

MR Imaging near orthopedic implants with artifact reduction using view-angle tilting and off-resonance suppression

C. Bos¹, C. J. den Harder², and G. van Yperen²

¹MR Clinical Science, Philips Healthcare, Best, Netherlands, ²MR CTO, Philips Healthcare, Best, Netherlands

Introduction

Metal orthopaedic implants are known to cause substantial artifacts in MR imaging of joints. The B₀-field inhomogeneity caused by the implant leads to slice distortions, displacements of signal in the readout direction and signal dephasing in gradient echo imaging. Slice distortions, or “potato-chipping”, include thickness variations that translate to signal intensity variations. Moreover, even disjunct regions of signal may arise that lead to particularly conspicuous bright edges in the image, due to the sudden thickness changes of the selected slice [1]. Usually, these regions are associated with high field offsets. Field offsets associated with metal implants can range from a few kHz (titanium) to well over 10 kHz (stainless steel).

View Angle Tilting (VAT), i.e. application of the slice select gradient during readout, has been proposed to counteract the displacements in readout direction [2]. Kolind et al. integrated VAT with maximum readout bandwidth that also serves to limit VAT blurring to yield a Metal Artifact Reduction Sequence [3]. Here, combining off-resonance suppression (ORS) with the VAT technique is proposed to limit interference of regions at high field offsets with otherwise usable areas of the image.

Theory

View angle tilting: In VAT imaging, a gradient G_{VAT} in slice direction is applied during readout, leading to a total displacement in readout direction of $\Delta x = \Delta B_0(\mathbf{r}) / G_{READ} + \Delta z G_{VAT} / G_{READ}$. Here, Δz is the offset in slice direction, $\Delta B_0(\mathbf{r})$ the field deviation at position $\mathbf{r} = (x, y, z)$, and G_{READ} the readout gradient. In the center of the excitation band correct positioning of the spins is obtained when G_{VAT} is equal to the excitation gradient G_{EX} [2]. The ratio G_{VAT} / G_{READ} defines the view angle β through $\beta = \tan^{-1}(G_{VAT} / G_{READ})$. So far, in VAT imaging G_{EX} has always been chosen equal to G_{REF} , the refocusing selection gradient [2,3].

Off-resonance suppression: For (T)SE imaging, however, intentionally choosing different values for G_{EX} and G_{REF} , can be used to limit the field off-sets that are refocused and thus contribute to the signal, Fig. 1. The signal tapers off as $|\Delta B_0|$ becomes larger, until a cutoff is reached when $\Delta z_{EX} - \Delta z_{REF} = STK$, the intended slice thickness. If we assume that STK is equal for excitation and refocusing:

$$\Delta B_{0,cutoff} = STK \left(\frac{1}{G_{EX}} - \frac{1}{G_{REF}} \right)^{-1} \quad (1)$$

with corresponding frequency cutoff $\Delta f_{0,cutoff} = \gamma \Delta B_{0,cutoff}$. A thicker slice for either one, will lead to a flat portion in the response for small frequency offsets. Note that this cutoff also limits the distance from the intended slice from which displaced signals may originate.

Methods

In vitro experiments were performed on a titanium and a stainless steel hip replacement sample. View-angle tilting with off-resonance suppression was implemented on a 1.5T clinical scanner, and was used to acquire datasets of eighteen slices of 2-mm slice thickness, 0.5 × 0.9 mm in plane resolution. Readout bandwidth was 500Hz/pixel. Imaging time was 5:10 min. Image sets were acquired without VAT and with VAT at a view angle of 28°. Off-resonance suppression was disabled, or enabled with $\Delta f_{0,cutoff} = 4.4\text{kHz}$, 1.2kHz, for weak and strong ORS, respectively. Finally, an otherwise healthy volunteer with stainless steel hip fixation screws was imaged. Here, an in plane resolution of 0.7 × 1.0 mm was used.

Results

Images acquired without VAT show in plane geometrical distortion, that is improved when VAT is enabled, Figure 2. ORS at 4.4kHz clearly reduces bright signals that are introduced by applying standard VAT imaging. With the titanium implant these can be completely suppressed using ORS at 1.2kHz, fig 2d; this bandwidth is too narrow for the stainless steel implant and causes large regions without signal, fig 2h. In the volunteer, VAT reduced geometrical distortion and bright signal overlaying the cartilage edge, fig. 3. Applying VAT with ORS further helped to suppress unwanted bright streaks in the femoral head.

