MRI Artifacts & Mitigations

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Outline

MRI Image Pipeline

Major Artifacts, Based on Origin

- RF-based, Tissue Properties,
  Reconstruction, Prescription, Ghosting

(in particular, leaving off annefact, T2 blurring, and lesser artifacts)

Artifacts from Specialized Sources

- Sequence-based
- 2D vs 3D
- Non-cartesian vs. Spin-Warp

pMRI-based Artifacts

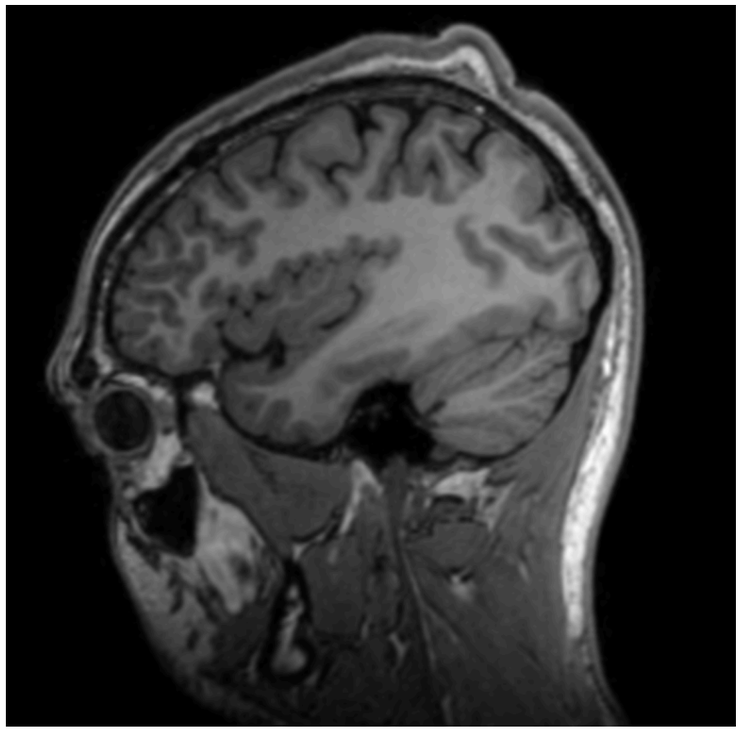
Sidenote #1: What is an “Artifact”?

Physicist (by origin): “Something happened with the system, and the image doesn’t look like it should.”

I.e., “The data is corrupted”.

Radiologist (by hindrance): “I’m having trouble making a diagnosis.”

I.e., “The data is corrupted”.



The source material:

(what is this, really?)

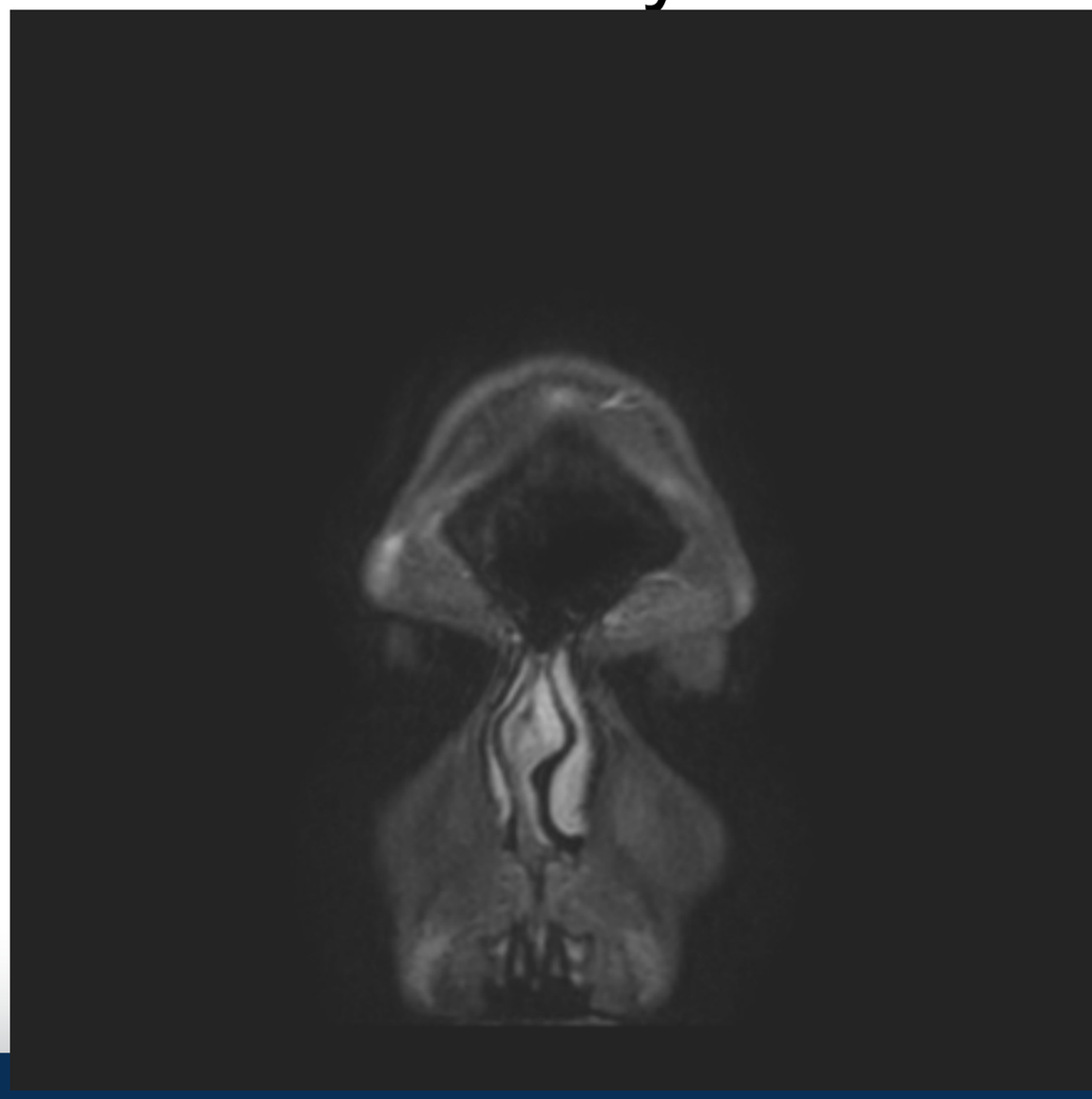
Myth #1: all artifacts are equally worthy of concern.

Sidenote #2: We're Making Artifacts Appear Worse than They Are

Radiologists do not diagnose with one image in hand.

What we see

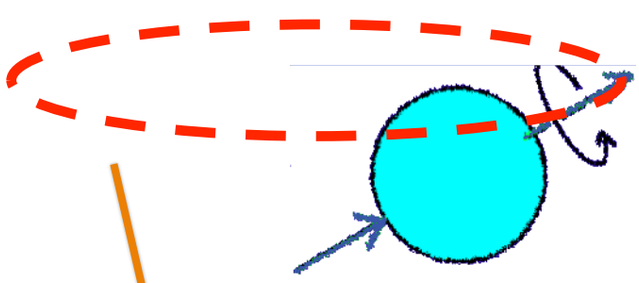
Reality



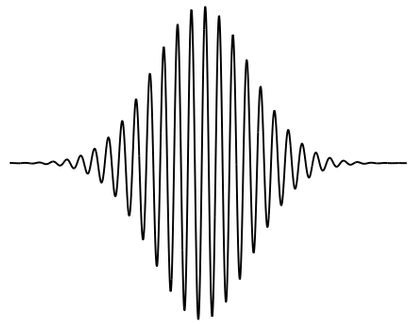
MRI Pipeline

MRI Pipeline

Excite Tissue
(RF/shim)



Data Readout
(RF/Electronics)



Patient
(Tissue)

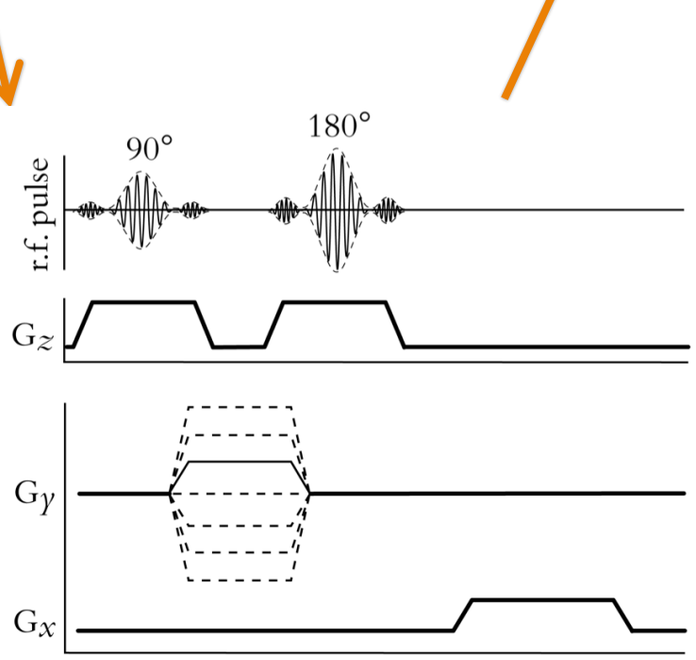
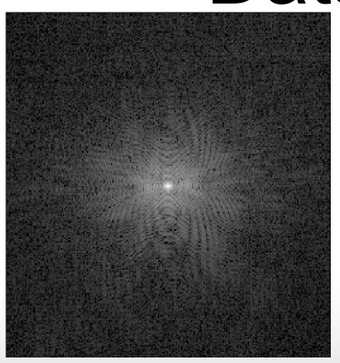
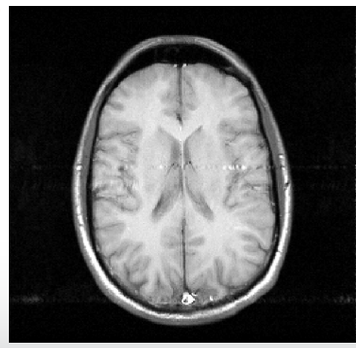


Image
Reconstruction
(Electronics/
Data integrity)



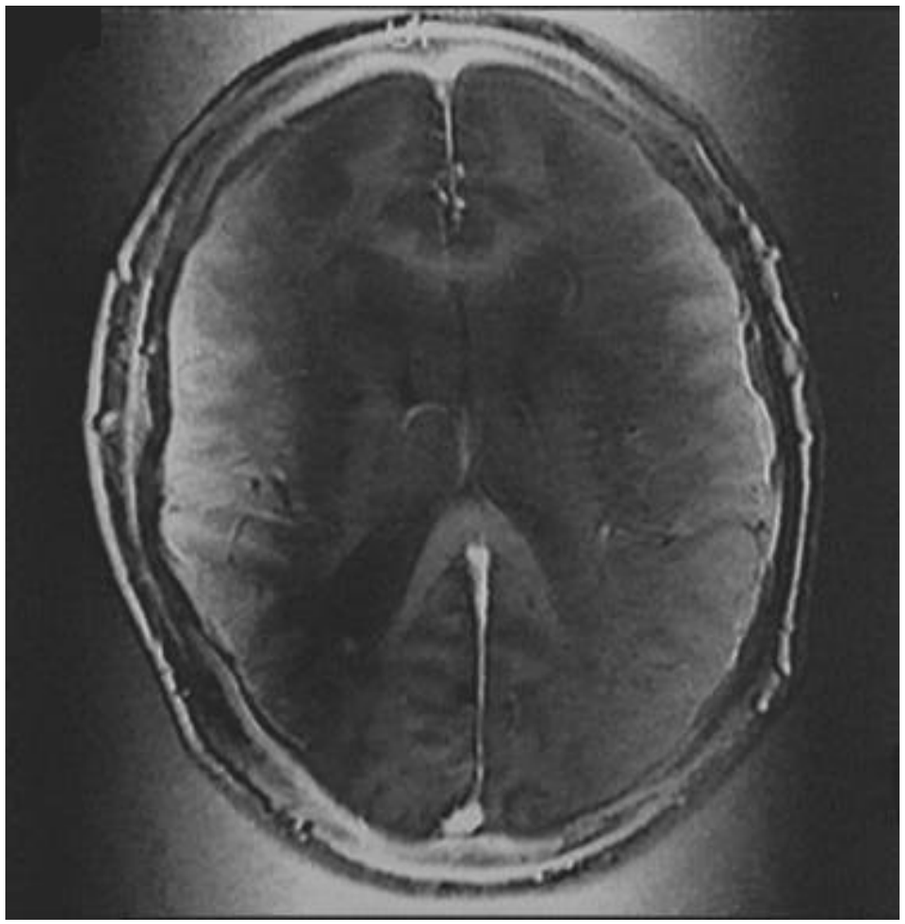
$\mathcal{FFT}^{-1}$



Spatial Encoding (Gradient/Prescription/
Tissue)

RF System-Based Artifacts

RF Overflow/Saturation

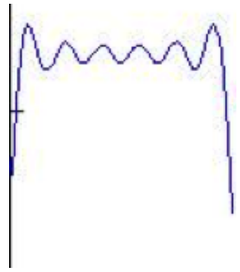


Causes:

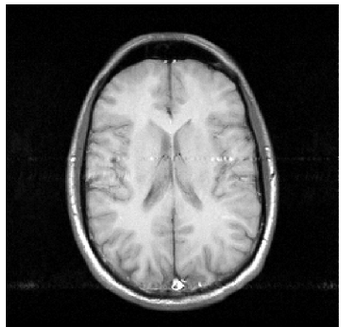
Pre-scan gain adjustment of receiver is too narrow to contain range of voltages observed in RF coil.

