Norfolk and Norwich University Hospitals
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Metal artefact reduction sequences in MR imaging of orthopaedic implants

An update

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Metal Artefact

Metal artefact.
- Caused by differences in magnetization between human tissues and orthopaedic implants.
- Most human tissues are diamagnetic, whereas many modern orthopaedic prostheses are paramagnetic or ferromagnetic
- The resulting inhomogeneity of the main external magnetic field produces 4 main types of artefact

Geometric distortion.
- Spatial localization in the x,y and z-axes is achieved through the use of gradients.
- It is assumed that these gradients are all linear, and that B_0 is homogeneous, but this is not the case in the presence of a para/ferromagnetic implant within diamagnetic tissues.
- Geometric distortion is warping of an image when inhomogeneities of the magnetic field cause different precessional frequencies of protons than would be expected.
- In the frequency encoding direction, this is known as "in-plane distortion"
- In the slice selection direction, this is known as "through plane distortion" or "potato chip" artefact (fig. 1).
- The phase encoding direction is resistant to metal artefact

Signal void/pile-up.
- Along the distorted gradient, signal from several different voxels may be erroneously attributed to a single pixel which will appear hyper-intense.
- Pixels corresponding to those voxels whose signal has been misattributed elsewhere will appear hypointense, giving signal void.
- There are two other causes of signal void.
  - Firstly, the lack of signal from the prosthesis itself.
  - Secondly, steep field gradients near the prosthesis will cause rapid dephasing of protons, such that any refocusing pulse will not be correctly timed, resulting in signal loss.

Failure of fat suppression.
- Frequency Selective Fat Saturation is highly susceptible to metal artefact because it relies on a homogeneous field strength to apply a narrow bandwidth suppression pulse.

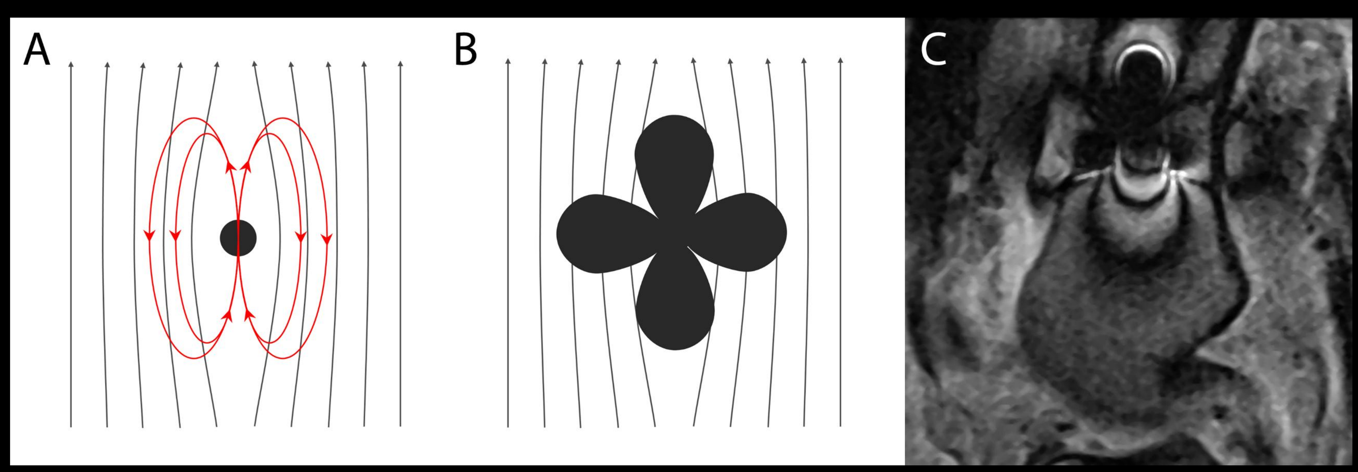


Diagram demonstrating a point or spherical ferromagnetic body placed in a static magnetic field (**A**), which will become highly magnetized, forming a dipole aligned with the outside field. The field lines of this dipole alternately align with and oppose the outside magnetic field, producing a "four-leaf clover" pattern of susceptibility artefact (**B**). In-plane frequency misregistration causes alternating bands of signal loss and signal pile-up (**C**).

Conventional Artefact Reduction

Field Strength:
- Since magnetization is proportional to field strength, greater artefact would be expected at 3T than at 1.5T.
- Using steep gradient fields can compensate for this, to a degree.

Prosthesis material:
- Paramagnetic titanium allows for almost complete artefact reduction
- Newer diamagnetic materials such as zirconium dioxide ceramics do not require metal artefact reduction.

Shape and orientation:
- Artefact can be reduced if the long axis of an implant is orientated parallel to the B_0 field.

Voxel size:
- Decreasing the voxel size (increasing matrix/decreasing slice thickness) can reduce the intravoxel dephasing caused by magnetic susceptibility
- Increasing the receiver bandwidth also increases the strength of the frequency encoding gradient, and therefore reduces susceptibility artefact.

Echo times:
- Short echo times allow for less dephasing, In practice, a TE of 30-40ms can produce intermediate weighted images which have adequate fluid sensitivity.

Fat suppression:
- STIR uses the T1 relaxation time of fat to achieve fat suppression, and is resistant to metal artefact
- 2-point Dixon techniques can compensate for gradual field variations, but still fail close to the prosthesis.

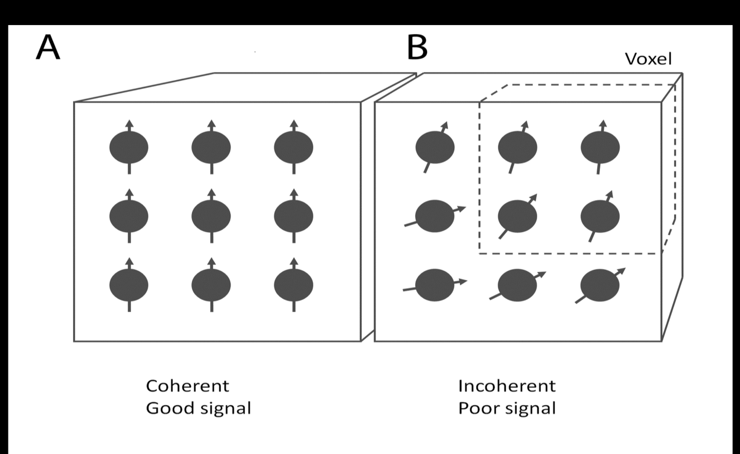
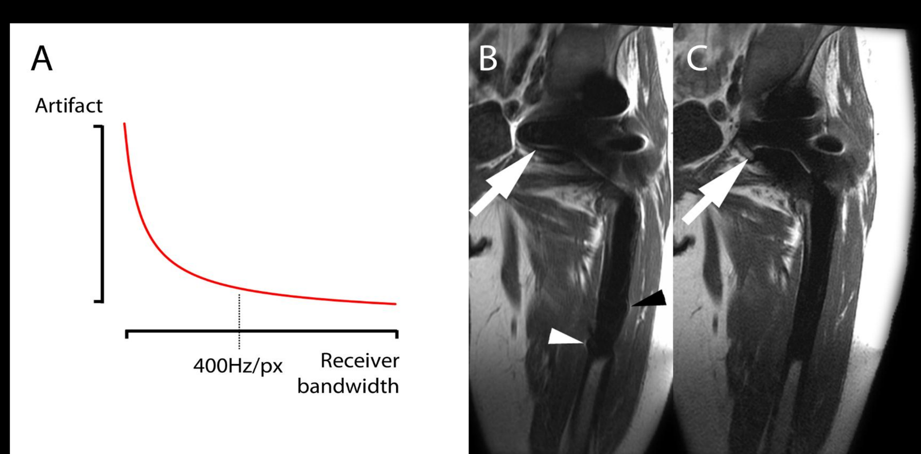


Diagram representing a voxel in which all the protons have the same phase of spin and are considered to be coherent (**A**), which results in good signal. In the presence of metal, a steep susceptibility field gradient will spread the phases across a voxel (**B**). The greater the spread of phases, the less coherence between protons there is and the worse the signal. The spread of phases within a voxel can be reduced by reducing the size of the voxel.



