Hong Kong J Radiol. 2023;26:58-65 | https://doi.org/10.12809/hkjr2317476

PICTORIAL ESSAY

Common Artifacts in Magnetic Resonance Imaging: A Pictorial Essay

CH Ho[1], L Xiao[2], KY Kwok[1], S Yang[1], BWH Fung[1], KCH Yu[1], WH Chong[1], TW Yeung[1], A Li[1]

[1]Department of Radiology, Tuen Mun Hospital, Hong Kong
[2]Medical Physics Unit, Department of Oncology, Tuen Mun Hospital, Hong Kong

INTRODUCTION

Magnetic resonance (MR) imaging provides a non-invasive, radiation-free mode of imaging. New MR technologies including MR spectroscopy and functional imaging provide a novel range of diagnostic information. With its complexity, diversity and versatility, MR imaging is one of the most powerful diagnostic tools in a wide variety of clinical situations.

MR artifacts are common in MR imaging. They are defined as any signal or void in the images that does not have an anatomic basis, or that arises as a result of distortion, addition or deletion of information.[1] MR artifacts can be related to patient motion, tissue characteristics, imaging techniques or hardware issues, and may be confused with genuine pathology or reduce image quality. Some MR phenomena, which contribute to MR artifacts, are also exploited for various clinical applications, e.g., out-of-phase imaging and susceptibility-weighted imaging (SWI). This article provides an overview of common MR artifacts. It is important for radiologists and MR technologists to recognise them and be able to minimise their effects.

COMMON MAGNETIC RESONANCE ARTIFACTS

Truncation Artifact

Truncation artifact, also known as Gibbs, ringing, or spectral leakage artifact, refers to alternating bright and dark lines that occur near an abrupt high-contrast boundary. This artifact is caused by an inadequate number of encoding steps for high spatial frequency data,[2] which represent the edge between areas of high contrast. When there is under-sampling, the highest spatial frequency data are cut off, leading to the artifact. It can occur in both frequency- and phase-encoding directions, but is more common in the latter due to fewer phase-encoding steps in most examinations. It can occur in the brain due to sharp signal changes between the brain parenchyma and cerebrospinal fluid (Figure 1). It may also simulate a syrinx in the spinal cord or a meniscal tear in the knee. Common remedies include increasing the size of matrix (more encoding steps) and reducing the field of view (FOV).[2]

Cross-Excitation Artifact

Cross-excitation artifact is caused by imperfect non-

Correspondence: *Dr CH Ho, Department of Radiology, Tuen Mun Hospital, Hong Kong*
Email: hch1931@ha.org.hk

Submitted: 21 Sep 2021; Accepted: 15 Dec 2021.

Contributors: All authors designed the study. CHH and LX acquired and analysed the data. CHH drafted the manuscript. All authors critically revised the manuscript for important intellectual content. All authors had full access to the data, contributed to the study, approved the final version for publication, and take responsibility for its accuracy and integrity.

Conflicts of Interest: All authors have disclosed no conflicts of interest.

Funding/Support: This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability: All data generated or analysed during the present study are available from the corresponding author on reasonable request.

Ethics Approval: This study was approved by New Territories West Cluster Research Ethics Committee of Hospital Authority (Ref No.: NTWC/REC/21064). Informed patient consent was waived by the Committee as this retrospective study involves no additional patient participation and all patient data are anonymised.

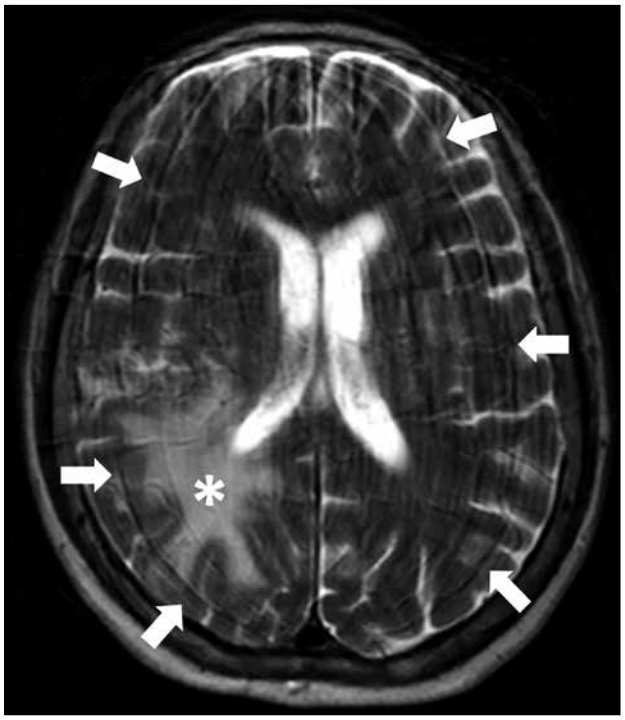

Figure 1. Axial T2-weighted image of the brain showing significant truncation artifact (white arrows) along the high-contrast brain-fluid interface, obscuring the normal anatomy. This patient has significant vasogenic oedema at the right frontal and parietal white matter (white asterisk) due to underlying brain metastasis.

