Artifacts in Abdominopelvic MR
A Pictorial Review

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Goals and Objectives

This exhibit provides radiologists at all training levels a concise review of common MRI artifacts in abdominopelvic imaging.

At the end of this exhibit, the radiologist will be able to:

• describe/recognize common artifacts
• give a brief explanation of the mechanism of each artifact
• understand how to eliminate/minimize each artifact

Knowledge of these artifacts and how to limit their influence on image interpretation will increase understanding and diagnostic quality of abdominopelvic MR imaging and reporting.

Disclosures

Nothing to disclose.
Patient Related Artifacts
Motion Artifacts:

**Respiratory Motion**

**Findings:**
- Copies of the repetitively moving chest wall extend from the image at regular intervals in opposite directions along the phase encoding gradient (aka ghosting).

**Mechanism:**
- Repetitive motion results in evenly spaced deviation from expected signal location.
- Distance between copies is determined by the difference between TR and respiratory rate.
- Results in phase shift of k-space filling.

**Solutions:**
- Shorten echo time.
- Respiratory gating.
- Varied k-space filling (BLADE/PROPELLER).
- Signal averaging/saturation.
- Swap phase and frequency encoding gradients.

**Shorter echo times are used (right side, SSFSE) to eliminate respiratory ghosting (left side, T1).**
Patient Related Artifacts
Motion Artifacts:

**Cardiac Motion**

**Findings:**
- Copies of the repetitively beating heart extend from the image at regular intervals in opposite directions along the phase encoding gradient (aka ghosting).

**Mechanism:**
- Repetitive motion results in evenly spaced deviation from expected signal location.
- Distance between copies is determined by the difference between TR and heart rate.
- Results in phase shift of k-space filling.

**Solutions:**
- Cardiac gating/shorten echo time
- Signal averaging/fat saturation
- Varied k-space filling (BLADE/PROPELLER)
- Swap phase and frequency encoding gradients

*Shorter echo times and fat saturation are used (right side, SSFSE, fat sat) to eliminate cardiac ghosting. (left side, 3D DualEcho).*
Patient Related Artifacts
Motion Artifacts:
**Vascular Pulsation**

**Findings:**
- Copies of the repetitively pulsating vessels extend from the image at regular intervals in opposite directions along the phase encoding gradient; can mimic hepatic lesions.

**Mechanism:**
- Repetitive motion results in evenly spaced deviation from expected signal location.
- Distance between copies is determined by the difference between TR and respiratory rate.
- Results in phase shift of k-space filling.

**Solutions:**
- Cardiac gating/shorten echo time.
- Signal averaging/saturation.
- Varied k-space filling (BLADE/PROPELLER).
- Swap phase and frequency encoding gradients.

*Vascular pulsation mimics a well circumscribed lesion in the left liver lobe (T2* FGRE).*
Patient Related Artifacts
Motion Artifacts: 
**Intestinal Peristalsis**

**Findings:**
- Copies of bowel extend from the image at irregular/imperceptible intervals in opposite directions along the phase encoding gradient (aka smearing).

**Mechanism:**
- Irregular motion results in irregularly spaced deviation from expected signal location.
- Deviation is determined by the difference between TR and irregular rate of peristalsis.
- Causes phase shifts of k-space filling.

**Solutions:**
- Pharmacologic reduction of peristalsis.
- Shorten echo time.
- Varied k-space filling (BLADE/PROPELLER).
- Signal averaging/saturation.
- Swap phase and frequency encoding gradients.

Shorter echo time (right, SSFSE) eliminates intestinal smearing seen on T2 fat saturated images (left).
Patient Related Artifacts

Motion Artifacts:

**Flow-Related** 1,2,3,4,5,6,7

**Findings:**
- Signal loss in a volume of fluid as it moves through the plane of SE/FSE imaging in vessels, bladder, amniotic sac, bowel; can mimic blood products

**Mechanism:**
- Target of an excitation pulse moves out of the plane being imaged prior to sampling (SE/FSE)
- Increased signal can be seen on GRE due to shorter echo times; fluid cannot move out of the plane prior to image acquisition

**Solutions:**
- Sequential imaging
- Pre-excitation pulses
- Saturation banding
- Gradient moment nulling
- Shorter echo time

*Shorter echo time (right, SSFSE) eliminates artifact related to amniotic fluid circulation (left, T2).*
Magnet Related Artifacts
Susceptibility Artifacts:
**Metallic Susceptibility** 1,2,3,4,5,6,7

**Findings:**
- Signal loss extending outward from a substance with significantly increased magnetic susceptibility, like metal (such as arthroplasty hardware); more common at 3T

**Mechanism:**
- Ferromagnetic materials (like some orthopedic hardware) are strongly susceptible to magnetization when placed in the magnetic field
- Results in inhomogeneous magnetic field, rapid decay of RF pulse and signal loss

**Solutions:**
- Lower magnetic field, TE
- Increase bandwidth, echo train length, matrix size
- STIR instead of fat saturation; SE instead of GRE
- Varied k-space filling (BLADE/PROPELLER)

*Inhomogeneity of the magnetic field is greater in T1 FSE fat sat images (left) compared with FSE IR (right).*
Magnet Related Artifacts
Susceptibility Artifacts:

**Air Susceptibility**

**Findings:**
- Signal loss extending outward from a substance with moderately increased magnetic susceptibility, like air; more common at 3T; can present with incomplete fat sat

**Mechanism:**
- Paramagnetic molecular oxygen in air is susceptible to magnetization when placed in the magnetic field
- Results in inhomogeneous magnetic field, decay of RF pulse and signal loss

**Solutions:**
- Image away from air containing structures
- Lower magnetic field strength, TE
- Increased bandwidth, echo train length, matrix size
- STIR instead of fat sat; SE instead of GRE
- Varied k-space filling (BLADE/PROPELLER)

*Inhomogeneity due to bowel gas susceptibility in the anterior abdomen results in incomplete fat sat of the left side of this T2 fat sat image.*
Magnet Related Artifacts

**Shading**

**Findings:**
- Moderate signal loss of a segment of an image, most common in FSE sequences
- Pathology may be obscured within the segment of signal loss

**Mechanism:**
- Rapid refocusing pulses in FSE results in saturation of macromolecules, which in turn saturate adjacent water, leading to less solid tissue intensity
- Can also occur if region of interest is insufficiently coiled

**Solutions:**
- Use SE
- Use appropriate coil, improve RF pulse precision
- Larger gap between image slices
- Non-sequential image acquisition

*The right liver lobe is shaded compared to the normal appearing left lobe on this fluid sensitive sequence.*
Magnet Related Artifacts

Moire Fringe

Findings:
- Curved bands of signal loss of an image segment, most common on GRE sequences
- Pathology may be obscured within the segments of alternating signal loss

Mechanism:
- Secondary to main field inhomogeneity from one side of the body coil to the other
- Results in aliasing and alternating enhancement and cancellation of signal, creating the light and dark bands seen

Solutions:
- Use SE or FSE, if possible

Alternating bands of signal loss are seen in the periphery of a FIESTA image (left). Use of SSFSE (right) eliminates this effect.
Magnet Related Artifacts

**Radio-Frequency Inhomogeneity**  

**Findings:**
- Inappropriate signal resulting from inconsistent RF across the span of the image
- Pathology may be obscured within the areas of signal loss, most common at 3T

**Mechanism:**
- Increased strength of the main magnetic field resists influence from RF pulse and degrades the RF signal
- Factors influencing main field strength include increased magnet strength (3T) and use of surface coils

**Solutions:**
- Use lower main field strength (1.5T)
- Coil shimming
- Avoid sequences that rely on susceptibility gradients, STIR instead of fat saturation, for example

*Incomplete fat saturation on the left side of this T2 weighted image secondary to RF inhomogeneity.*
Magnet Related Artifacts
Dia, Para and Ferromagnetic

Findings:
- Signal loss extending outward from a substance with different magnetic susceptibility
- Seen in stronger magnetic fields (3T); can obscure/distort adjacent soft tissues