Graph demonstrating how misregistration artefacts can be reduced in the frequency-encoding directions by increasing the receiver bandwidth (**A**), although this effect plateaus at about 400 Hz/pixel on a 1.5 T system. At 256 Hz/pixel (**B**), there is the typical susceptibility artefact around the femoral component of a total hip replacement comprising signal loss, pile-up, and geometric distortion (arrow), which is reduced when the receiver bandwidth is increased to 480 Hz/pixel (**C**) but is accompanied by an increase in noise. The longitudinally oriented femoral stem (arrowheads) produces much less artefact.

Advanced Methods

Field Mapping
- For fairly smooth frequency errors, in-plane geometric distortion can be predicted with field mapping techniques eg. echo shifted images. The frequency errors can then be.
- Field mapping is unable to correct for the steep inhomogeneities that result in signal void or pile-up

View Angle Tilting
- View Angle Tilting (VAT) is better at correcting in-plane distortion than field mapping.
- Re-applying the slice selection gradient G_z during the readout phase compensates for the in-plane misregistration.

Off Resonance Suppression (ORS)
- ORS uses different strengths for RF excitation and refocusing pulses to exclude some misregistration.
- There is increasing signal loss as the frequency offset between pulses increases.
- ORS can be combined with VAT to further improve in-plane distortion.

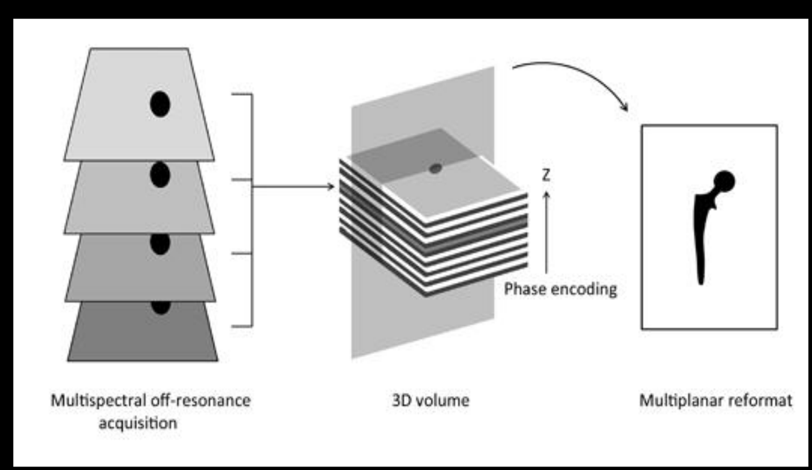
Multiacquisition Variable-Resonance Image Combination (MAVRIC)
- MAVRIC is a multispectral technique that corrects for in-plane and through-plane artefact.
- It uses a spatially non-selective 3D acquisition that is repeated. Each acquisition has variable central RF frequencies during transmission and acquisition. These can be combined to form a final image.
- MAVRIC also uses phase encoding in the z-axis, as it is resistant to susceptibility artefact.
- Limitations include the lack of a phase-wrap option, and there is some blurring of the image.
- Additionally, until recently only PD and T2-weighted images were widely available.

Slice Encoding for Metal Artefact Correction (SEMAC)
- Like MAVRIC, corrects for both in- and through-plane distortions.
- Uses additional phase encoding in the z-axis over set FOVs to correct for through plane distortions.
- A VAT compensation gradient is used to correct in-plane distortions.
- Potentially long scan times, but several acceleration techniques are available.
- Both SEMAC and MAVRIC have similar efficacy.