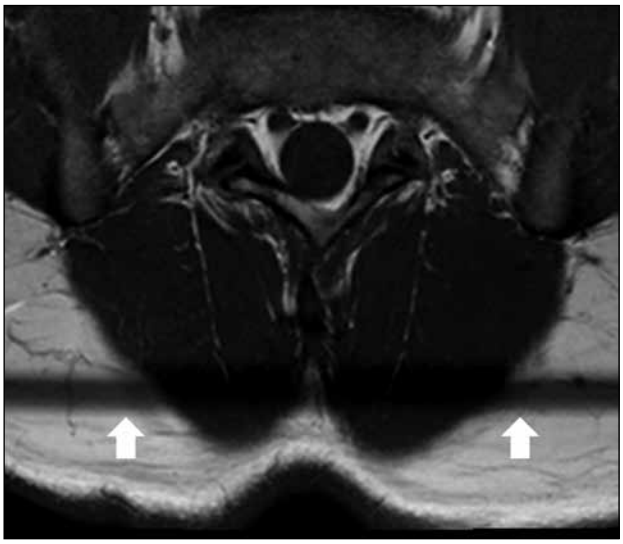

Figure 2. Axial T1-weighted image of the lumbar spine with multi-angle acquisition. Hypointense signal band (white arrows) is observed due to cross-excitation with saturation effect.

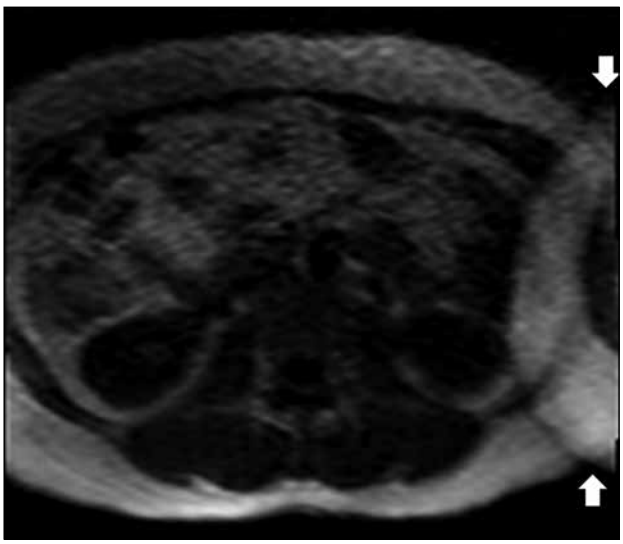

Figure 3. Axial localiser scan of the abdomen demonstrates aliasing artifact (white arrows). The body part outside the field of view is projected to the opposite side of the image and masks the relevant anatomical structure.

rectangular shape of radiofrequency (RF) excitation or multi-angle acquisition. As a result, there is some overlap between adjacent slices during sequential acquisition. Tissue within the overlapping region is excited repeatedly during acquisition, causing saturation effect and decreased signal intensity[3] (Figure 2). Common remedies include increasing slice gap and using interleaved slices for acquisition.

Aliasing

Aliasing occurs when the body part outside the FOV is projected inside and overlaps on the opposite side of the image[1,4] (Figures 3 and 4). It can mask the anatomical structures in the region of clinical interest. It can occur in both frequency- and phase-encoding directions but is generally more severe along the phase-encoding axis.

During image acquisition, structures outside the FOV are also excited and produce signals. If the frequencies of the signals outside the FOV exceed the Nyquist frequency (the highest frequency that can be unambiguously sampled), those signals will be falsely detected as lower frequencies and misregistered, leading to wraparound phenomenon.[4,5] For phase-encoding direction, similar ambiguity and misregistration can result due to its circular nature that repeats every 360°C.[1] In parallel acquisition techniques, aliasing artifacts have different appearances and the location of the artifacts depends on the acceleration factor. Common remedies include increasing FOV (at the expense of resolution), oversampling, reducing the acceleration factor, adding pre-saturation pulses for structures outside the FOV, using surface coils and switching phase- and frequency-encoding directions.[4]

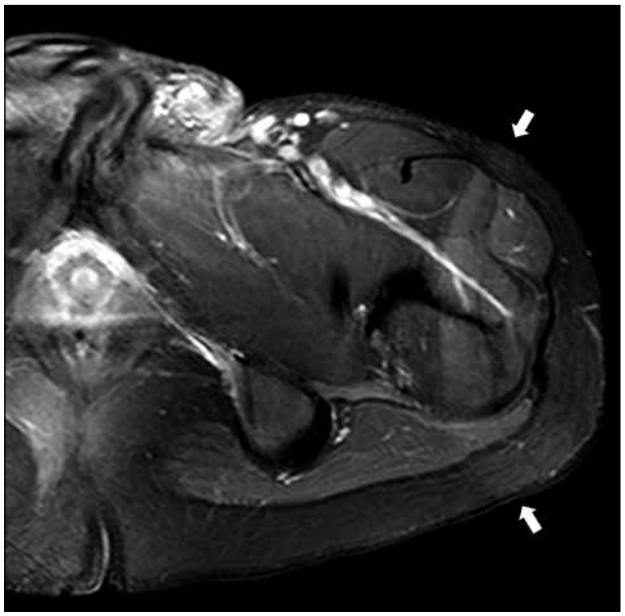

Figure 4. Axial T1-weighted post-contrast image of the left hip showing aliasing artifact at the lateral aspect of left hip, with a rim of signal hyperintensity overlapping the anatomy (white arrows).