Case courtesy of Dr J. Ray Ballinger, Radiopaedia.org, rID: 22006

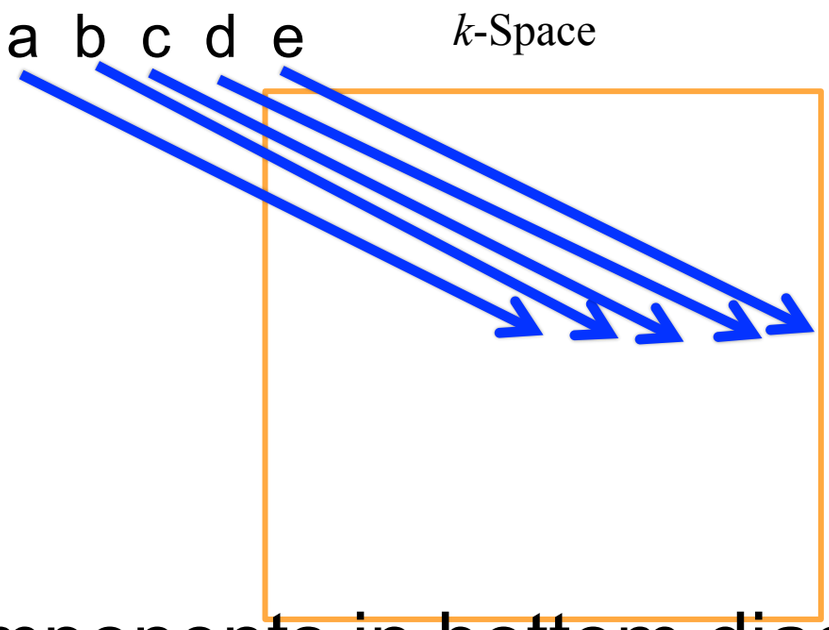
RF Overflow/Saturation

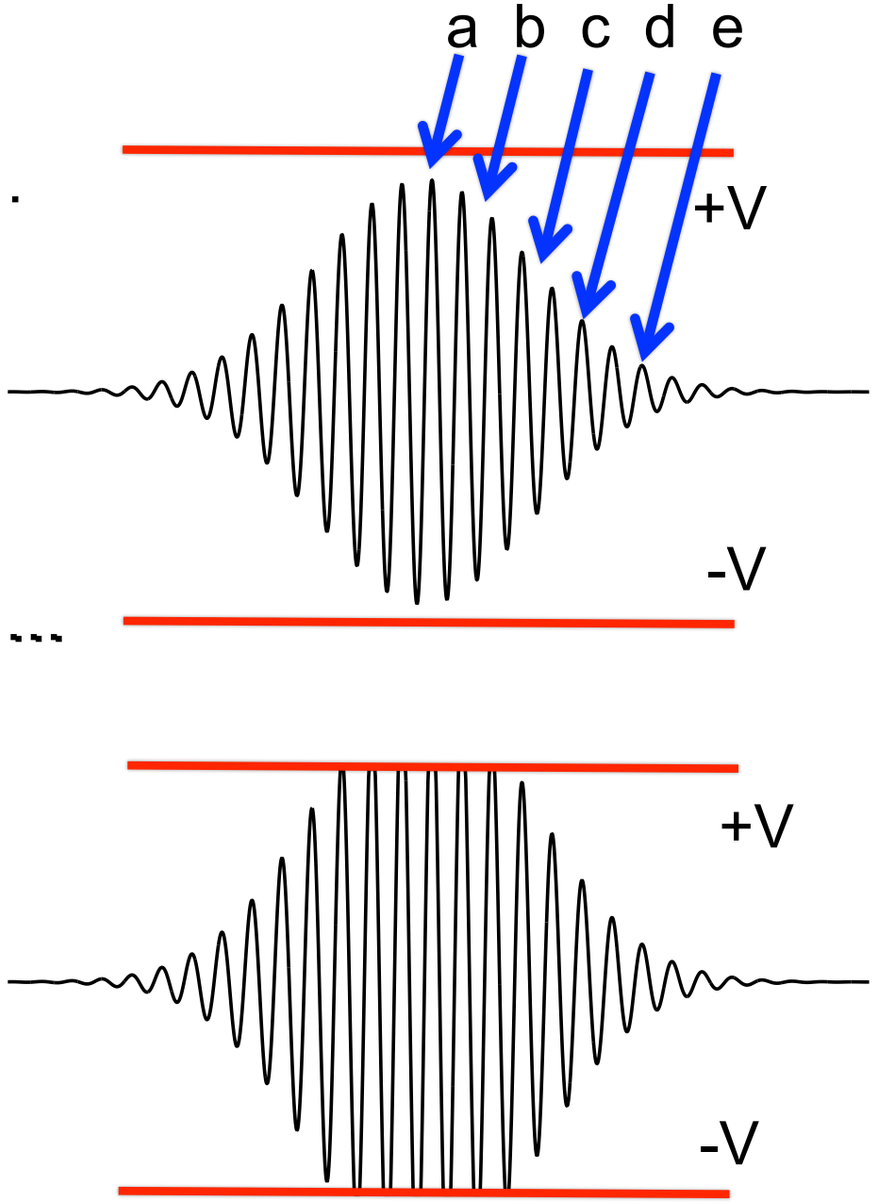


= a* +b* +c* +d* + …



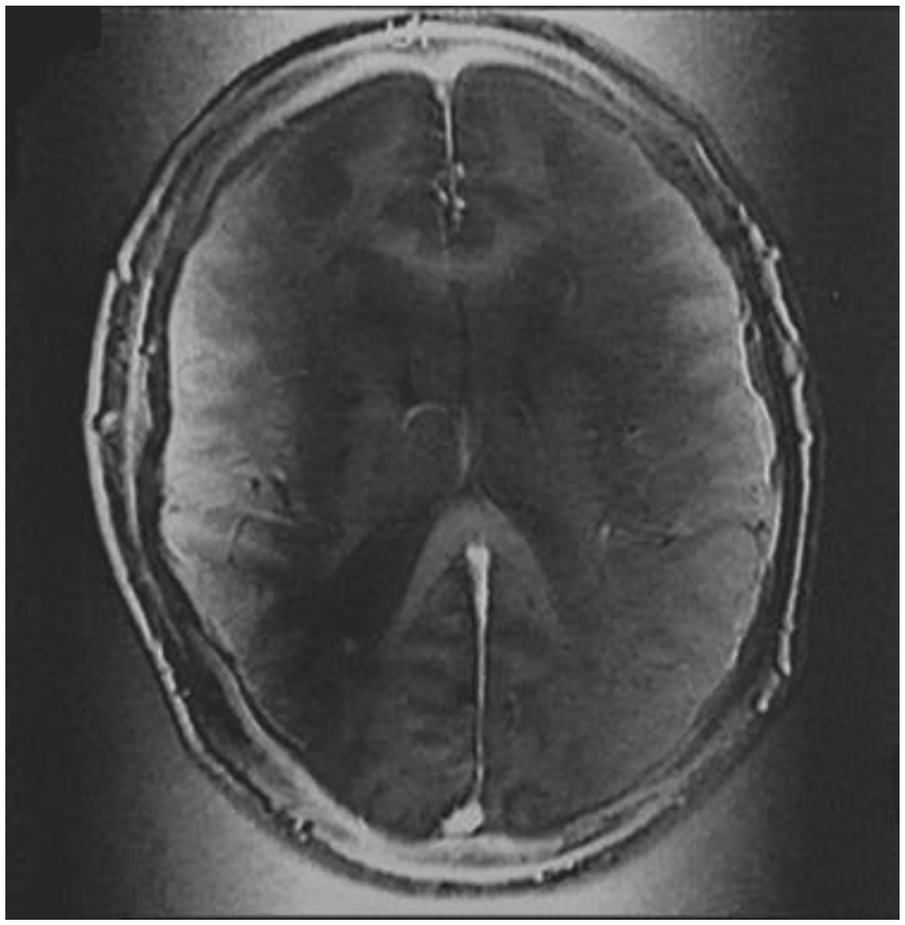
= α* +β* +c* +d* +e* + …





Note: fourier components in bottom diagram may not correspond to actual k-space locations shown in slide.

RF Overflow/Saturation



Case courtesy of Dr J. Ray Ballinger, Radiopaedia.org, rID: 22006

Causes:

Pre-scan gain adjustment of receiver is too narrow to contain range of voltages observed in RF coil.

Common Occurrences:

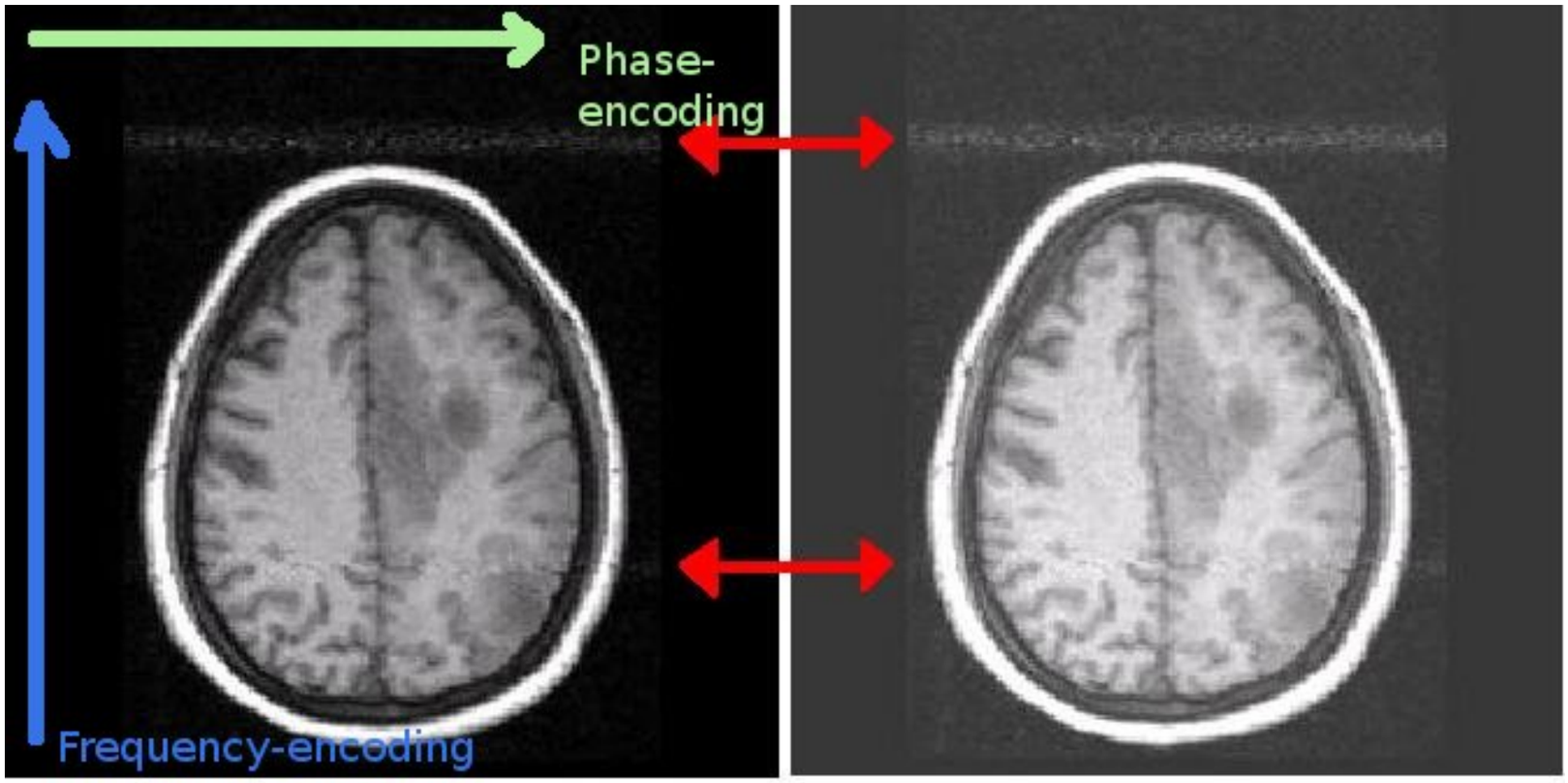
Any scan…however, most detrimental for T1 DCE breast imaging.

Remediate:

Rescan.

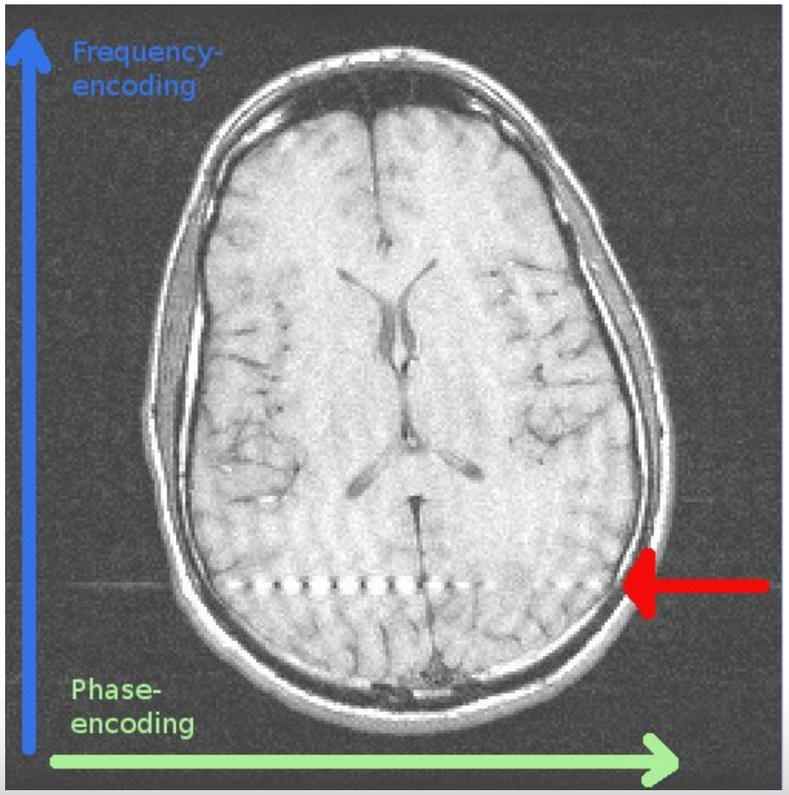
Call field engineer.

Manual prescan and set gain slightly lower.



Zippers

Pictures from Yanasak, et al. (MRI: Image Formation RSNA web module)

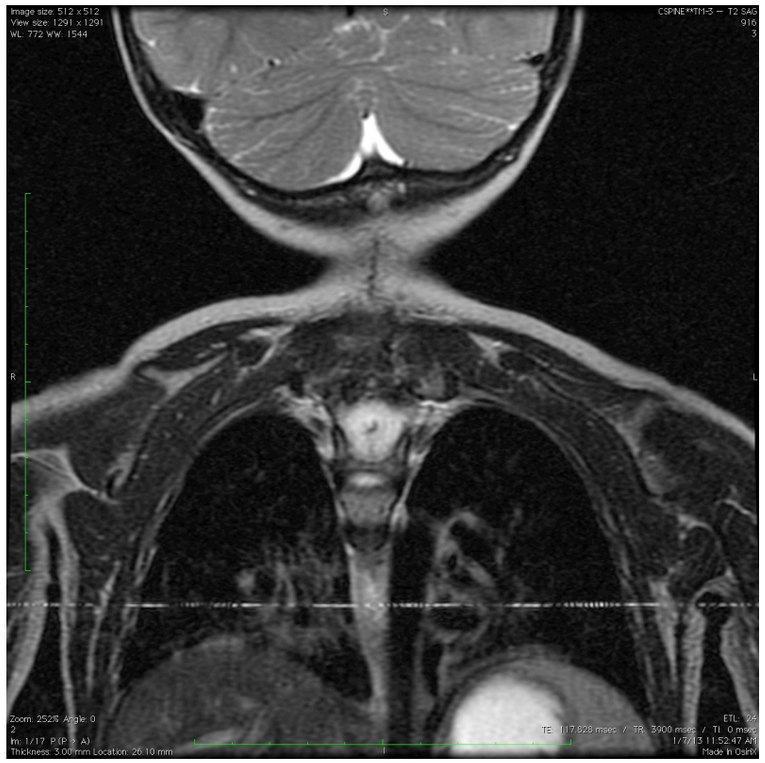


Causes:

Extraneous RF signal leaking into room during readout.

Contaminates the received signal.

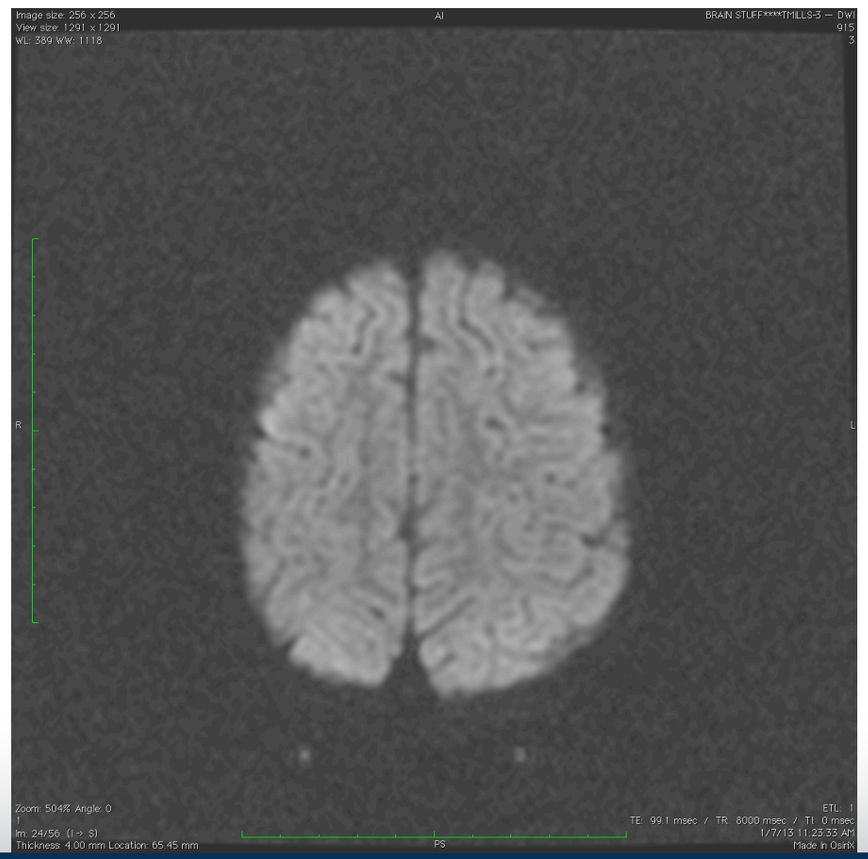
Zippers



Pictures from Yanasak, et al. (MRI: Artifacts RSNA web module)

Zippers may also change in appearance on different sequences (due to BW, TE, etc…)

See pMRI later.



Zippers

Common Occurrences:

Breached RF shielding of scan room.

Faulty scan room door.

Incompatible or malfunctioning medical equipment inside MR scan room

Remediate:

Make sure that door is closed.

Have equipment within the scan room serviced

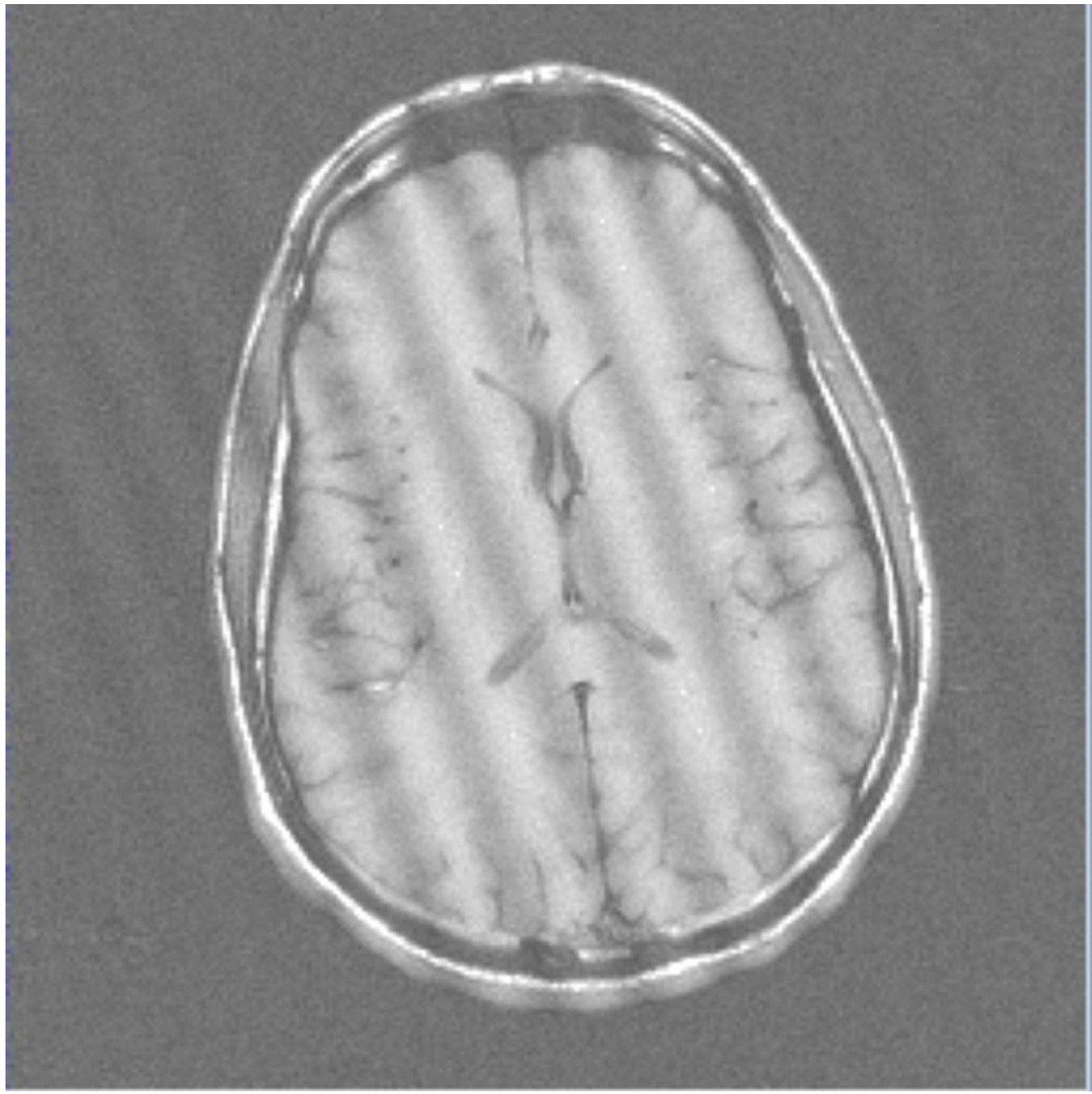
Call field engineer to find RF leak in shielding.

K-Space Spikes/Herringbone

Causes:

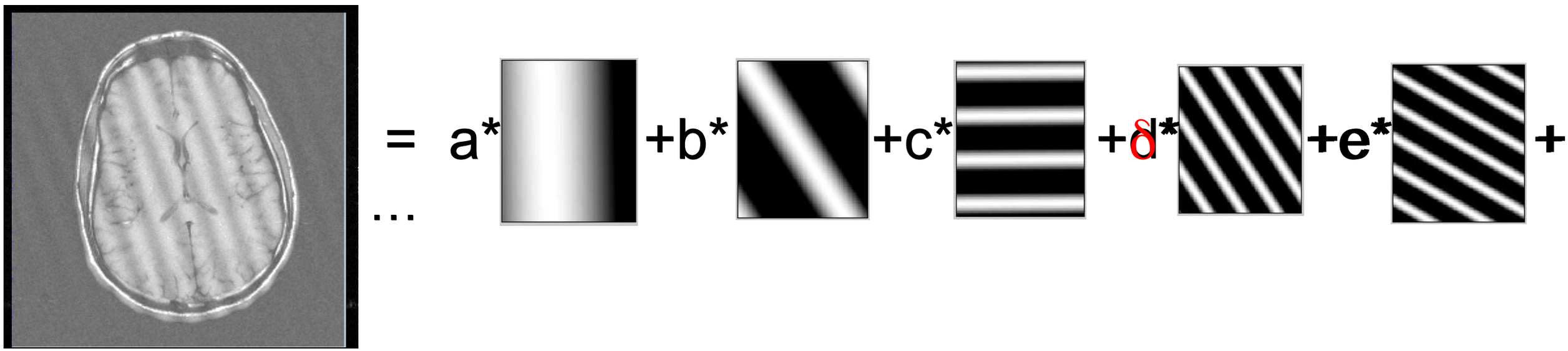
Erroneous detection of large signals at one or more times during readout.

Production of RF arcs in the scan room (e.g., light bulbs, vibrating metal).



Pictures from Yanasak, et al. (MRI: Image Formation RSNA web module)

K-Space Spikes/Herringbone



Common Occurrences:

Can appear in any image.

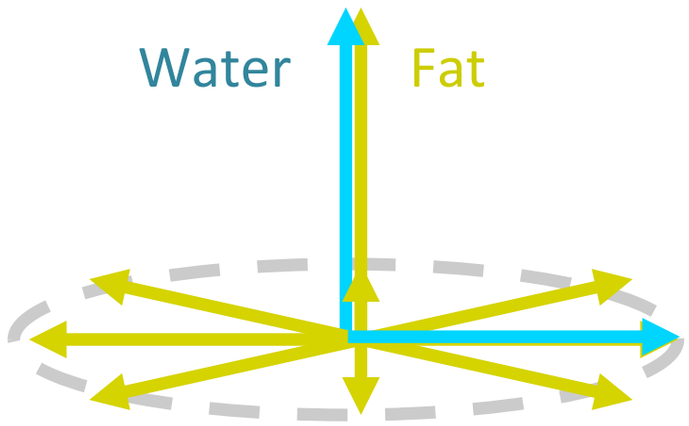
Remediate:

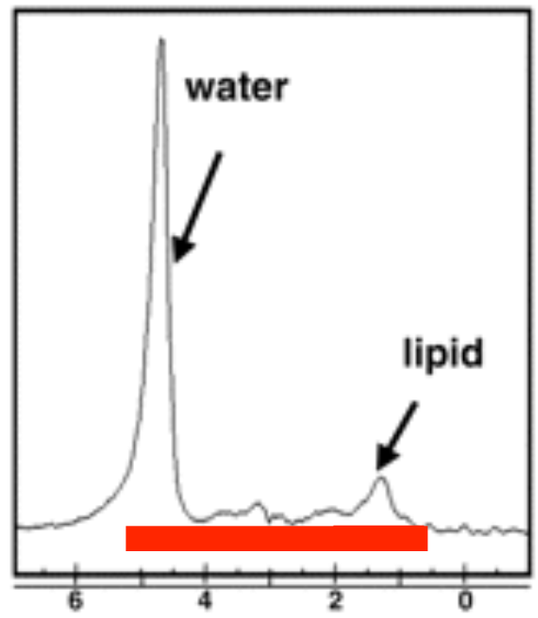
Check lights in room.

Call your field engineer.

Tissue Property-Based Artifacts

Fat Sat Failures





Causes:

Resonant frequency of fat is not uniform in the image.

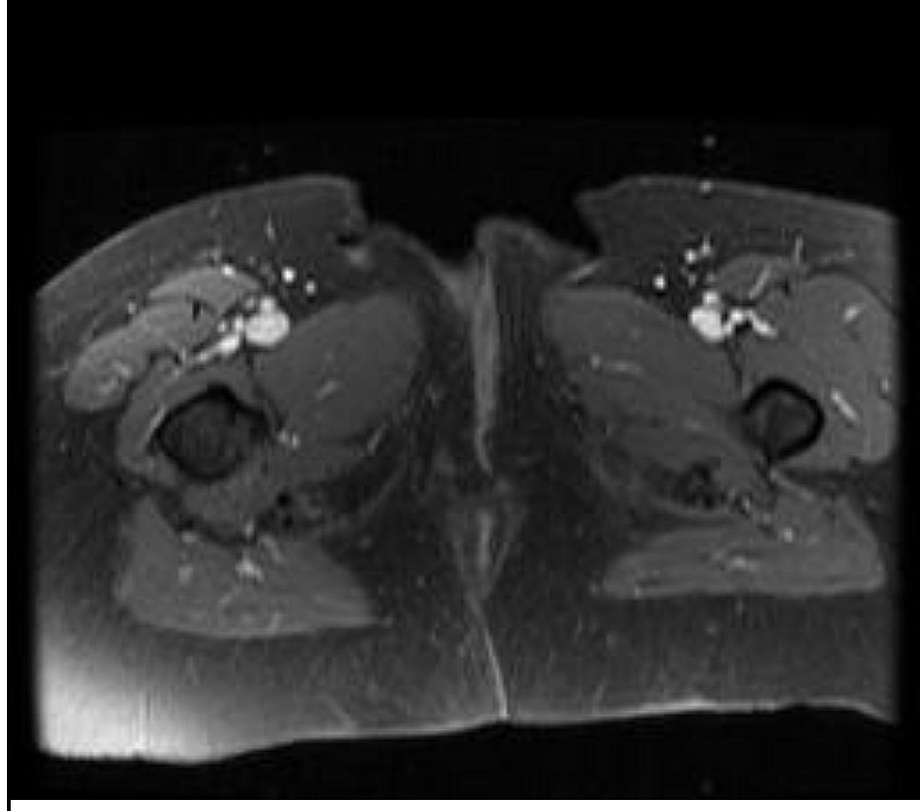
Fat Sat Failures

Common Occurrences:

MRI scanner with poorly-shimmed magnetic fields.

Anatomy is distant from magnet isocenter (e.g., shoulder).

Non-uniform anatomy in FOV (e.g., breast, orbits, brachial plexus)



Picture from Yanasak, et al. (MRI: Artifacts RSNA web module)

Remediate:

Apply shimming within the ROI.

Do not shim over regions with differing susceptibility.

Move anatomy as close as possible to isocenter.

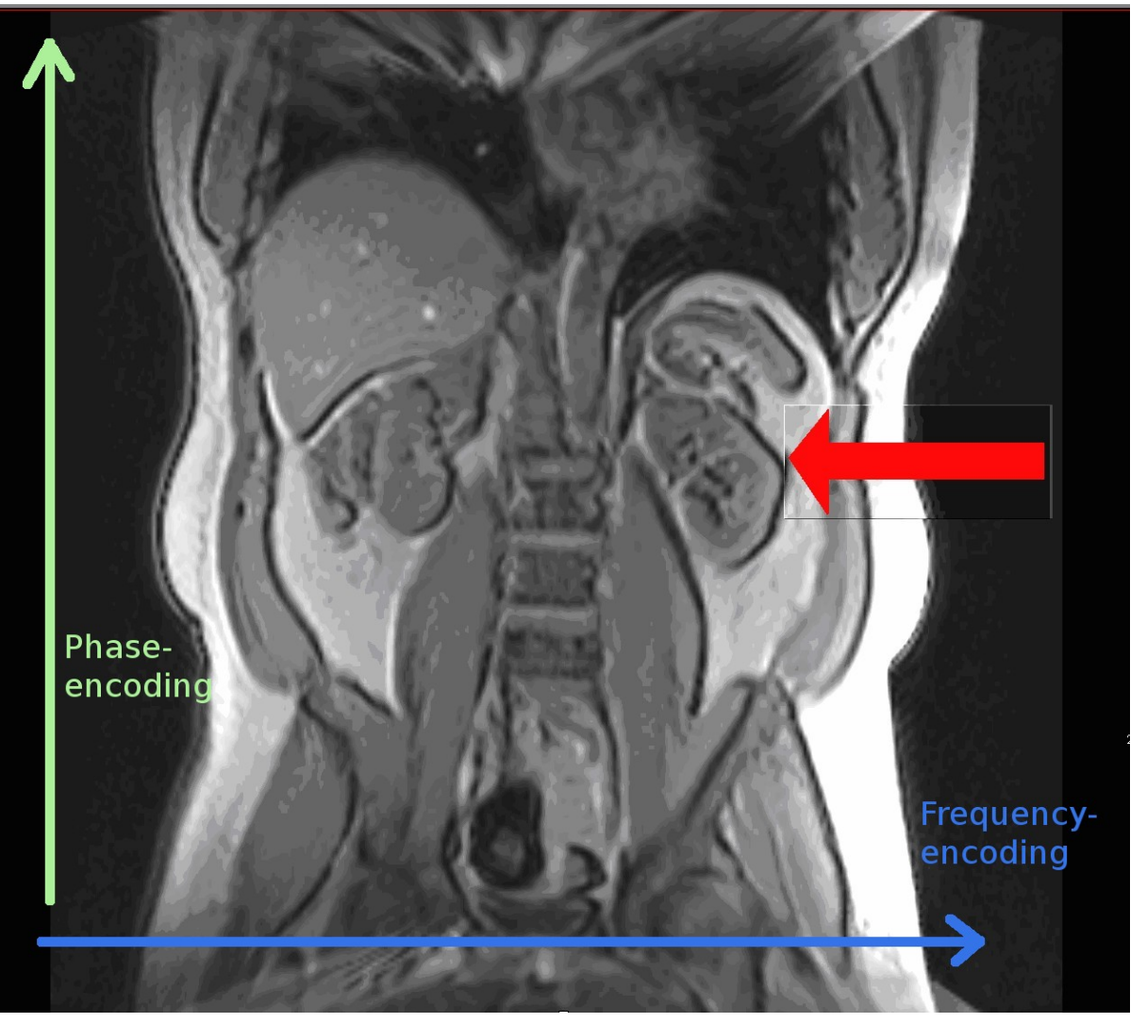
For fingers, ask the patient to hold them together.

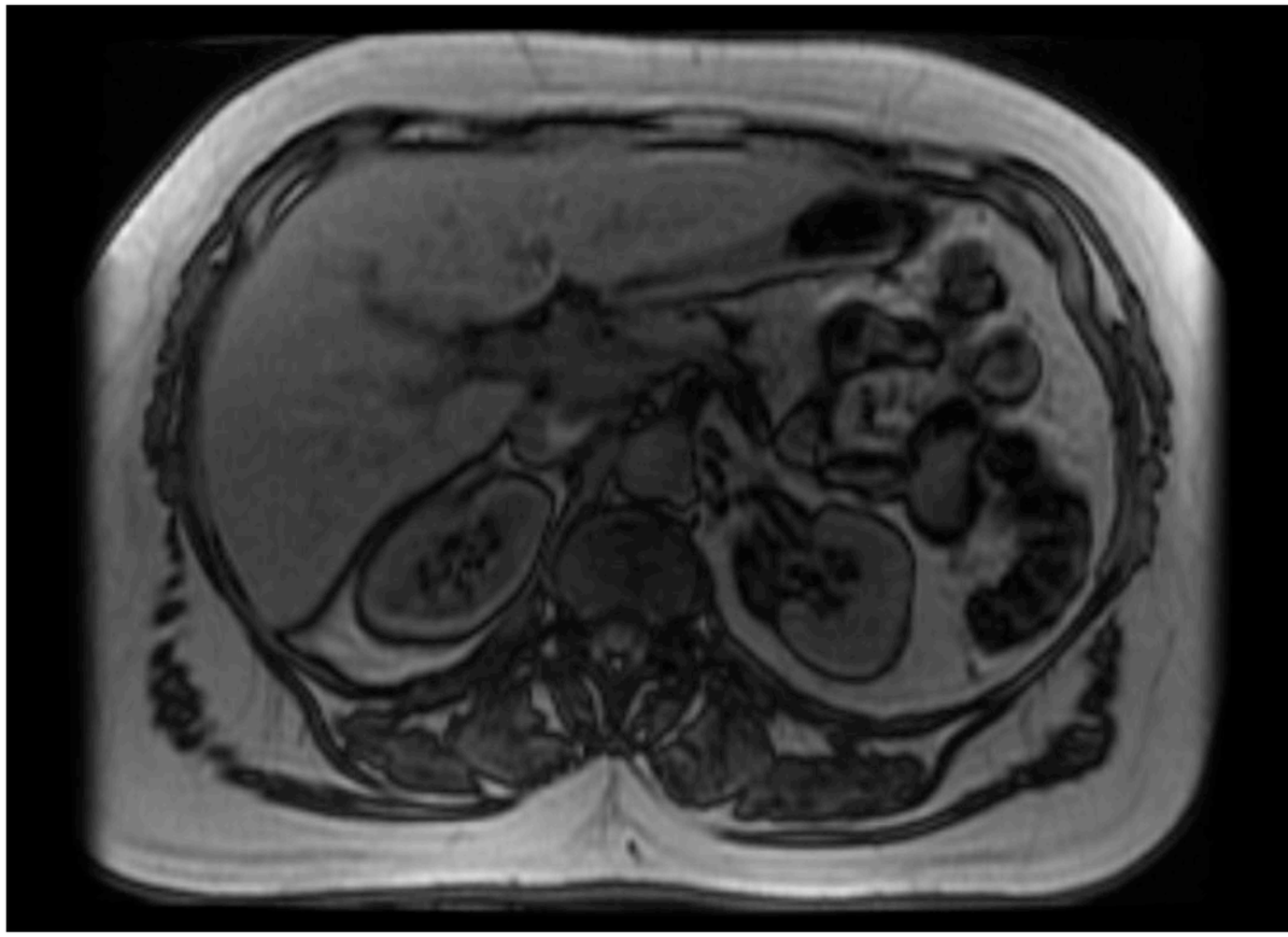
Lee, et al. Radiographics, 2007.

Pictures from Yanasak, et al. (MRI: Image Formation RSNA web module)

Chemical Shift

Pictures from Yanasak, et al. (MRI: Artifacts RSNA web module)





Causes:

Fat and water have different resonant frequencies.

Tissues near each other that are pure water or pure fat.

Type 1 artifact: small receiver bandwidths

Type 2 artifact: TE choices make fat and water out of phase with each other.

Chemical Shift

Common Occurrences:

Type 1: head – skin and subcutaneous fat abdominal imaging: kidney and intra-abdominal fat

Type 2: Abdominal imaging

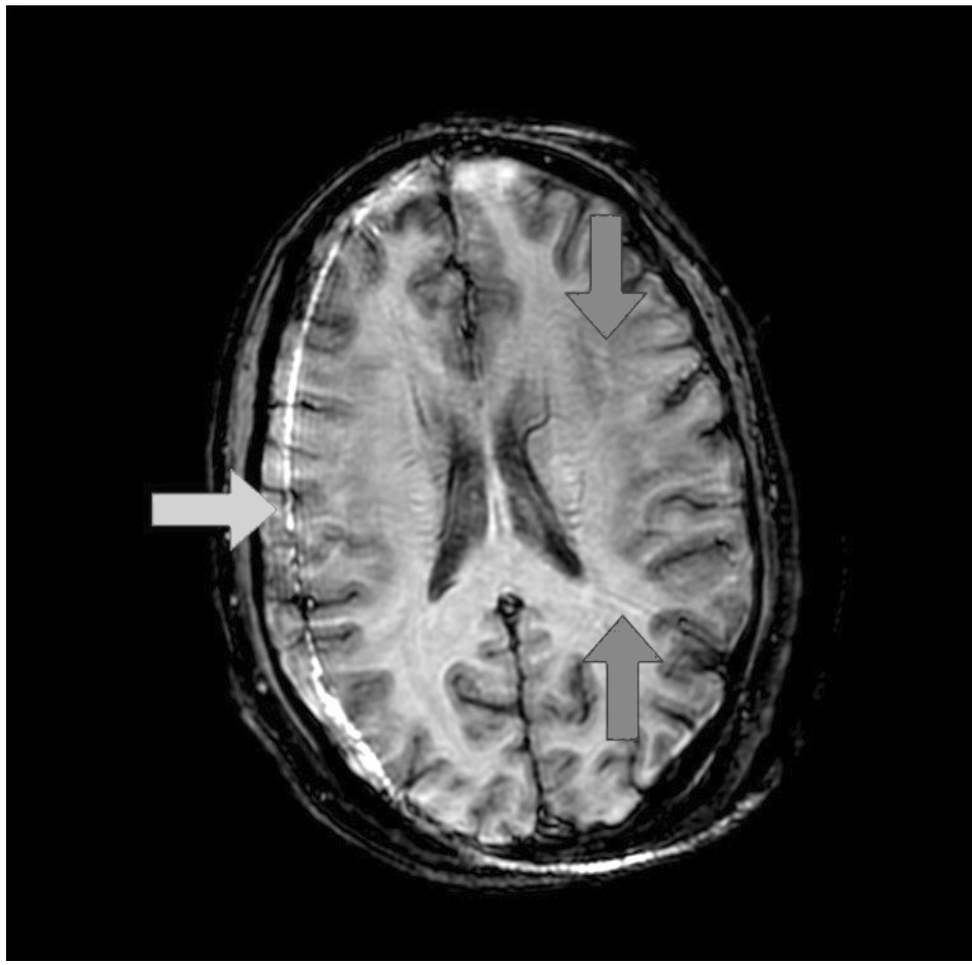
Remediate:

Type 1: increase the BW

Type 2: adjust TE such that fat and water are mostly in phase

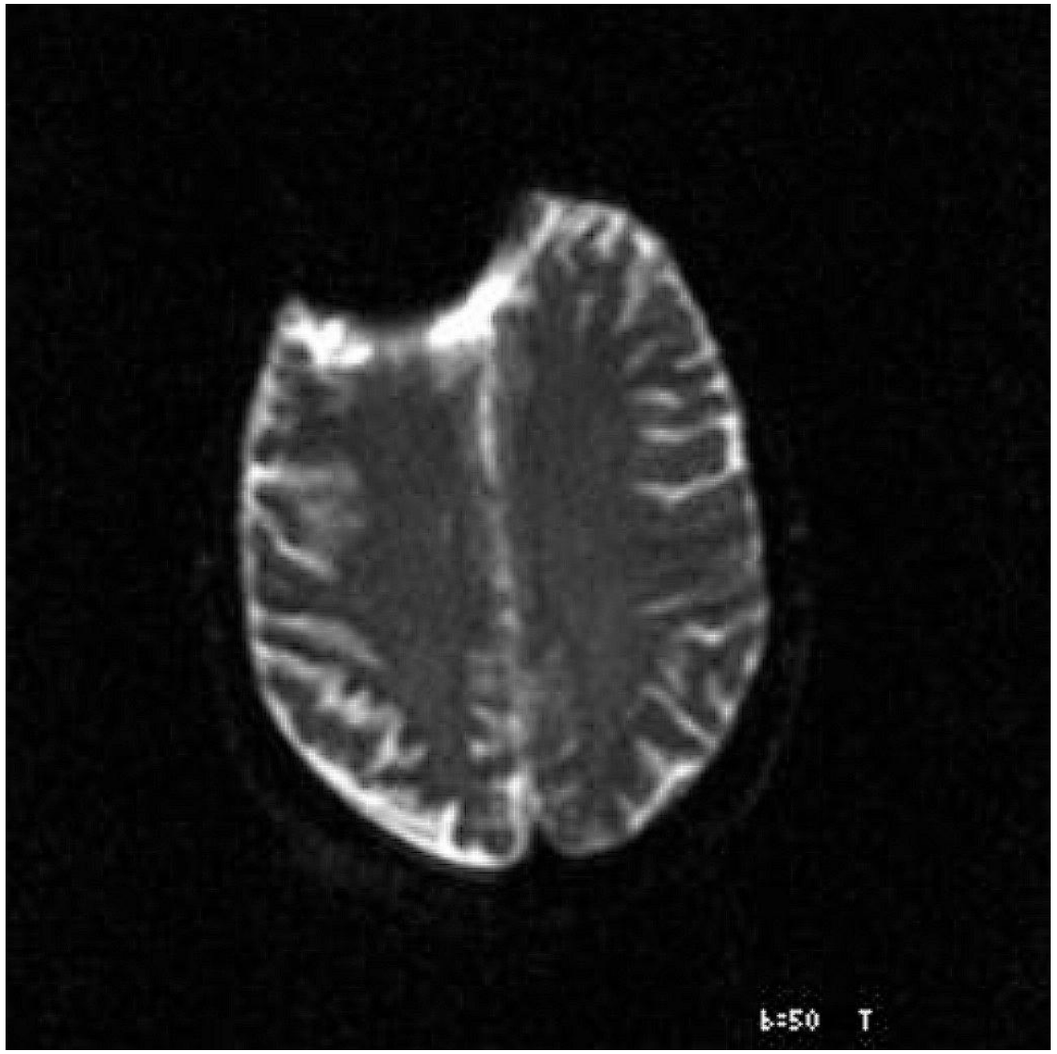
Lengthen TE > 30 msec, and shim over the FOV.

Flip phase- and frequency-encoding to confirm.

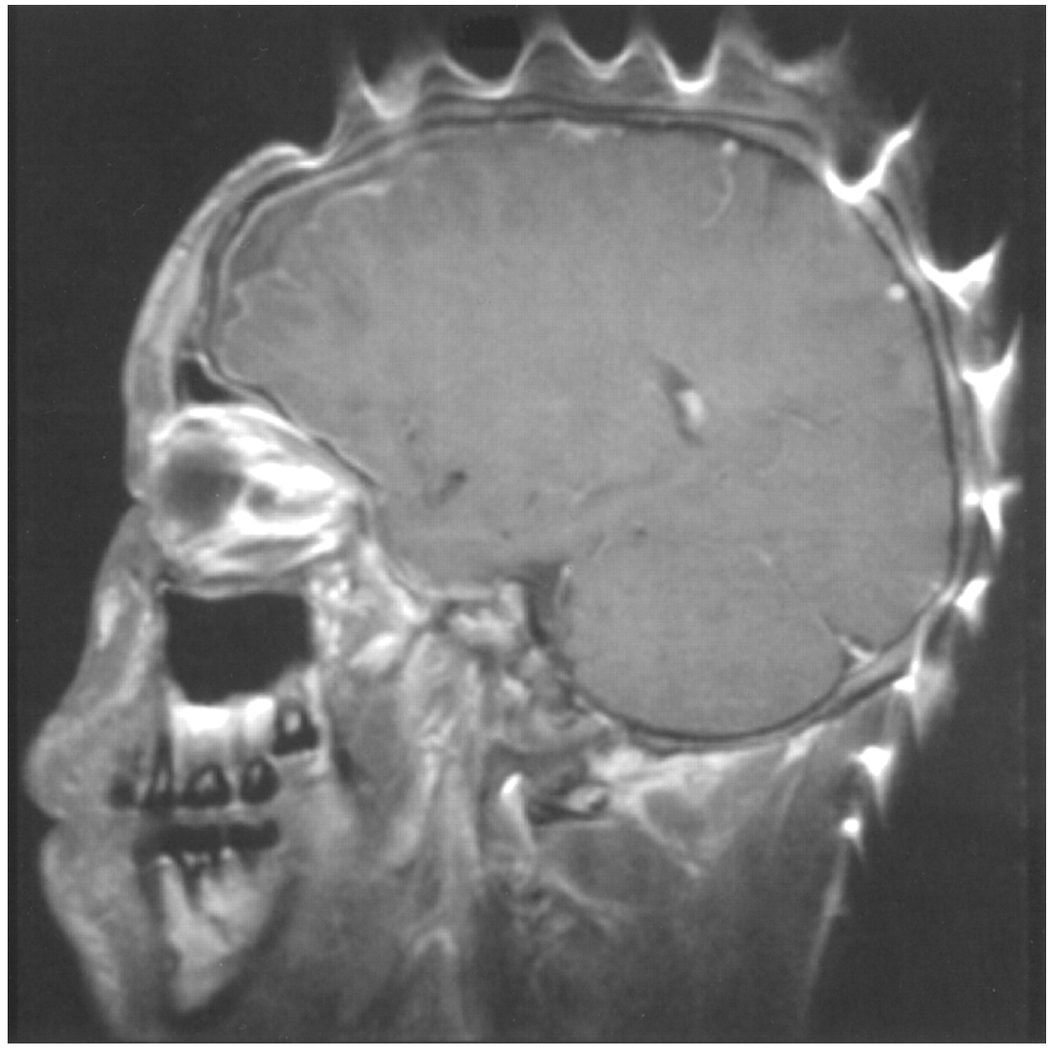


Kelly & Yanasak, Radiographics, 2014

Susceptibility



Picture from Yanasak, et al. (MRI: Artifacts RSNA web module)



McKinstry & Jarrett, AJR 2004

Causes:

Unwanted regional changes in magnetic susceptibility.

Presence of metal objects in patient or in scanner.

Susceptibility

Common Occurrences:

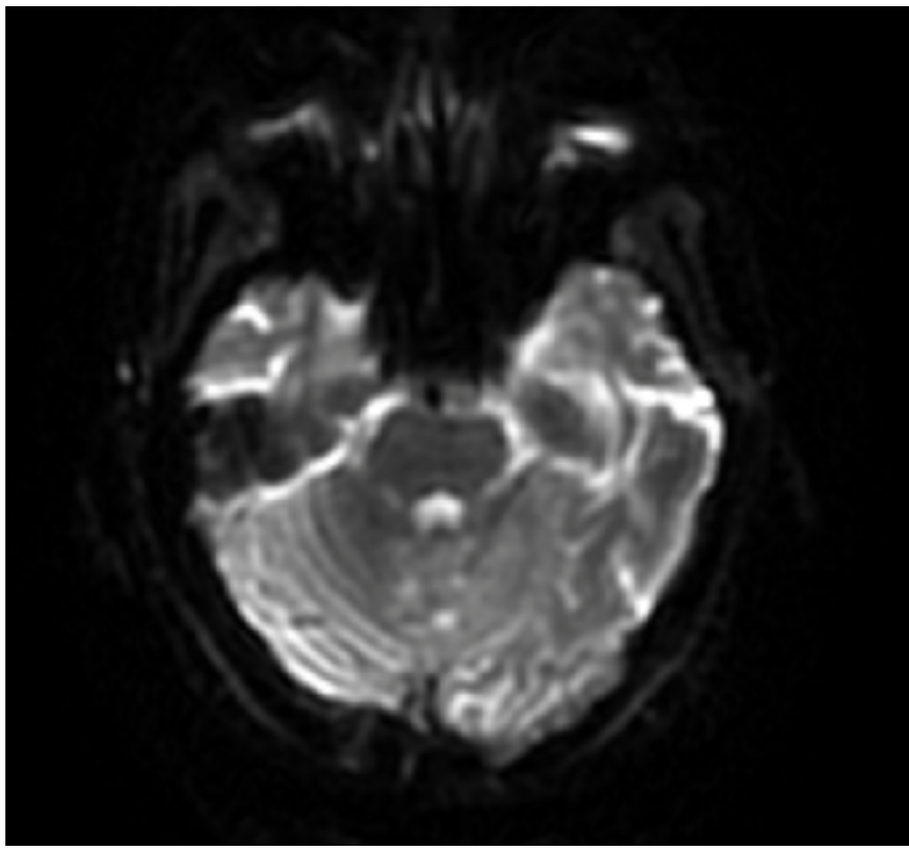
Near tissue boundaries

Near conducting material

Near ferrous material

Pathology (sometimes)

Picture from Yanasak, et al. (MRI: Artifacts RSNA web module)



Remediate:

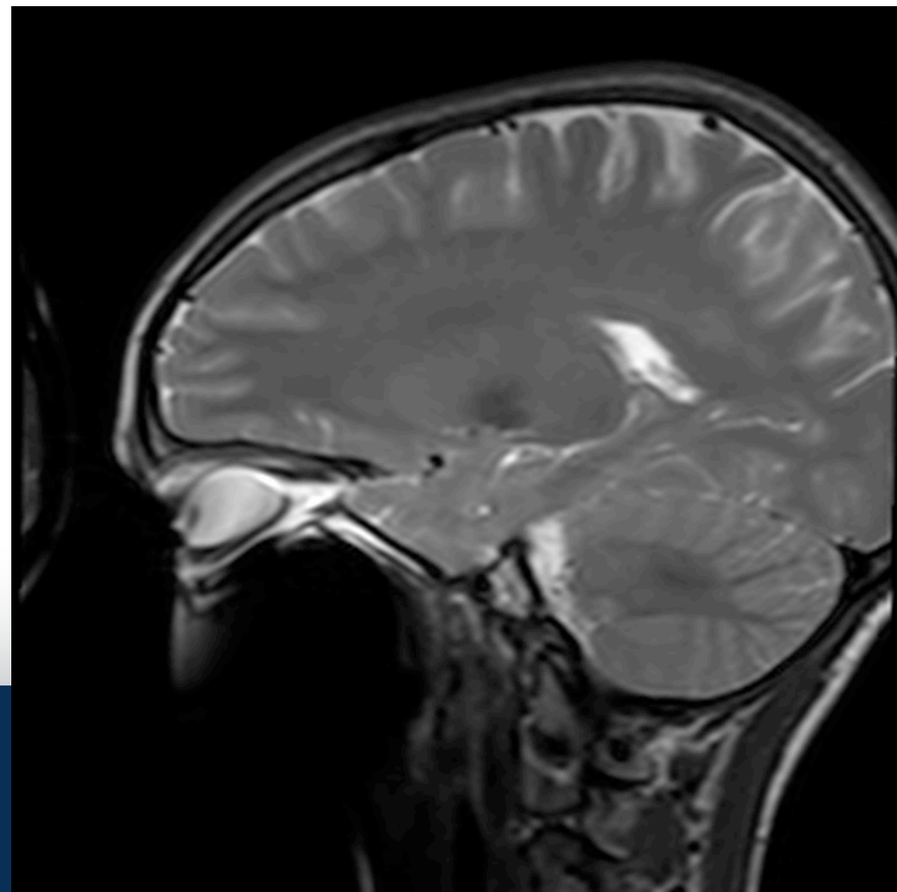
Remove metal

Use non-GRE sequences and non-EPI* (see later)

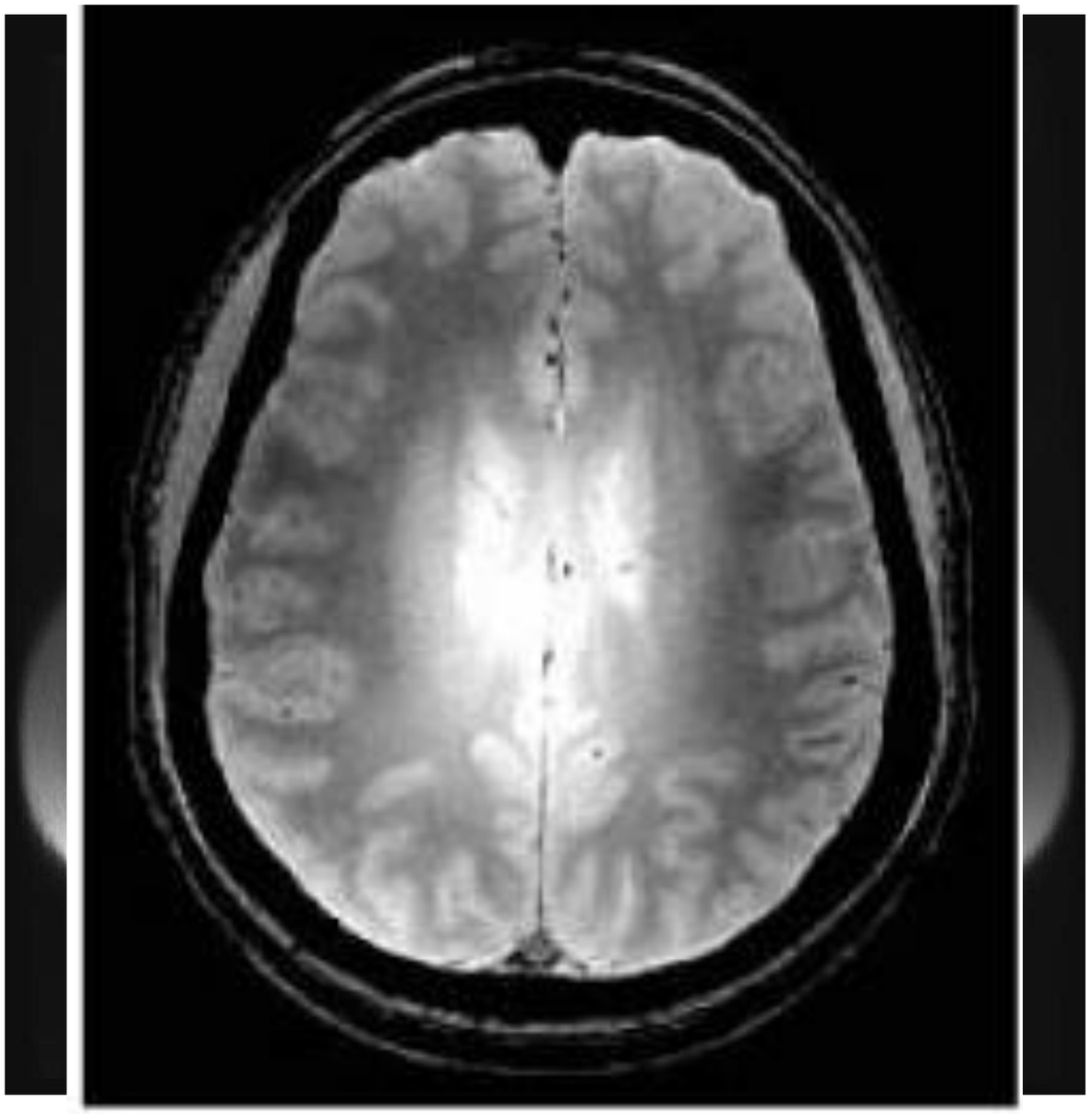
Increase BW & matrix (meh…)

Decrease slice thickness (meh…)

Try parallel imaging (if minor)

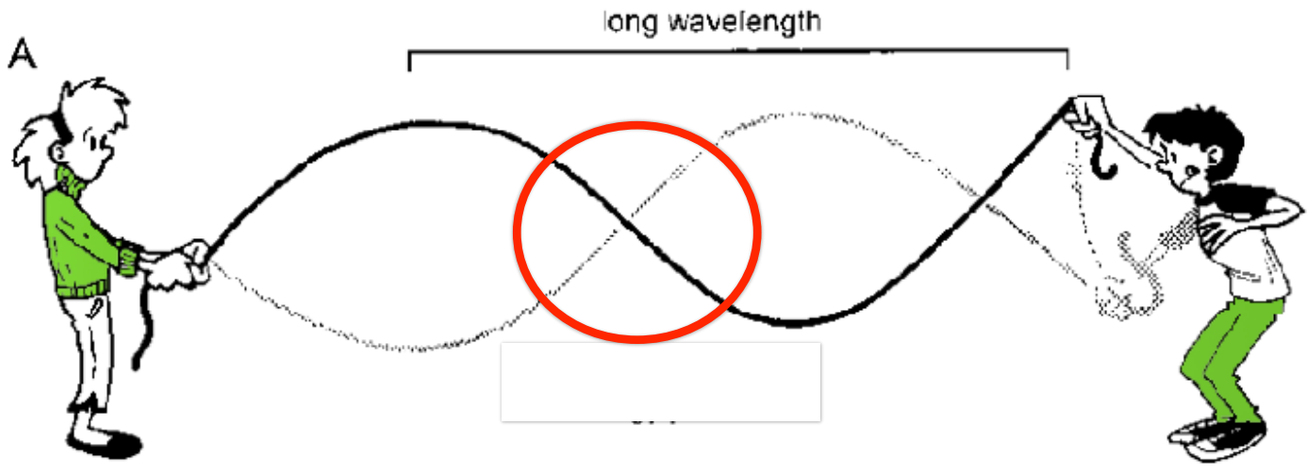


Dielectric Effect



Picture from Yanasak, et al. (MRI: Artifacts RSNA web module)

Basically, if the RF wavelength is comparable to anatomical width, we can get standing-wave currents set up → RF "node"



From https://hishamsrevisionblog.wordpress.com/physics-chapter-2notes/

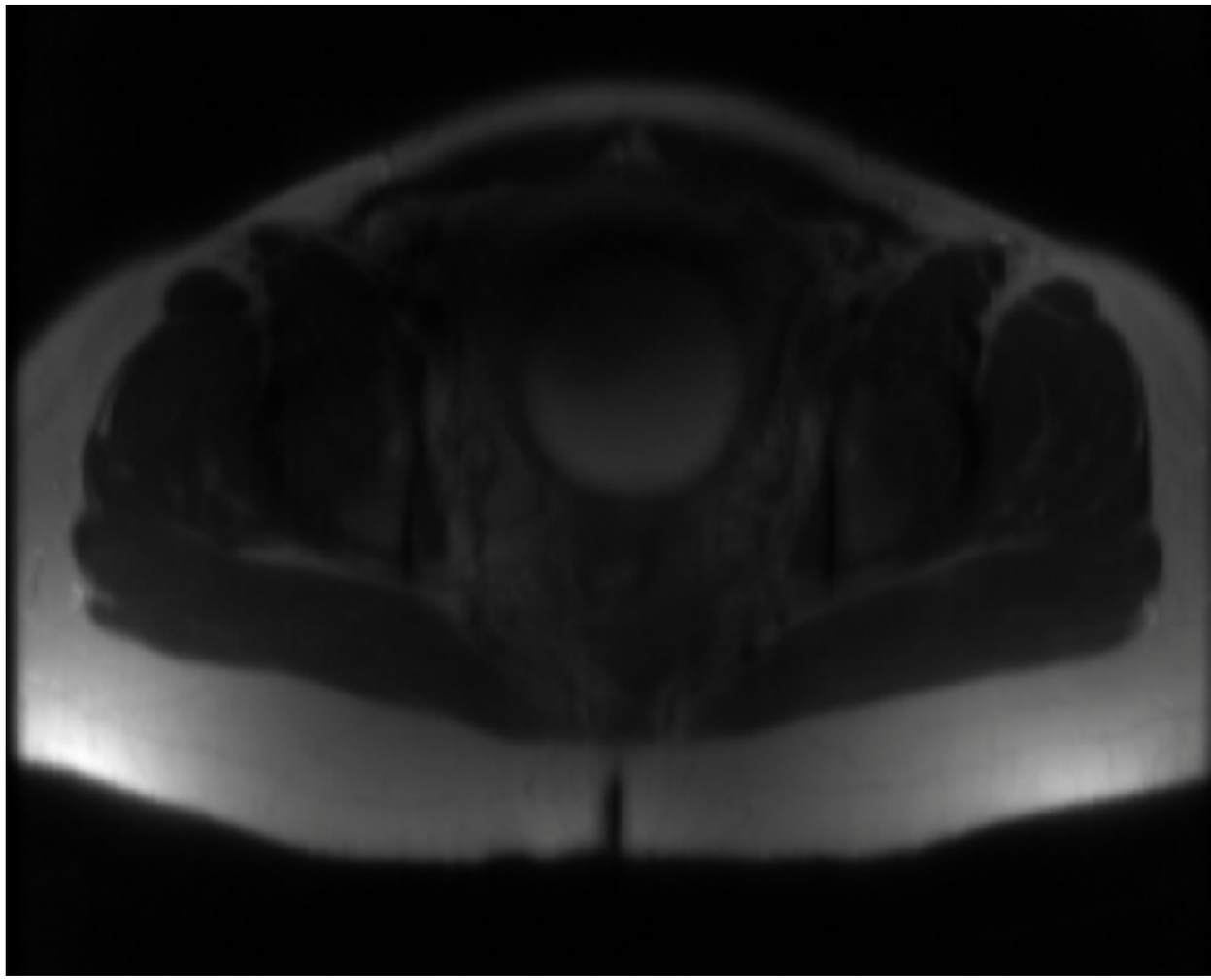
Causes: 7T head image (Merkle, et a. MRM, 2012)

Variation in tissue conductivity.

Large diameter anatomy (comparable to RF wavelength)

Dielectric Effect

Picture from Yanasak, et al. (MRI: Artifacts RSNA web module)



Common Occurrences:

Abdominal imaging

Spinal imaging

Imaging of large water volume (e.g., pregnancy, ascites)

Obesity

Higher-field MR (3T)

Remediate:

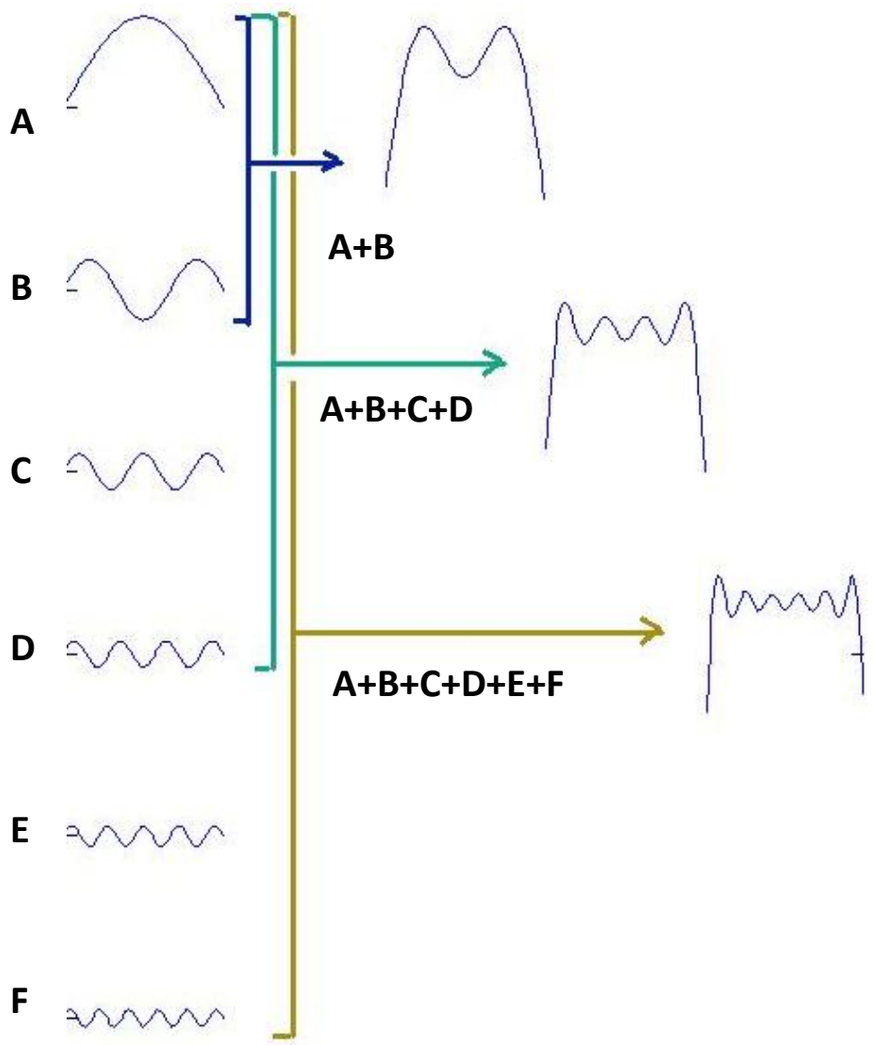
Use dielectric pads

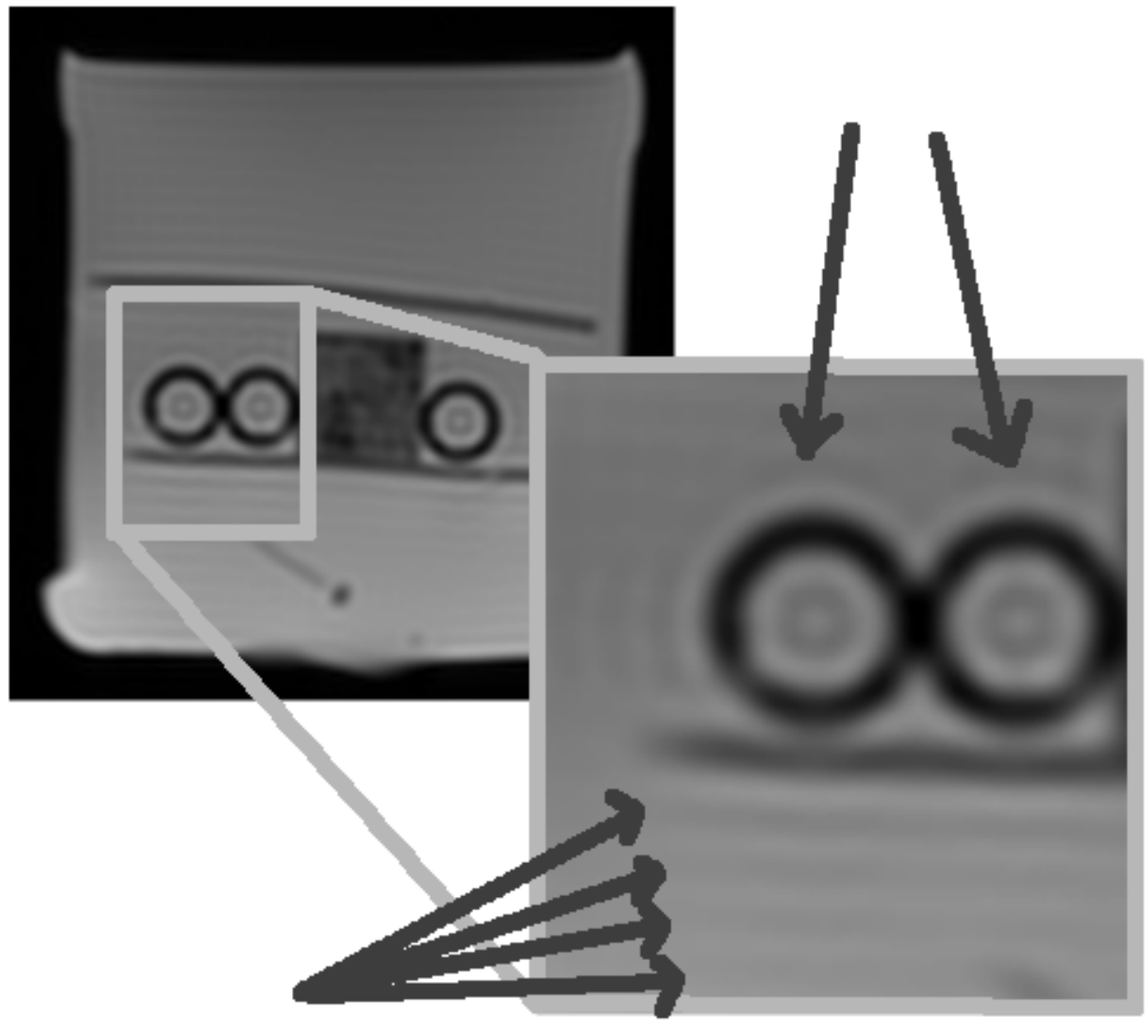
Engage multi-channel transmission if possible

Reschedule on 1.5T scanner.