Discussion

These results show that the combination of VAT and ORS can be used to reduce susceptibility artifacts of metal implants commonly used clinically at high resolution with out time penalty. Potential blurring introduced by VAT was minimized by using thin 2-mm slices and high readout bandwidth [3,4]. The ORS cutoff frequency in relation to the implant material needs to be selected, but for the materials used here 4 kHz proved effective. Recently, SEMAC and MAVRIC have been introduced as techniques that are highly effective at suppressing metal artifact.

However, imaging times are long and reported well over 10 minutes [5,6]. In addition, spatial resolution has been limited to 1×2×3 mm, so far for both methods. In conclusion, ORS is a practical modification to standard VAT to further reduce the extent of metal artifacts, and is applicable to implants that cause moderate field disturbances comparable to that of titanium in the hip.

References

- 1) C.J.G. Bakker et al., Magn Reson Imag, 11:539 (1993)
- 2) Z.H. Cho et al., Med Phys, 15:7 (1988)
- 3) S.H. Kolind et al., J. Magn Reson Imag, 20:487 (2004)
- 4) K. Butts et al., Magn Reson Med, 53:418 (2005)
- 5) W. Lu et al., Magn Reson Med, 62:66 (2009)
- 6) K.M. Koch et al., Magn Reson Med, 61:381 (2009)

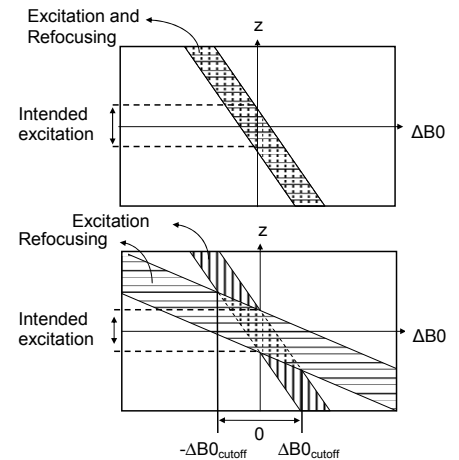


Figure 1: When excitation and refocusing gradients are equal, regions that are excited (vertical lines) and refocused (horizontal lines) completely overlap, irrespective of ΔB_0 (top). If gradient strengths differ, the signal response is limited to a range of ΔB_0 . (Bottom)

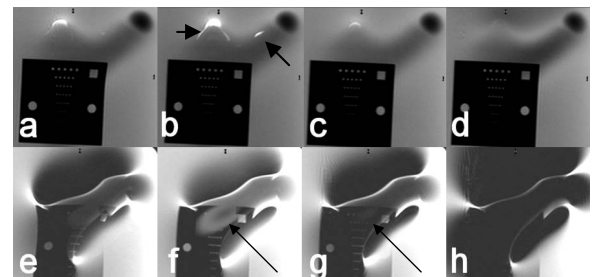


Figure 2: Images of titanium (top row) and stainless (bottom row) steel hip implants. VAT off (a,e), VAT without ORS (b,f), VAT with weak ORS (c,g) VAT with strong ORS (d,h). ORS removes excessive bright signal (thick arrows). ORS reveals structures underlying off-resonance signals (thin arrows).

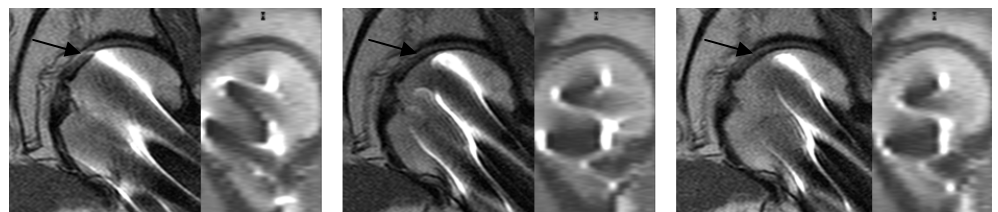


Figure 3: Details of coronal image of hip with fixation screws, with sagittal reformats. VAT off (left), VAT enabled (middle) and VAT with ORS (right). VAT with ORS results in a clearer cartilage edge (arrows).