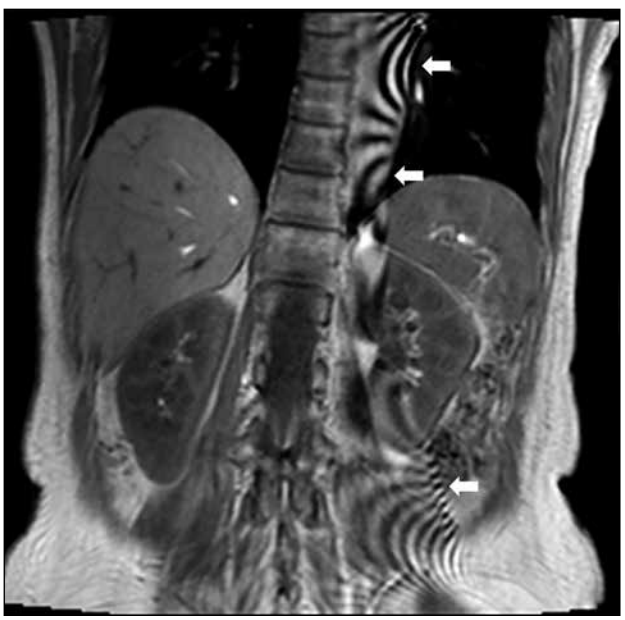

Figure 5. Coronal T1-weighted gradient echo image of the abdomen demonstrates the Moiré fringes or zebra artifacts (white arrows). This artifact is caused by a combination of aliasing and magnetic field inhomogeneity.

Moiré Artifact

The combination of aliasing artifact and magnetic field inhomogeneity can cause Moiré fringes or zebra artifacts.[1] Homogeneity of the magnetic field degrades towards the edges of the field, especially when the FOV is large, causing phase differences between the two edges. When aliasing occurs, the overlapping signals with mismatched phases cause interference patterns and produce Moiré artifact[1,5] (Figure 5). This is more commonly seen in gradient echo imaging with body coil. Common remedies are similar to those for aliasing artifact.

Zipper Artifact

Zipper artifact is most often caused by the interference of extrinsic RF signals to the MR scanner and is picked up by the receiver system. The appearance varies with the frequency and bandwidth of the source. Broadband source will affect the entire image, while narrow-frequency source will create discrete bright and dark broken lines perpendicular to the frequency-encoding direction[6] (Figure 6). The sources of the extrinsic RF include electronic devices (e.g., monitoring equipment), static electricity, opened door and a breach in the RF shield. Common remedies include removing the external RF sources, closing the door completely before scanning, and inspecting thoroughly the scanner room for any breach of RF shield.[1]

Geometric Distortion

Geometric distortion can arise from different sources and can be hardware-related or tissue-related. The main

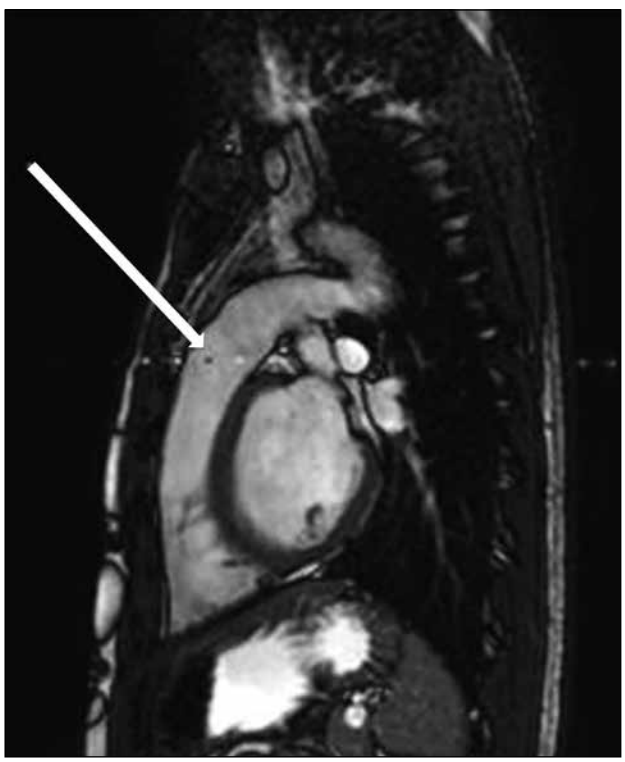

Figure 6. Sagittal balanced steady-state free precession image of the thorax showing zipper artifact (white arrow) perpendicular to frequency-encoding direction from a narrow-frequency source.

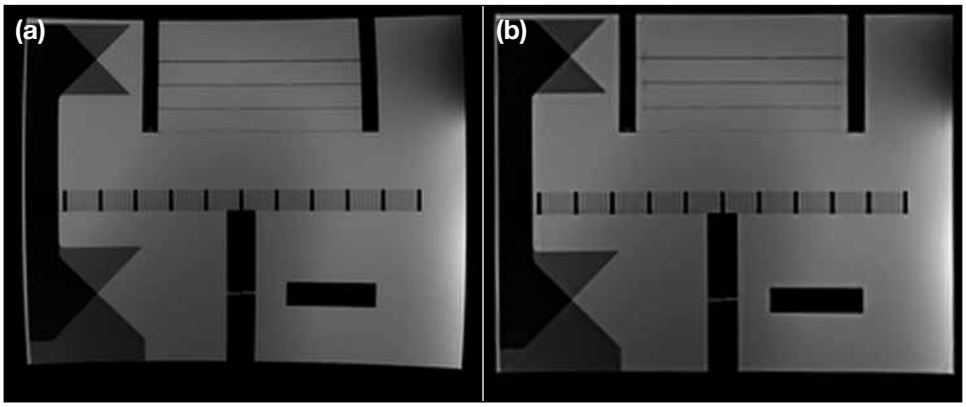

Figure 7. (a) Phantom image showing geometric distortion within the slice plane indicated by the curved outline of the phantom image. (b) After the manufacturer's correction algorithm was applied, the acquisition was repeated and showed significant improvement of the geometric distortion.

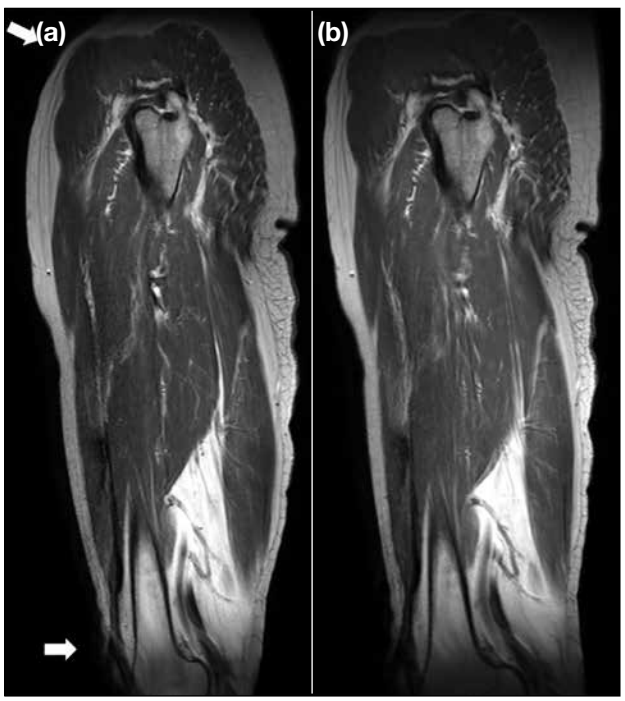

Figure 8. (a) Axial T1-weighted image of the right thigh demonstrates geometric distortion due to gradient field non-linearity (white arrows), more significant at the periphery of the image. (b) After application of the manufacturer's correction algorithm, the acquisition was repeated and the geometric distortion was significantly minimised.

hardware-related source is gradient field non-linearity in contemporary MR systems, in which the gradient strength and slew rate (rate of gradient rise) are much higher[7] (Figures 7 and 8). Distortions are usually minimal at the isocentre and more significant at the periphery. Geometric distortion becomes a clinical concern when a high level of spatial precision is required, e.g., during MR-guided interventions or radiotherapy planning. Different correction algorithms are available from major manufacturers of MR systems to minimise hardware-related geometric distortion.

Susceptibility Artifact

Magnetic susceptibility refers to the tendency of a structure to contribute a magnetic field on its own under an external magnetic field.[4] This will create local magnetic field inhomogeneities, altering the frequency and phase of local spins and also leading to stronger dephasing of the spins.[8] Severe artifacts can occur near ferromagnetic objects, e.g., metallic implants and distort normal anatomy (Figure 9). Such effect can also be found at the boundary of tissues with different susceptibilities, for example a tissue-air interface. Increasing field strength worsens the magnitude of this effect. Common remedies include using spin echo instead of gradient echo sequences, orienting the phase-encoding gradient along the same axis as the susceptibility gradient, reducing echo time, reducing slice thickness, increasing the acquisition matrix, improving the local field homogeneity, and increasing receiver bandwidth.[8]

The differences in tissue susceptibility can be exploited in SWI to help diagnose haemorrhage and calcifications. Both appear hypointense on SWI images. The filtered phase images of SWI sequences can help further differentiate paramagnetic (haemorrhage) and diamagnetic (calcification) products since the latter have different phases.[9]

Chemical Shift Artifact

Chemical shift artifact refers to signal alterations that result from inherent differences in the Larmor frequencies of protons when they are in a different chemical environment, most frequently observed between water and fat.[10] It occurs in both spin echo and gradient echo

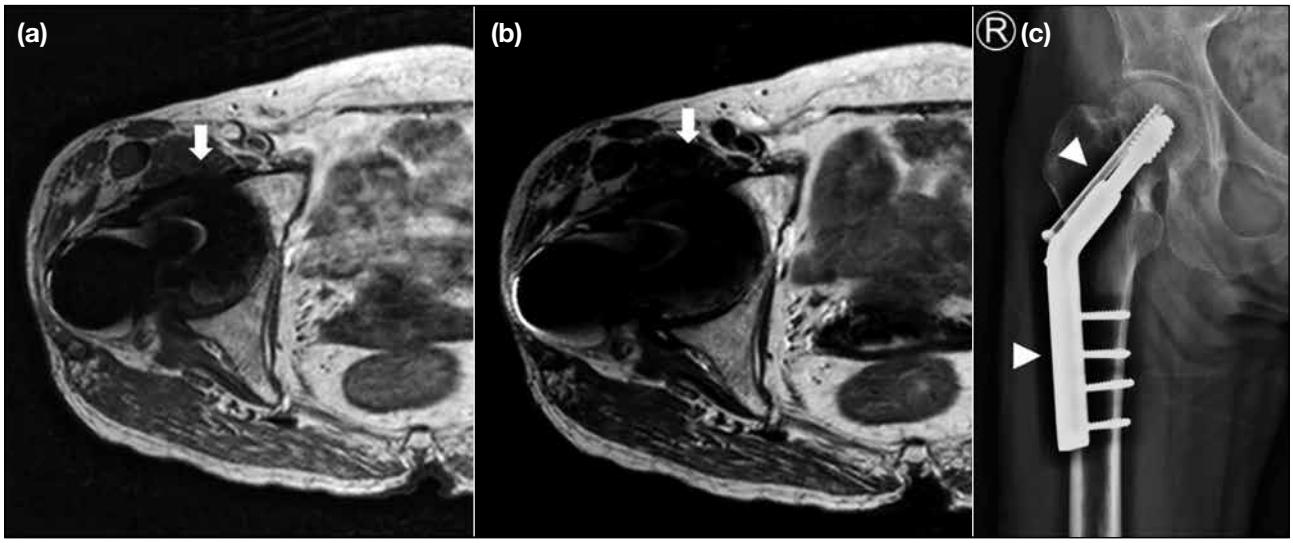

Figure 9. (a and b) Axial T1-weighted and T2-weighted fast spin echo images of the right hip at 1.5T magnetic resonance imaging showing significant susceptibility artifact (white arrows) due to the presence of metallic screw at the proximal right femur. (c) Radiograph of right hip showing the presence of metallic screw at the proximal right femur (white arrowheads).

imaging, and along the frequency-encoding direction. It creates signal void as well as superimposition due to the shifting, and usually manifests as a bright line on one side and a dark line on the opposite side of the fat-water interfaces (Figure 10).

The difference is caused by different chemical structures of fat and water. The hydrogen atoms in fat are contained in a much larger molecule compared with those in water. As a result, there is a much stronger shielding effect from the molecule's electron shell of fat on the static magnetic field, and the Larmor frequency of the hydrogen atoms in fat is lowered.[10] The difference in Larmor frequency is usually expressed as a difference of 3.5 parts per million relative to the Larmor frequency of water.[11] It is directly proportional to the main field strength. Common remedies to chemical shift artifact include using a higher receiver bandwidth, decreasing FOV and using a fat suppression technique.

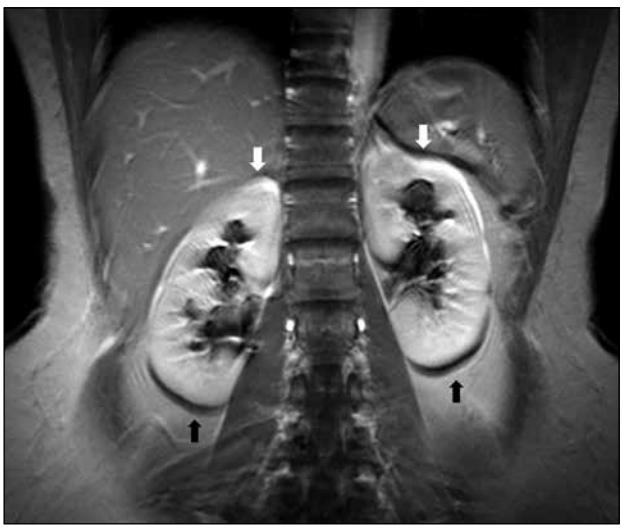

Figure 10. Coronal T1-weighted image of the upper abdomen demonstrates chemical shift artifact of the first kind around the kidneys. Bright rims are seen around the superior pole of the kidneys (white arrows) and dark rim is seen at the opposite sides (black arrows).

Out-of-Phase Signal Cancellation Artifact

Out-of-phase signal cancellation, or type 2 chemical shift artifact, refers to intravoxel signal cancellation due to phase difference between the spinning protons in fat and water. Since the precession of hydrogen atoms in water and in fat are at different frequencies, they have different phase directions at different time points and therefore at certain time points, they can be in-phase or 180°C out-of-phase. At 1.5T, out-of-phase occurs at 2.2 ms and in-phase occurs at 4.4 ms. By adjusting the echo time, both in-phase and out-of-phase images can be produced.

At out-of-phase imaging, the signals from protons in water and fat within the same pixel are cancelled out, leading to the appearance of a dark band at the fat-water interface. Unlike chemical shift artifact of the first kind that can be seen in both spin echo and gradient echo imaging, this artifact occurs only in gradient echo sequences since the 180°C rephrasing RF pulse in spin echo imaging will compensate this phase shift.[11] Moreover, type 2 chemical shift artifacts can be seen in all pixels along a fat-water interface, unlike chemical

shift artifact of the first kind that is limited to the frequency-encoding direction.

The out-of-phase signal cancellation effect is valuable for diagnostic purposes. A drop in signal intensity at out-of-phase images indicates the presence of fat within the voxel. This is helpful for diagnosing fat-containing lesions e.g., adrenal adenoma or renal angiomyolipoma (Figure 11).

Another added benefit of this dual gradient echo imaging is to assess signal loss related to magnetic susceptibility effect. Magnetic susceptibility causes signal intensity loss with time, therefore more signal loss occurs in in-phase images with longer echo time than out-of-phase images. This is helpful when diagnosing iron deposition, haemorrhage and siderotic hepatic nodules, etc[11] (Figure 12).

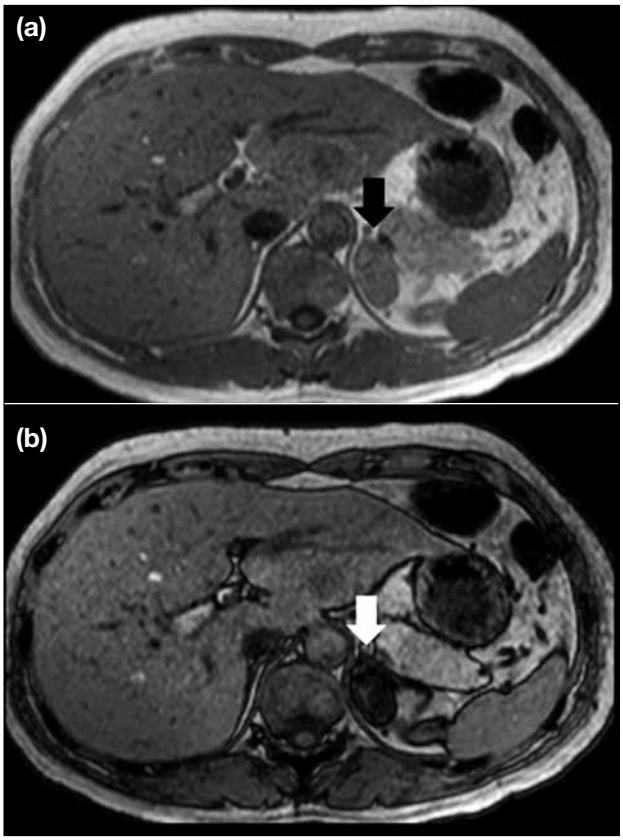

Figure 11. Case of left adrenal adenoma. (a) Axial T1-weighted in-phase gradient echo image of the abdomen showing a left adrenal mass (black arrow). (b) Axial T1-weighted opposed-phase gradient echo image of the abdomen showing signal drop at the left adrenal mass (white arrow), signifying the presence of intravoxel fat which is a feature of adrenal adenoma.

Motion Artifact

Motion artifact is the principal source of artifact in MR imaging, primarily due to the prolonged time required for most MR imaging sequences. It can be briefly classified as periodic (e.g., pulsation of blood vessels) or random (e.g., bowel peristalsis) [Figures 13 and 14]. Random motion generally creates a blurring of images while periodic motion produces ghost images.[1] Motion artifact is usually most apparent in the phase-encoding direction due to the much slower sampling time.

Recent advances have improved the situation in some cases, for example breakthrough in parallel imaging enables faster imaging that decreases the chance of involuntary patient motion. Nonetheless improvement in resolution and signal-to-noise ratio will also increase the sensitivity to motion.[12]

There are different remedies to reduce motion artifacts, including motion reduction (e.g., physical immobilisation or sedation), rapid imaging sequences (e.g., parallel imaging, triggering and gating for periodic movements, such as respiratory or cardiac movements), and motion artifact reduction sequences (e.g., the PROPELLER [periodically rotated overlapping parallel lines with enhanced reconstruction] technique).[12]

Coil-Related Artifact

Signal intensity artifact can result from improper coil or patient positioning and manifests as areas of signal intensity loss (Figure 15). This error is easily corrected and should be recognised before the more complicated investigations. Other signal intensity artifacts related to coils include intensity gradient from local coils, local intensity shift artifact from RF-induced eddy currents, protocol errors, failure of decoupling mechanisms, and improper coil tuning[13] (Figure 16).

Dielectric Effect

Dielectric effect manifests as abnormal bright and dark areas due to the interaction of matter with the electric field. This artifact is mainly found in abdominal and pelvic imaging at 3T or higher field strength. The wavelength of RF pulses decreases as the main magnetic field strength increases. The wavelength at 1.5T is approximately 52 cm in soft tissue, larger than the size of most adults. Nonetheless at 3T, the wavelength becomes approximately 26 cm in soft tissue, similar to the body torso size of adults. This results in standing wave effects that lead to areas of constructive and destructive interference and prevents excitation of the spins at the centre of imaged volume. Another reason for this

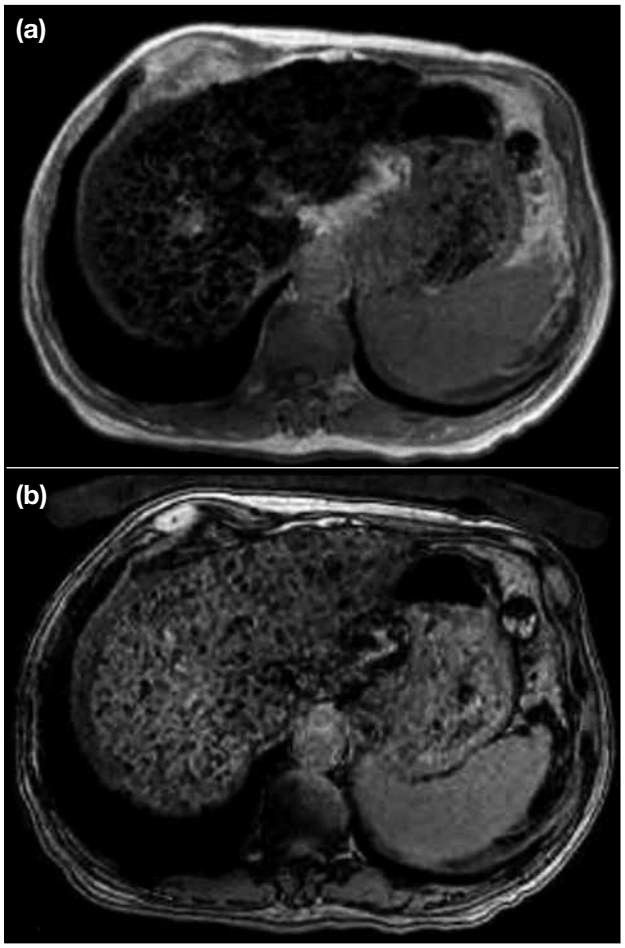

Figure 12. Case of iron overload due to thalassaemia. Axial T1-weighted gradient echo images of the abdomen with in-phase and opposed-phase show signal drop of the liver parenchyma in in-phase image. It is due to susceptibility artifact from iron overload due to thalassaemia. This patient also has liver cirrhosis.

