Magnetic resonance (MR) imaging around metal implants has been a long standing challenge. Field inhomogeneities near implants with high susceptibility $\chi$ (see Table 1) interfere with slice selection and frequency encoding and cause severe image degradation. MR imaging near metal implants is compromised by distortions due to both the $B_1$ and $B_0$ magnetic fields, which alter signal intensity and spatial encoding mechanisms. Using conventional imaging sequences, $B_0$ artifacts dominate $B_1$ artifacts at both 1.5T and 3.0T. Here, the basic physics driving $B_0$ artifacts is presented. Methods and techniques for reducing these artifacts are then introduced.

The artifacts encountered near metal implants using clinical spin echo based MRI sequences can be grouped into two categories:

1) **Signal voids due to:**
   a) Spins that are not excited due to transmit bandwidth (tBW) limitations of the RF excitation pulse. For example, spins close to the implant may have resonance frequencies outside the tBW. They are often not excited and hence do not contribute to the image, resulting in signal void near the implant.
   b) Intra-voxel dephasing during phase evolution due to the large gradients of field inhomogeneities. This results in $T2^*$ decay during data acquisition.

2) **Image distortions:**
   a) In-plane: Image displacements are determined by the proportion of the off-resonance frequencies contained within the imaging FOV relative to the read bandwidth (rBW). As reported by Koch et al. [1], field inhomogeneities can exceed $\pm 10$ kHz near metal implants at 1.5T (or more at 3T). Using a $\pm 125$ kHz rBW with a 256 image matrix,
results in approximately 1 kHz/pixel frequency encoding, so that a ±10kHz field inhomogeneity can result in ±10 pixel displacement of signal. These pixel displacements can cause signal voids when the signals are displaced away from the real positions, or signal pileup when signals get superimposed.

b) Through-plane: The susceptibility gradients also interfere with the slice-selection gradients. Therefore, a spin volume that is no longer a rectangular slice (or slab) is excited. This may severely compromise information contained in each individual image.

The combined effects of 1) and 2) are highlighted in Figure 1, which shows a clinical 2D FSE image of a knee containing multiple stainless steel screws. Near the screws, there are severe voids (signal loss) and pileups (high signal).

<table>
<thead>
<tr>
<th>Material</th>
<th>$\sim \chi$ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tissue/Bone</td>
<td>-10</td>
</tr>
<tr>
<td>Air</td>
<td>0.3</td>
</tr>
<tr>
<td>Tantalum</td>
<td>178</td>
</tr>
<tr>
<td>Titanium</td>
<td>182</td>
</tr>
<tr>
<td>Cobalt-Chromium$^1$</td>
<td>900</td>
</tr>
<tr>
<td>Cobalt-Chromium-Molybdenum$^2$</td>
<td>1300</td>
</tr>
<tr>
<td>Stainless Steel (MR Safe)</td>
<td>3000-5000</td>
</tr>
</tbody>
</table>

Figure 1: Clinical 2D FSE image of a knee fitted with multiple stainless steel screws.

**Remedies:**

Several techniques have been developed to mitigate or correct these problems and these will be described in the seminar. The methods include single point imaging [2], pre-polarized MRI [3], and view angle tilting (VAT) which usually utilizes two-dimensional (2D) fast spin echo (FSE)
sequences [4,5]. VAT can be combined with additional slice phase encoding to resolve the distortions in the slice selection direction in a technique called: slice encoding for metal artifact correction (SEMAC) [6,7]. Another technique called multi acquisition variable resonance image combination (MAVRIC) [1,7] acquires several three-dimensional (3D) FSE images at different off-resonance frequencies. These spectral images are combined to generate the final image.

Finally, ultra-short TE (UTE) sequences [8,9] have the ability to operate at TEs close to zero. UTE hence minimizes the time between excitation and readout and therefore reduces the accumulation of spin de-phasing. When such UTE images are obtained at different off-resonance frequencies and combined as in MAVRIC, they also have the potential to further reduce signal voids and distortions near metal implants.

References:


