syngo WARP – Metal Artifact Reduction Techniques in Magnetic Resonance Imaging

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The term WARP summarizes methods to minimize the impact of metal implants on image quality.

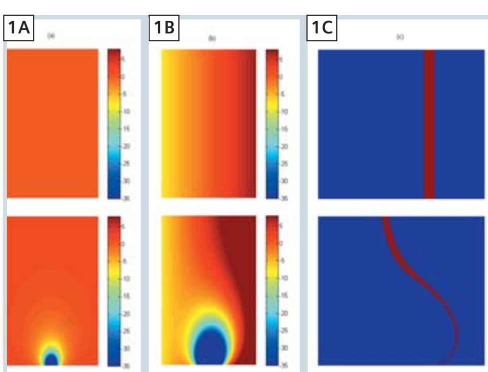
Challenges

Metals have highly different susceptibility constants compared to tissue. When metallic implants are present in the MRI examination, the static magnetic field in their vicinity is manipulated by strong local off-resonances induced by the implants. The degree of field distortions depends on the shape, the location and the material properties of the metal implant.

Distortions of the static magnetic field result in:

- Intra-voxel dephasing: Signal voids are visible as black areas in the image.
- Changes in tissue contrast: Failure of fat suppression and saturation bands.
- In-plane distortion: The local field offset leads to a shift of image pixels in the readout encoding (i.e. frequency encoding) direction.
- Through-plane distortion: The local field offset leads to curved and frayed slices instead of the expected flat image plane (Fig. 1).

Since both in-plane and through-plane distortions shift image pixels away from their real positions, image geometry appears to be distorted. In both cases, regions with severe field changes will lead to signal voids visible as black spots and signal pileups visible as bright spots. However, it makes sense to distinguish between in- and through-plane artifacts, since different techniques are needed to reduce these types of artifacts.



1 The upper row visualizes the ideal case of slice selection, while the lower row displays the effects on the slice selection by a distorted background field: **(1A)** B_0 field map in slice select direction, **(1B)** B_0 field map in direction of slice encoding with superimposed magnetic gradient field for excitation, and **(1C)** position of the excited slice.

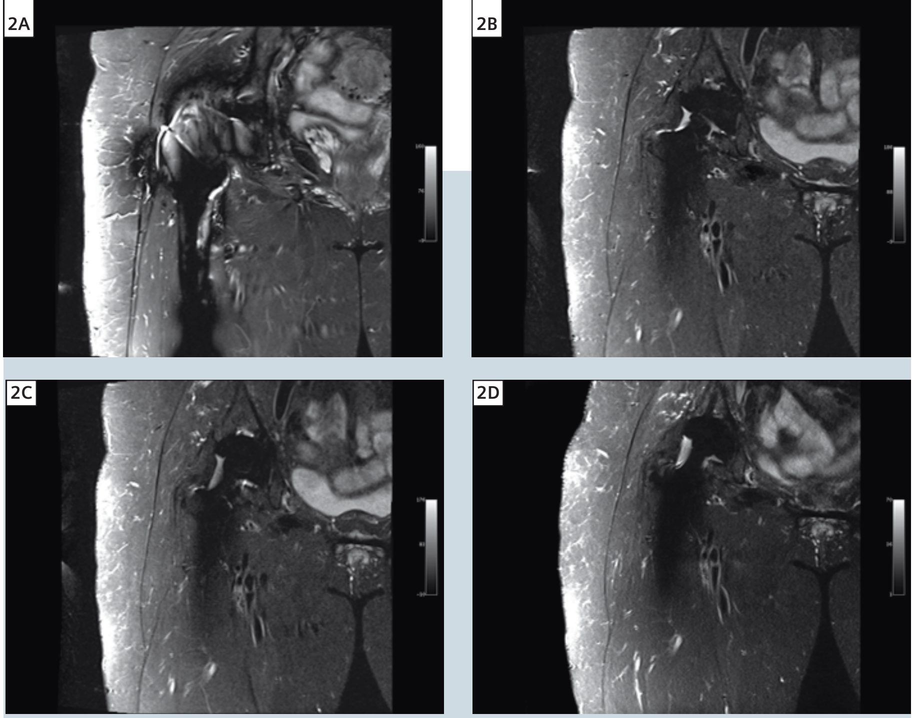
Approaches to avoid metal artifacts

Imaging in the presence of metal implants is mostly based on (turbo) spin echo sequences due to its high immunity with regard to signal dephasing induced by local off-resonances.
In the following, three approaches to reduce metal artifacts are presented, that have shown promising results in clinical settings. Figure 2 depicts their effects *in-vivo* compared to imaging with standard protocols. Although other techniques exist, they are often constrained by excessive scan times or special hardware requirements.