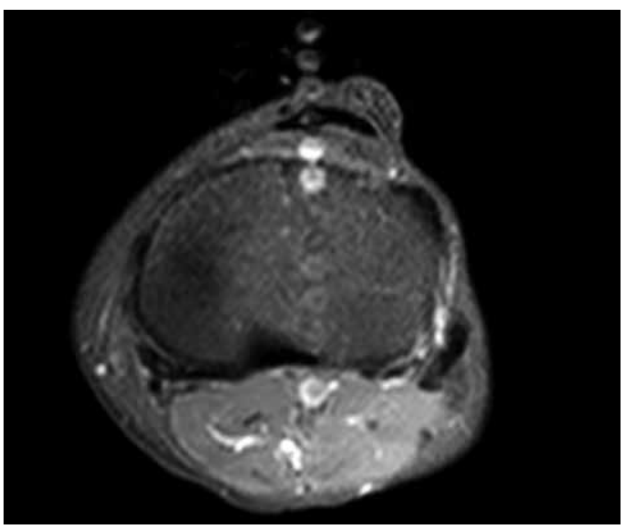

Figure 13. Axial T1-weighted post-contrast image of the knee with fat saturation showing ghosting artifact of the popliteal artery along the phase-encoding direction due to pulsation.

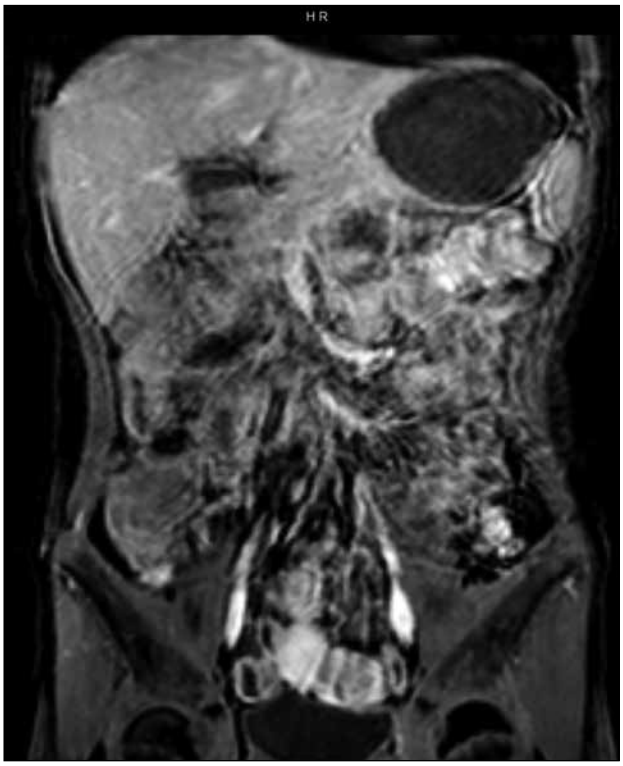

Figure 14. Coronal T1-weighted post-contrast image of the abdomen with fat saturation showing blurring of the image due to the combination of breathing motion, bowel peristalsis and patient's movement.

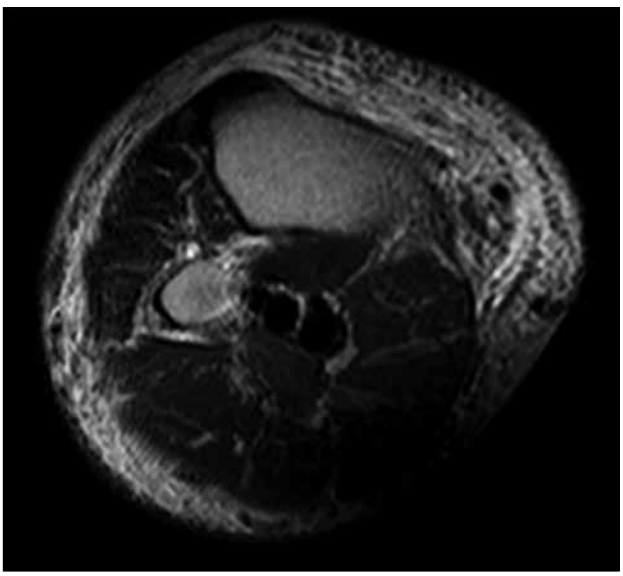

Figure 15. Axial T1-weighted image of the leg showing focal area of signal loss at the posterior compartment of the leg. This is due to suboptimal positioning of the coil.

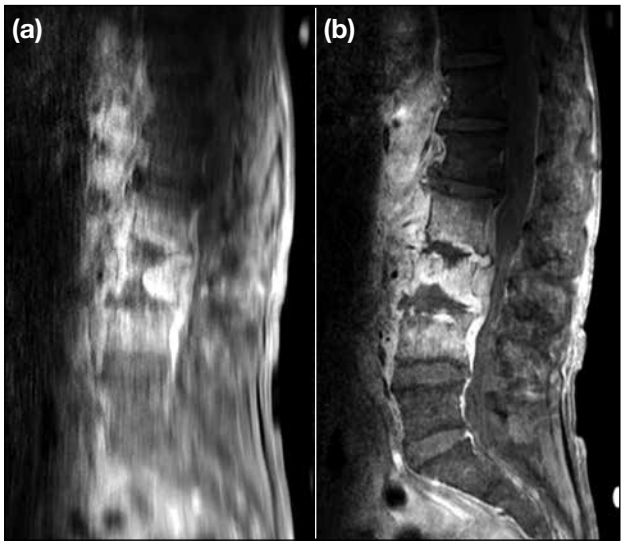

Figure 16. (a) Sagittal T1-weighted fat-saturated post-contrast image of the lumbar spine. Severe blurring of the image is noted due to coil connector malfunction. (b) After changing the connector, the artifact is no longer observed. This patient has an infective spondylodiscitis at the lumbar spine.

