3T whole-body scanner was used in combination with the prototype of a local Tx/Rx spine coil, featuring an optimized surface coil design for spine imaging[5]. Turbo spin echo (TSE) sequences in two RF modes were compared: The first RF mode (conventional) meets the specifications of the body coil and employs numerically optimized pulses with a bandwidth of 850Hz. The second RF mode (HiBW) employs SINC pulses with an RF bandwidth of 3.3kHz and can be applied by the local transmit coil only. Phantom experiments: A titanium bar (Ø 1cm, 10cm long) with 3 notches of 0.5cm, 1cm and 1.5cm was placed on plastic bricks in a bin filled with doped water. The distance of the metal to the bottom of the bin was 2.9cm, and the long axis of the rod was collinear with the x-axis of the scanner. A B1 map[6] was used to calibrate a flip angle of 90° in the region of interest. T2-weighted TSE images (TE/TR = 76/2000) were acquired with an in-plane resolution of 0.5x0.5mm² and with a slice thickness of 3mm; both RF modes were applied separately by using the prototype Tx/Rx spine coil. In-vivo comparison: The TSE sequence in both RF modes was repeated in a volunteer. For the HiBW mode, the previous coil setup was used, while the conventional mode was applied by the body coil (transmit) and a standard spine coil (receive). The following sequence parameters were modified compared to phantom experiments: TE/TR = 76/4500, dz = 4mm.

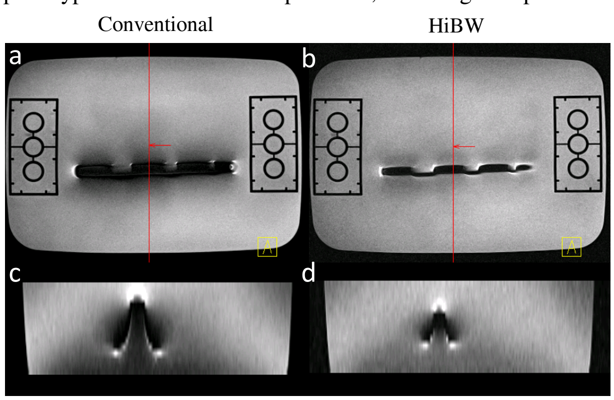

Fig. 2: Phantom experiments: coronal TSE images in (a) conventional, (b) HiBW mode; red lines indicate the position of axial reformats (c,d).

Results

The mean flip angle declines with increasing distance to the coil (fig. 1) and it is 94° at the location of the titanium rod. Figs. 2a and b visualize the coronal slice of the phantom at the central position of the metal in conventional and HiBW mode, while the corresponding axial reformats are shown in c and d. In conventional mode, the extension of the V-shaped through-plane distortion is 2.91cm, while in HiBW mode, it is 1.65cm. This results in significant signal drop-out in the conventional coronal image, while slight signal pile-ups are visible in HiBW mode. In-vivo images (fig. 3) demonstrate the imaging capability of the local Tx/Rx coil and the effects of its different receive and excitation field characteristics, which manifest in a distinct variation of SNR and contrast over a large field of view as compared to the body coil.

Fig. 3: In-vivo comparison: (a) HiBW mode applied by the Tx/Rx spine coil, (b) conventional mode applied by the transmit body coil and local spine receive coil.

Discussion and Conclusion

This work analyzes the reduction of through-plane distortion by the use of a local Tx/Rx spine coil. Experiments were carried out on a 3T system, where metal artifacts are particularly challenging. The imaging performance was restricted by very conservative SAR assumptions; future investigations are needed to improve this limitation. In vivo, the adjustment of B1 in a specific depth of the spine results in varying contrast due to the declining flip angle in anterior direction, and a non-optimized receive coil setup decreases the signal-to-noise ratio. However, presented experiments prove that the increased transmit bandwidth significantly reduces the extent of metal artifacts, which may improve the diagnostic image quality or reduce the scan time by avoiding time-consuming artifact compensation.

References [1]Elixhauser et al, Archives of Surgery 2010;145.12:1201-1208; [2]Cho et al, Med Phys 1988;15:7–11; [3]Lu et al, MRM 2009;62:66-76; [4]Bachschmidt et al, JMRI 2014;doi: 10.1002/jmri.24729; [5]Schoepfer et al, ISMRM 2014;p.1313; [6]Chung et al, MRM 2010;64:439–446.