Mechanism:
- Diamagnetic- Electrons paired, mildly opposes magnetic field; eg. soft tissues
- Paramagnetic- Unpaired electrons, lightly susceptible to magnetic field; eg. O₂
- Ferromagnetic- Profoundly susceptible to magnetic field; eg. Co, Ni, Fe

Solutions:
- Remove magnetic substances, if possible
- Use FSE, if possible
- Decrease TE; Increase ETL, bandwidth, matrix size

Paramagnetic bowel gas yields susceptibility that distorts the adjacent abdominal wall (top, FIESTA). SSFSE corrects this distortion (bottom).
Magnet Related Artifacts
Gradient Related Artifacts: Nonlinearity\textsuperscript{4,5,7}

Findings:
• Distortion, signal loss or skewing present at the extreme periphery of an image

Mechanism:
• Gradient linearity of an image degrades as the subject extend to the edges of the field of view
• Most pronounced at the image edges, as the image degrades most rapidly in the area furthest from the magnet center

Solutions:
• Work around the artifact, as signal degradation is usually far from area of interest
• Image post-processing

Signal rapidly fades at the upper and lower edge of this image, with mild splaying of the upper edge, all related to nonlinearity of the magnetic field.
**Magnet Related Artifacts**

**Gradient Related Artifacts:**

**Eddy Current**

**Findings:**
- Concave or skewing defects most notable at image periphery
- Common in DWI and images with short TE

**Mechanism:**
- Electrical currents are induced with rapid changes in gradient that come with repeated RF pulsation
- Susceptible materials near or within the scanner can induce a secondary magnetic field that disrupts the desired signal

**Solutions:**
- Shielding
- Eddy current compensation

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Small focus of concavity and signal distortion involving the anterior abdominal wall originating from a small nearby eddy current.
Magnet Related Artifacts
Gradient Related Artifacts:

Errors in the Data\textsuperscript{4,6,7}

**Findings:**
- Presents as multiple diagonal stripes that traverse the entire image

**Mechanism:**
- Results from a calculation error during k-space filling
- Calculation error can mis-register an incorrectly perceived signal value in k-space

**Solutions:**
- Repeat sequence

*Characteristic, diagonally oriented distortion reflective of an error in k-space filling on this fluid sensitive image.*
Magnet Related Artifacts
Gradient Related Artifacts:
**Dielectric Effect**\textsuperscript{2,3,5,6,7}

**Findings:**
- Signal loss obscuring the middle of the image, more common at 3T and in patients with increased abdominal girth (obese, ascites, pregnant)

**Mechanism:**
- As main magnetic field increases, RF wavelength decreases to a point that approaches abdominal girth
- When girth exceeds RF wavelength, a standing wave can form that contributes to a large central area of signal loss

**Solutions:**
- Use weaker magnetic field (1.5T)
- Use dielectric pads to alter perceived girth of the patient

Large area of central signal loss due to a standing wave in this image obtained at 3T.
Acquisition Parameter Related Artifacts

**Wrap-Around**

Findings:
- Portions of an image outside of the field of view (FOV) appear to overlap the image within the FOV on the opposite side of the image; can appear similar to ghosting.

Mechanism:
- FOV smaller than the area imaged results in 'aliasing' or wrap-around of structures along the phase encoding gradient beyond the FOV.
- Can mimic lesions and obscure evaluation of underlying tissue.

Solutions:
- Appropriately sized FOV
- Surface coils/saturation of objects outside of FOV
- Switch the phase encoding gradient

Hepatic pseudolesion results from wrap-around of left humeral bone marrow signal. Larger FOV reveals the source of artifact (inset).
Acquisition Parameter Related Artifacts

Zebra Stripes

Findings:
- Bands of signal loss in the periphery of an image, most common in GRE sequences
- Pathology may be obscured by the segments of signal loss

Mechanism:
- Results from combination of air-tissue susceptibility and aliasing
- FOV smaller than the area imaged results in 'aliasing' or wrap-around of the signal void brought on by air-tissue susceptibility artifact

Solutions:
- Increase timing/space between image slices
- Obtain interleaving slices in two separate acquisitions
- Work around if artifact does not involve region of interest