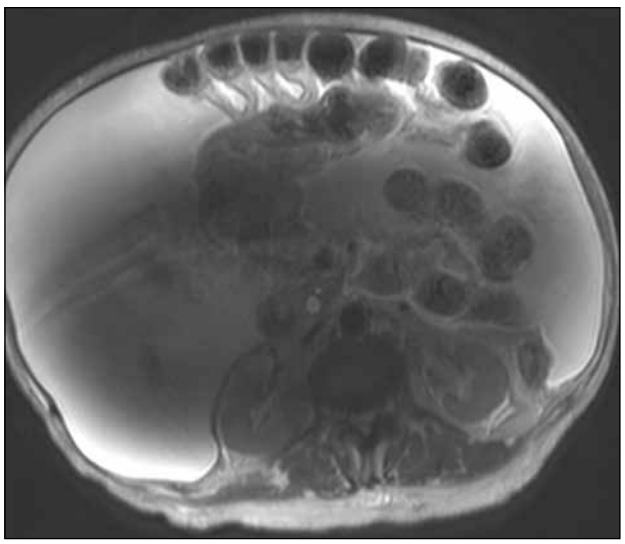

Figure 17. Axial T2-weighted image of the abdomen showing the dielectric effect with signal loss at the centre of the abdomen. Note that this patient has significant ascites that contributes to the dielectric effect.

artifact is the generation of eddy current from RF pulses, which is more pronounced at 3T, causing magnetic field inhomogeneity. The combined effects of standing wave and eddy current cause focal areas of abnormal signals[14] (Figure 17).

This artifact is accentuated when the imaged structures are large, e.g., patients with ascites, obesity or pregnancy. Dielectric effects are variable and difficult to predict, since the shape of the body surface and the conductivity of the tissue determine the conditions.[15] Common remedies include placing a dielectric pad and using a 1.5T scanner instead.

CONCLUSION

MR artifacts are common in clinical MR imaging. This article gives an overview of common MR artifacts encountered in clinical practice. It is important for radiologists and MR technologists to recognise the artifacts and know how to minimise their effects. On the contrary, some of these MR phenomena can have clinical applications and help in making diagnosis.

REFERENCES

1. Stadler A, Schima W, Ba-Ssalamah A, Kettenbach J, Eisenhuber E. Artifacts in body MR imaging: their appearance and how to eliminate them. Eur Radiol. 2007;17:1242-55.
2. Gallagher TA, Nemeth AJ, Hacein-Bey L. An introduction to the Fourier transform: relationship to MRI. AJR Am J Roentgenol. 2008;190:1396-405.
3. Schwaighofer BW, Yu KK, Mattrey RF. Diagnostic significance of interslice gap and imaging volume in body MR imaging. AJR Am J Roentgenol. 1989;153:629-32.
4. Morelli JN, Runge VM, Ai F, Attenberger U, Vu L, Schmeets SH, et al. An image-based approach to understanding the physics of MR artifacts. Radiographics. 2011;31:849-66.
5. Zhuo J, Gullapalli RP. AAPM/RSNA physics tutorial for residents: MR artifacts, safety, and quality control. Radiographics. 2006;26:275-97.
6. Budrys T, Veikutis V, Lukosevicius S, Gleizniene R, Monastyreckiene E, Kulakiene I. Artifacts in magnetic resonance imaging: how it can really affect diagnostic image quality and confuse clinical diagnosis? J Vibroengineering. 2018;20:1202-13.
7. Wang D, Strugnell W, Cowin G, Doddrell DM, Slaughter R. Geometric distortion in clinical MRI systems part I: evaluation using a 3D phantom. Magn Reson Imaging. 2004;22:1211-21.
8. Stradiotti P, Curti A, Castellazzi G, Zerbi A. Metal-related artifacts in instrumented spine. Techniques for reducing artifacts in CT and MRI: state of the art. Eur Spine J. 2009;18 Suppl 1:102-8.
9. Haacke EM, Mittal S, Wu Z, Neelavalli J, Cheng YC. Susceptibility-weighted imaging: technical aspects and clinical applications, part 1. AJNR Am J Neuroradiol. 2009;30:19-30.
10. Hood MN, Ho VB, Smirniotopoulos JG, Szumowski J. Chemical shift: the artifact and clinical tool revisited. Radiographics. 1999;19:357-71.
11. Shetty AS, Sipe AL, Zulfiqar M, Tsai R, Raptis DA, Raptis CA, et al. In-phase and opposed-phase imaging: applications of chemical shift and magnetic susceptibility in the chest and abdomen. Radiographics. 2019;39:115-35.
12. Zaitsev M, Maclaren J, Herbst M. Motion artifacts in MRI: a complex problem with many partial solutions. J Magn Reson Imaging. 2015;42:887-901.
13. Jones RW, Witte RJ. Signal intensity artifacts in clinical MR imaging. Radiographics. 2000;20:893-901.
14. Huang SY, Seethamraju RT, Patel P, Hahn PF, Kirsch JE, Guimaraes AR. Body MR imaging: artifacts, k-space, and solutions. Radiographics. 2015;35:1439-60.
15. Schick F. Whole-body MRI at high field: technical limits and clinical potential. Eur Radiol. 2005;15:946-59.