Image Reconstruction Artifacts

Gibbs Ringing/Truncation





Picture from Yanasak, et al. (MRI: Image Formation RSNA web module)

Causes:

Fourier-based imaging technique leads to image errors near sharp boundaries.

Gibbs Ringing/Truncation

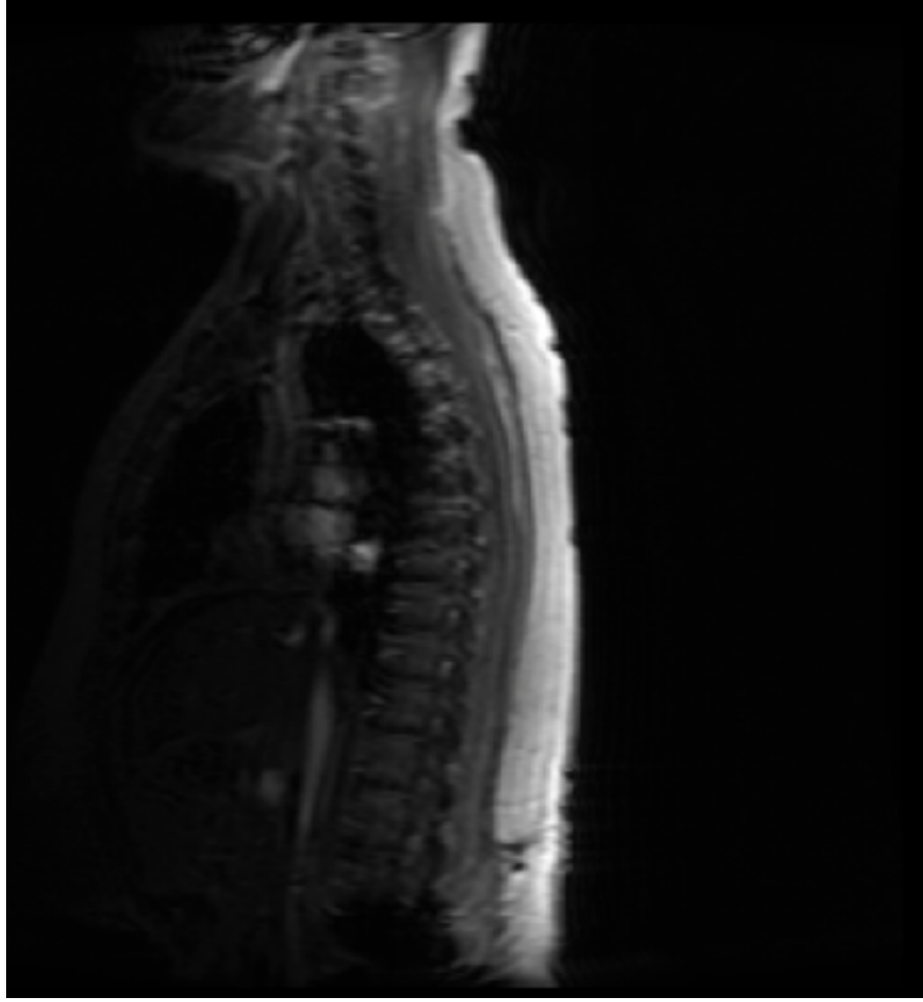
Common Occurrences:

Images of spinal cord (near CSF)

Fluid-filled regions of T2W images

Boundaries of fat and tissue in T1W images

Pictures from Yanasak, et al. (MRI: Artifacts RSNA web module)

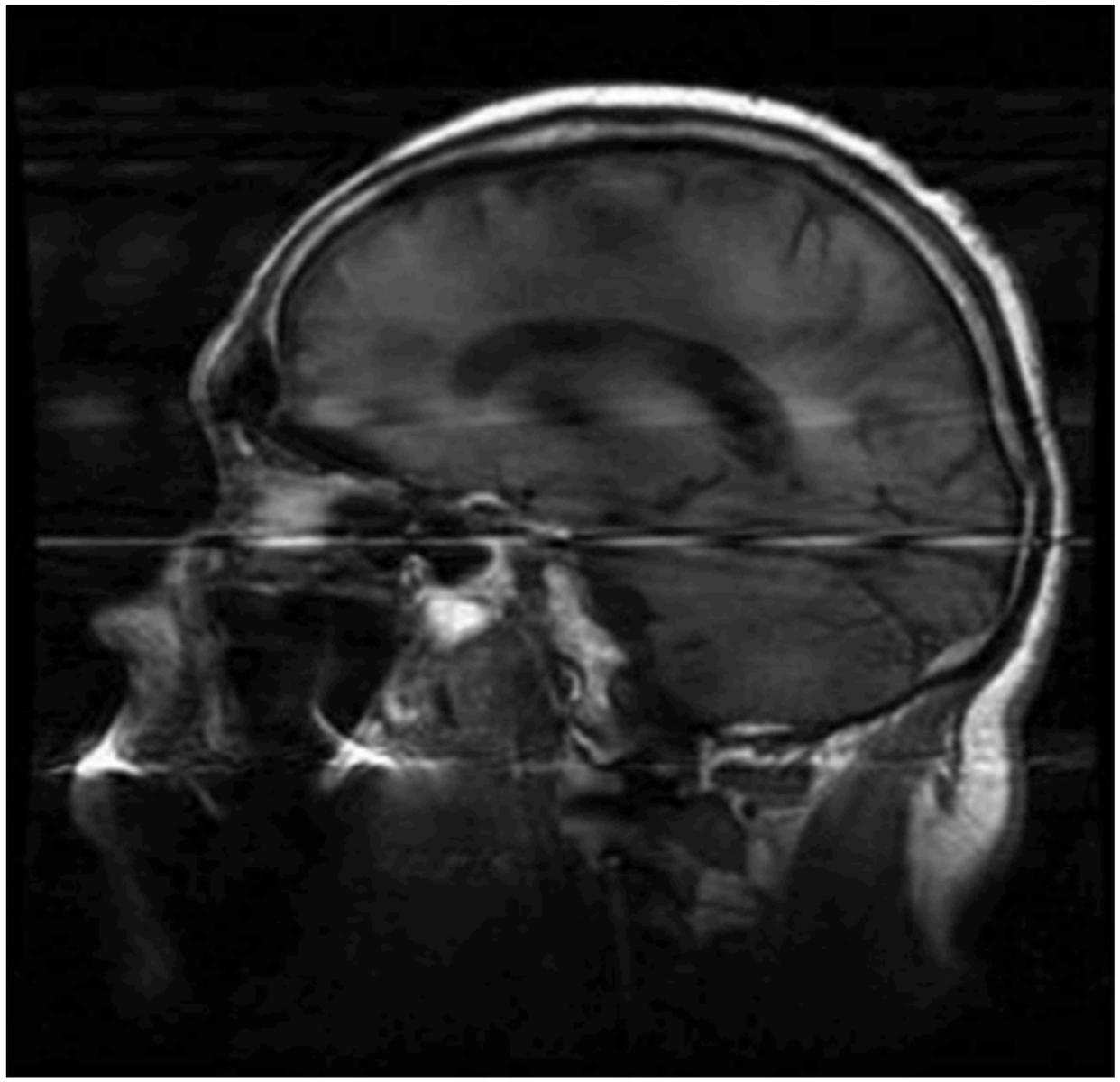


Remediate:

Increase the matrix

Apply post-reconstruction image filtration.

Gradient/Reconstruction Failures



Pictures from Yanasak, et al. (MRI: Artifacts RSNA web module)

Causes:

Gradients aren’t achieving expected performance.

Reconstruction engine failure

Look like profound encoding errors.

Gradient/Reconstruction Failures

Common Occurrences:

**Hopefully not.

pMRI has its own set of reconstruction failures (see later).

Remediate:

Call field engineer, PRONTO!