FIESTA image depicts several bands of signal loss, most prominent on the right side of the image, characteristic of zebra stripe artifact.
Acquisition Parameter Related Artifacts

RF Related Artifacts:

**Cross-Talk**

1, 4, 6, 7

**Findings:**
- Linear bands of diminished signal/image degradation
- Common in pelvic/lumbosacral angled image acquisition

**Mechanism:**
- Pre-excitation of nearby tissue voxels result from non-rectangular shape of RF pulses as well as angled image acquisition
- Pre-excited tissue is distorted, as the timing between RF pulse and image acquisition is altered

**Solutions:**
- Increase space/timing between image slices
- Obtain interleaving slices in two separate acquisitions
- Work around if artifact does not involve region of interest

Pre-excited voxels of tissue due to angulation of a previous RF pulse through the current slice produces a dark band posterior to the spine.
Acquisition Parameter Related Artifacts

RF Related Artifacts:

**Zipper** 4, 6, 7

**Findings:**
- A dotted line of distortion spans the image along the frequency encoding gradient
- Number of lines reflects the number of discrete frequencies exposed to the scanner

**Mechanism:**
- Results from contamination of the image with a frequency from a device exposed to the MRI machinery
- May also come as a result of a hardware or software error

**Solutions:**
- Close MRI scanner room door; no electronic devices in scanner vicinity
- RF shielding
- Call service rep if a hardware/software issue

Several instances of linear signal distortion are due to exposure of this fluid sensitive image to several different contaminant frequencies.
Image Processing Related Artifacts

Chemical Shift, type 1

Findings:
• Alternation of bright and dark signal at a margin between water and fat along the frequency encoding direction; can mimic blood products

Mechanism:
• The lower frequency of fat can be mismapped in a lower pixel along the frequency encoding direction when it shares a voxel with water
• The lower frequency pixel increases in intensity, while the fat/water pixel decreases

Solutions:
• Increase bandwidth; fat suppression
• Swap phase and frequency encoding directions

Chemical shift can be seen surrounding the right kidney on the left side of the image (FIESTA). This effect is not seen on SSFSE fat sat (right).
Image Processing Related Artifacts

Chemical Shift, type 2

Findings:
• Black boundary is seen at interfaces between fat and water/organs; occurs in all directions, not just along frequency encoding gradient; no accompanying bright signal

Mechanism:
• Depending on magnetic field strength, fat and water protons will be in and out of phase at predictable time intervals
• When the frequency of fat and water are out of phase, they cancel out, resulting in a pixel devoid of signal

Solutions:
• 180 degree refocusing pulses
• Set in-phase TE
• Increase bandwidth

Out of phase image (right) depicts black boundary at every interface of fat and water. In phase image (left) shows no such artifact.
Image Processing Related Artifacts

Gibbs Ringing\textsuperscript{2,4,5,6,7}

**Findings:**
- Ripple-like artifact extends from edges of tissue with vastly different signal intensity
- Commonly seen in portions of the abdomen adjacent to the diaphragm/lungs

**Mechanism:**
- Results from errors in approximation of signal intensity, approximation/truncation is better suited for gradual signal transitions
- Signal from voxels at abrupt transitions are truncated, but there is still increased T2 signal that is recorded to a pixel in error

**Solutions:**
- Increase image resolution
- Decrease pixel size

Several ripples extend from the juxtaposition of the upper abdominal organs and hemidiaphragms/lungs, characteristic of Gibbs ringing.
Image Processing Related Artifacts

Partial Volume Averaging\textsuperscript{1,6,7}

**Findings:**
- Loss of contrast between tissues, most notable in smaller objects as they approach MR image thickness; conceptually similar to partial volume averaging in CT imaging

**Mechanism:**
- Contribution of two different or separate tissue signals from the same voxel results in an averaged signal value in the resultant image pixel

**Solutions:**
- Thinner image slices
- Decrease pixel size; smaller FOV, larger matrix
- Longer RF pulse duration

SSFSE image with 7mm slices (right) depicts more fine detail of the perirectal/perivesicular fat than with 10mm SSFSE slices (left).
References/Recommended Reading


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