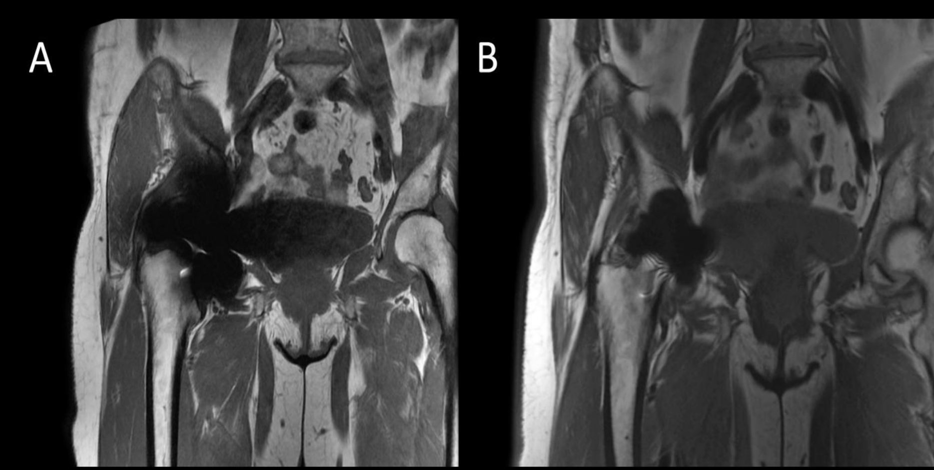
MAVRIC SL
- MAVRIC SL is a hybrid sequence, which combines the z-phase encoding of SEMAC with the spectral selectivity of MAVRIC, to further minimise artefact
- More recently, an automatic prospective interleaved spectral bin distribution has been described allowing T1 and STIR image weighting in MAVRIC and MAVRIC SL.

MAVRIC-UTE
- Ultrashort TE (UTE) imaging has the potential to resolve signal from tissues with very short T2 times, such as cortical bone. The assessment of these can be of clinical significance in the periprosthetic region.
- Combining MAVRIC with UTE allows for the detection of such tissues, as well as further minimisation of metal artefact.

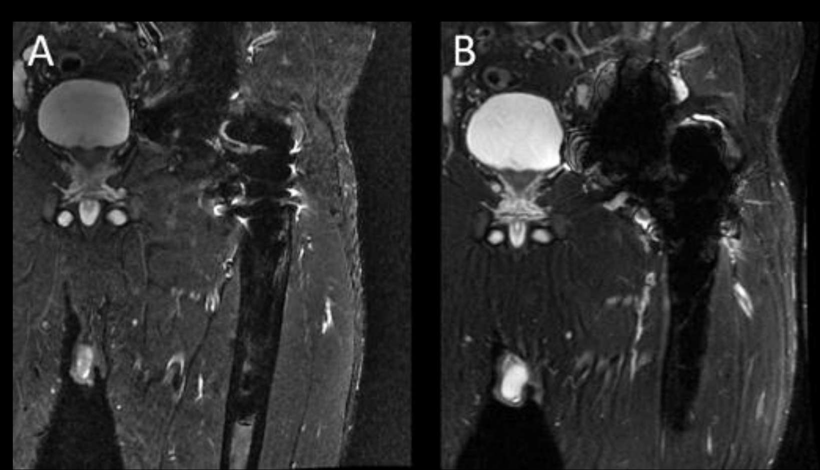
ORS for MSI
- ORS can be combined with MAVRIC and SEMAC sequences, allowing a tuneable trade-off between scan time and proximity to the implant, and reducing through-plane aliasing.
- Downsides include signal voids and loss of homogeneity due to far off-resonance suppression.
- A recent study has demonstrated that these techniques are feasible with reasonable scanning times, more evidence is needed to assess their clinical applicability.



Multispectral imaging techniques acquire data at multiple specific frequencies (spectra) rather than slice selections. These are then converted into a 3D volume using phase encoding instead of frequency encoding from which the final image is reformatted.



Coronal T1W MR image (**A**) of a right resurfacing arthroplasty at 3T with optimized matrix and receiver bandwidth compared to a corresponding coronal PD-weighted image (**B**) using MAVRIC at 3T demonstrating dramatic metal artefact reduction.



There are two options for acquiring useful fat suppressed images. The first is to use STIR imaging **(A)** in which receiver bandwidth and matrix can be optimized to reduce misregistration. Fat suppression is uniform but SNR is low. 2-point Dixon techniques **(B)** produce better SNR and good fat suppression but are more prone to artefact.

Metal artefact continues to be an issue in the imaging of periprosthetic tissues, which has significant clinical importance. Several established techniques to reduce metal artefact are widely available. More recently, 3D techniques such as SEMAC and MAVRIC have been introduced which further reduce artefact. Additional advances are currently being investigated.

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