High bandwidth sequence parameters

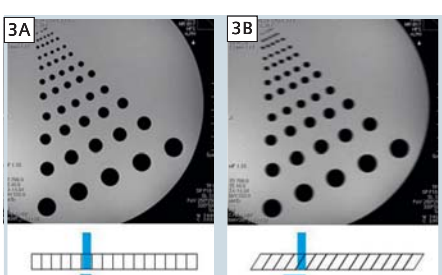
Basic acquisition parameters are adjusted to what is called high bandwidth (BW) parameters to make the MR sequence less sensitive to field distortions.
What is done:
The bandwidth of both the excitation pulse and the signal readout is increased.
What it effects:
A high bandwidth sequences reduces the through-plane distortion of the slice profile. This implies less severe variations of the apparent slice thickness, i.e. the amount of signal voids and pileups is reduced compared to standard protocols with a low bandwidth.
A high signal readout bandwidth

Implant imaging at 3T:
There is a significant difference between MR imaging at 3T and 1.5T. In contrast to common clinical imaging, higher field strength does not necessarily imply better image quality for patients with metal implants. Apart from increased safety concerns, the level of image distortions scales with the strength of the static field, i.e. the level of artifacts is higher at 3T than at 1.5T. Additionally, the efficiency of artifact reduction techniques is reduced by the increased SAR constrains at 3T.



2 Image comparison: **(2A)** standard protocol, **(2B)** high BW, **(2C)** VAT* and **(2D)** SEMAC**.

addresses in-plane distortions: Intra-voxel signal dephasing and geometrical shift in the readout encoding direction are reduced. Consequently, the image has less signal voids and less pileup artifacts related to in-plane distortions.
The main drawback of high bandwidth protocols is reduced signal-to-noise ratio (SNR) and increased specific absorption rate (SAR). High bandwidth sequences are very demanding in terms of scanner hardware, mainly gradient and RF power performance. Ultimately, the RF power applied by high bandwidth RF pulses is limited by the patient (SAR). Hence, the RF pulse bandwidth is more affected by these restrictions and in-plane artifact reduction is more efficient.



3 VAT* blurring caused by the shearing of the slice: **(3A)** Image without VAT: the signal of a vertical structure (vertical blue line) is well localized in a pixel (horizontal blue line); **(3B)** blurred image with VAT: The vertical structure appears smeared over multiple pixels.

VAT* (View Angle Tilting)

VAT is a modified sequence acquisition scheme that is able to compensate for in-plane distortions. It can be easily implemented into a turbo spin echo (TSE) sequence.
What is done:
Simultaneously with the conventional readout gradient, an additional readout gradient is applied along the slice selective direction. Its amplitude equals the one applied during the excitation RF pulse.
What it means:
The additional gradient causes shearing of the imaged pixels, as if the slice were viewed at an angle. From a different point-of-view, the VAT gradient brings back all excited spins within the RF bandwidth and local off-resonances are cancelled exactly. Hence, the pixel shift in readout direction is fully compensated.
What it effects:
In-plane distortions, more precisely those along the readout direction, are corrected. However, VAT may cause blurring of the image caused by two separate effects. One cause is the geometric slice shear, causing edges to be smeared out along the shearing direction (Fig. 3). This effect can be reduced by using thin slices and a high resolution. The second source of blurring is a low-pass filter superimposed on the signal readout by the additional VAT gradient. This can be reduced by a short readout duration.

SEMAC** (Slice Encoding for Metal Artifact Correction)

SEMAC is based on a 2D TSE sequence. An additional encoding dimension is introduced to enable the correction of through-plane distortions.
What is done:
Each slice is additionally phase-encoded in the third dimension, very similar to a 3D scan. This provides information on how the slice profile is distorted, such that signal shifted perpendicular to the image plane can be corrected by post-processing during image reconstruction.
What it effects:
Gross through-plane artifacts, which usually cannot be handled efficiently by high bandwidth parameters, can be corrected. In particular, imaging of large metal structures like full knee or hip replacements is being studied. This method is very time-consuming. Despite the use of advanced undersampling techniques, such as partial Fourier and parallel imaging, it is challenging to achieve scan times acceptable for routine examinations.

**510(k) pending. Not for sale in the U.S. and in other countries.*

***WIP: Work in progress. SEMAC is currently under development; is not for sale in the U.S. Its future availability cannot be guaranteed.*

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