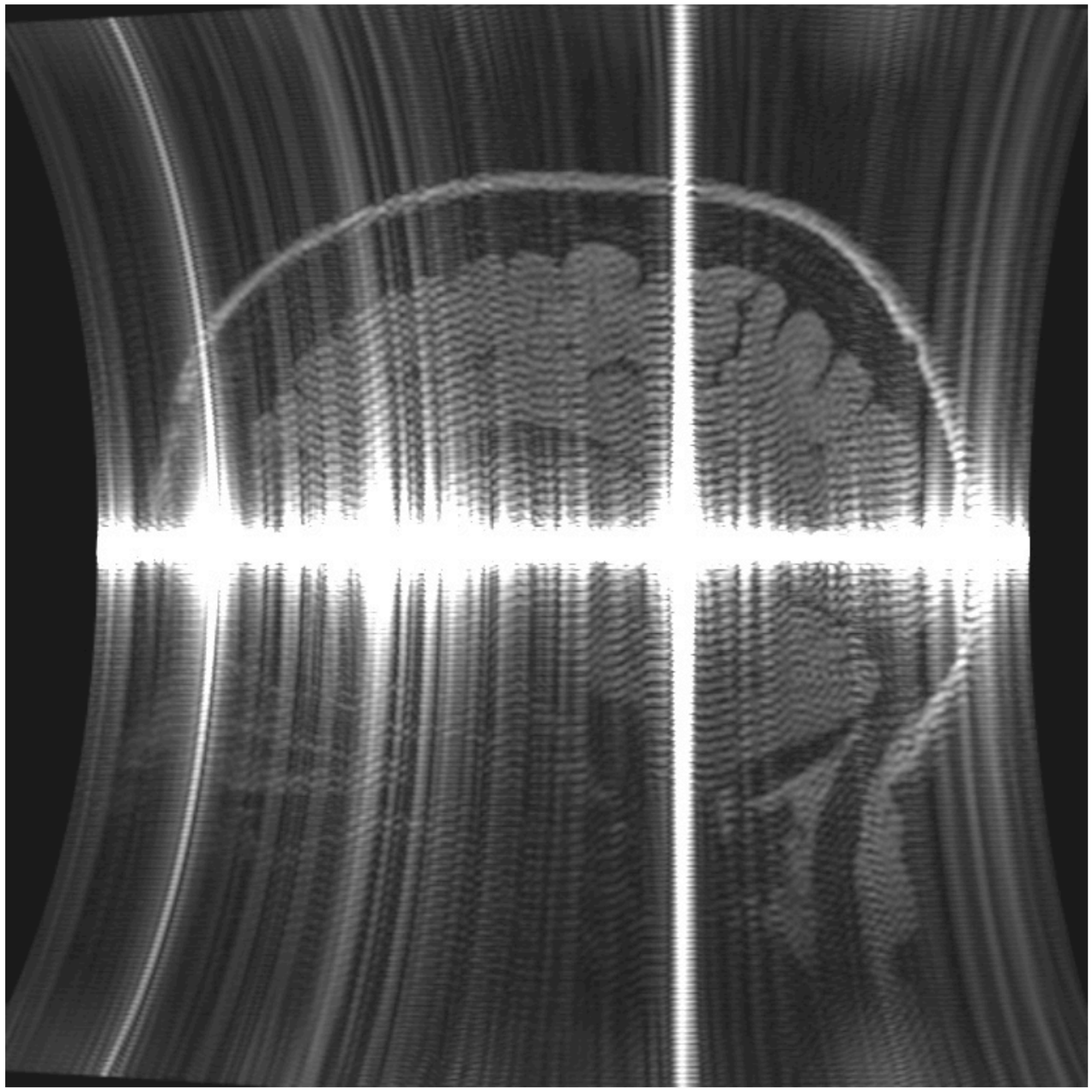
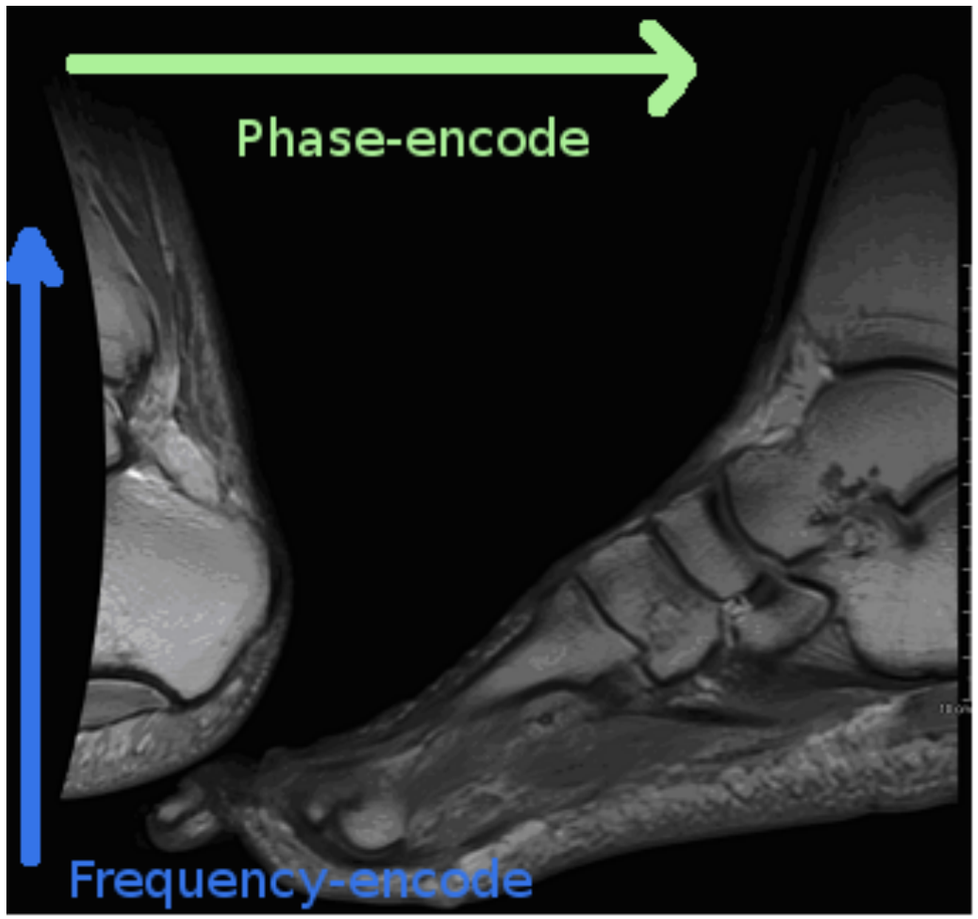
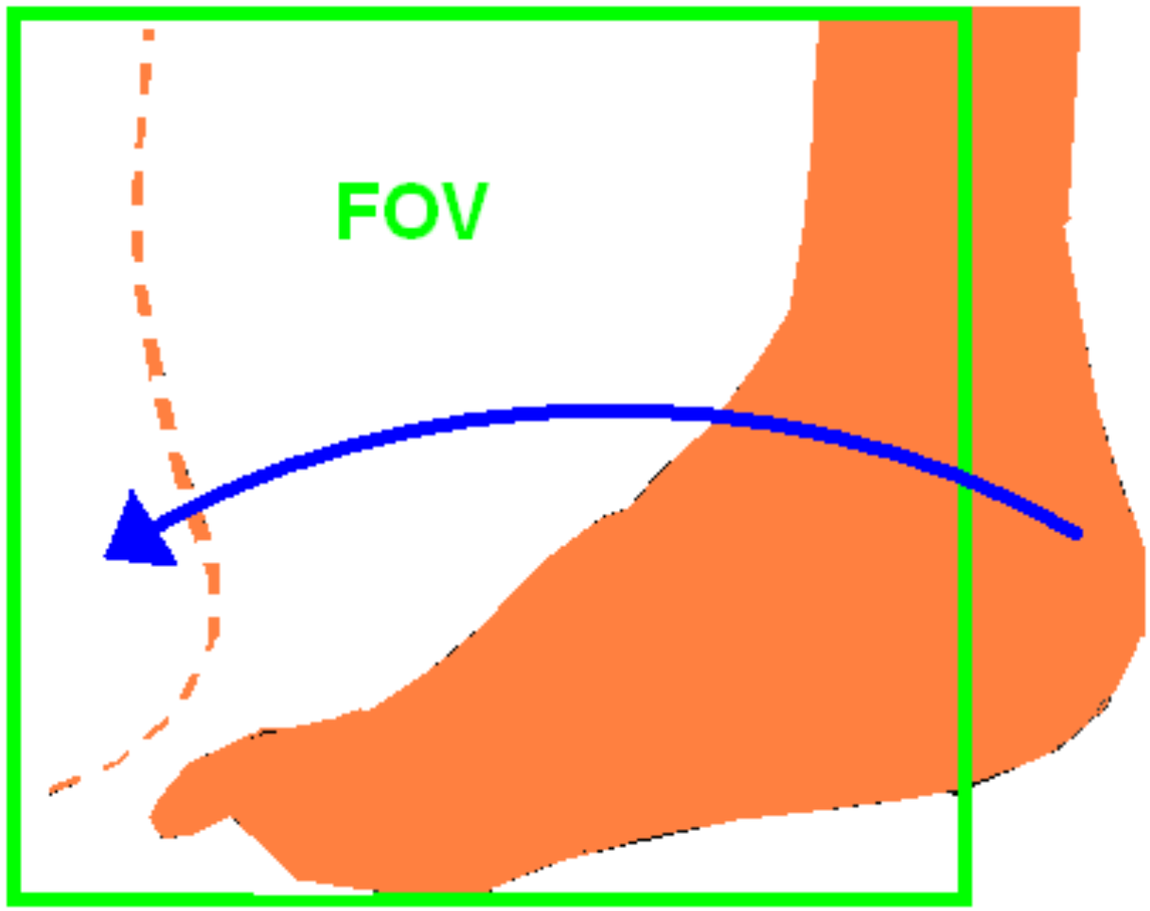


Image Prescription-Based Artifacts

Aliasing



Image



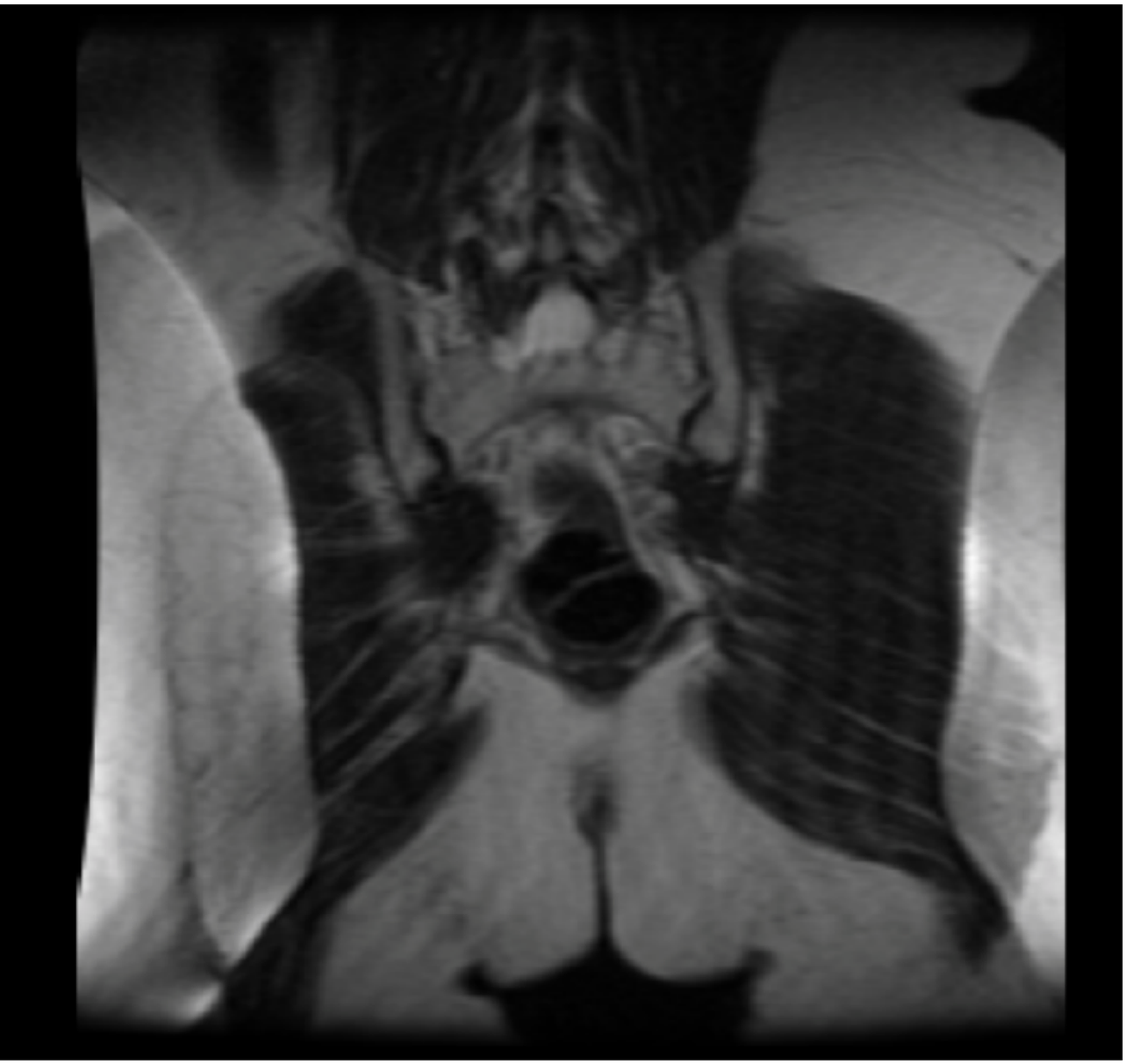
Schematic of FOV choice

Pictures from Yanasak, et al. (MRI: Image Formation RSNA web module)

Causes:

Tissue outside of the FOV is recorded artifactually within the FOV.

SE vs. GRE Aliasing



Pictures from Yanasak, et al. (MRI: Artifacts RSNA web module)

Appearance of aliasing for gradient echo- and spin echo-sequences is very different.

Aliasing

Common Occurrences:

Use of a FOV smaller than anatomy (e.g., cardiac)

3D sequences

Sagittal abdominal imaging (e.g., lumbar spine), with insufficient application of spatial sat bands outside FOV.

Remediate:

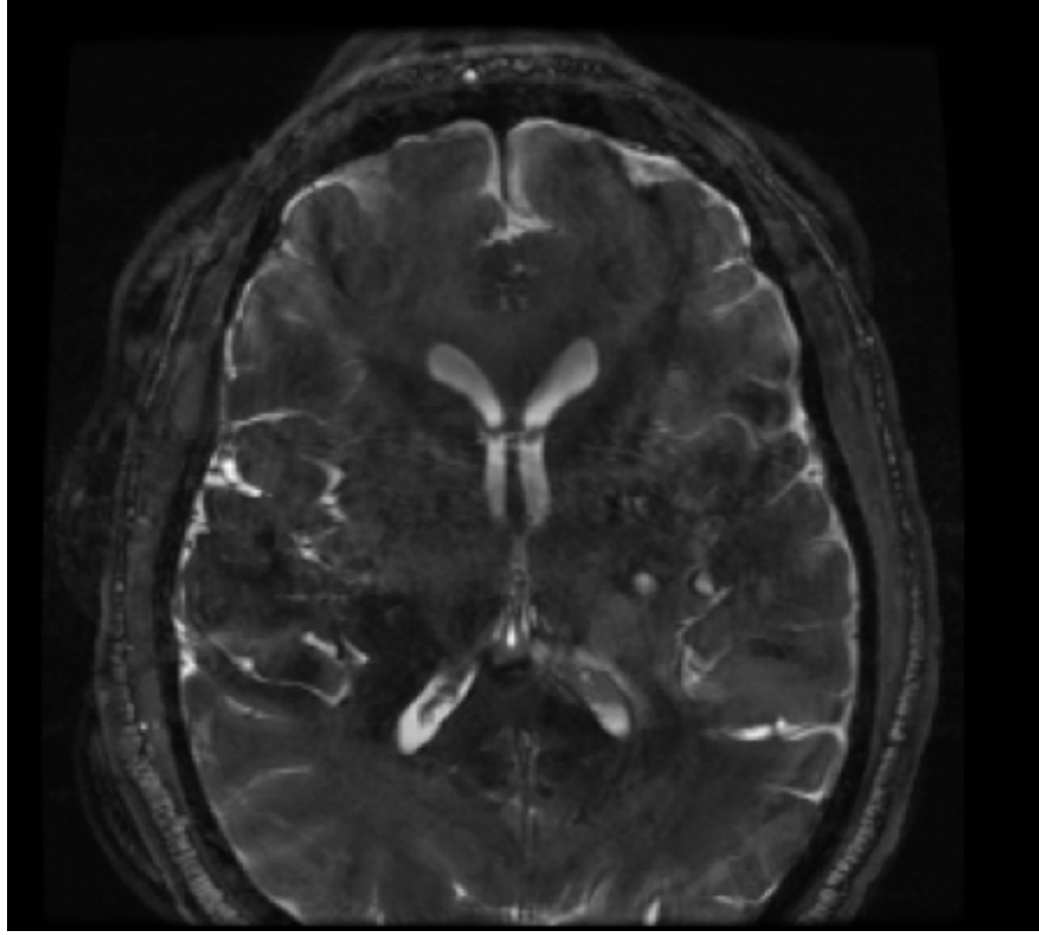
Orient thinnest axis of anatomy along the PE direction.

Phase oversampling (a little time).

Enlarge the FOV (loss of resolution).

Exclude ALL anatomy from the top few slices (3D).

Use spatial sat bands.



Pictures from Yanasak, et al. (MRI: Artifacts RSNA web module)

Ghosting-type Artifacts

General Comments on Ghosting

Causes (Many):

In MR, we usually expect the patient or tissue to hold still during imaging → spatial encoding can do its thing.

When motion occurs, tends to show along the phase-encoding axis.

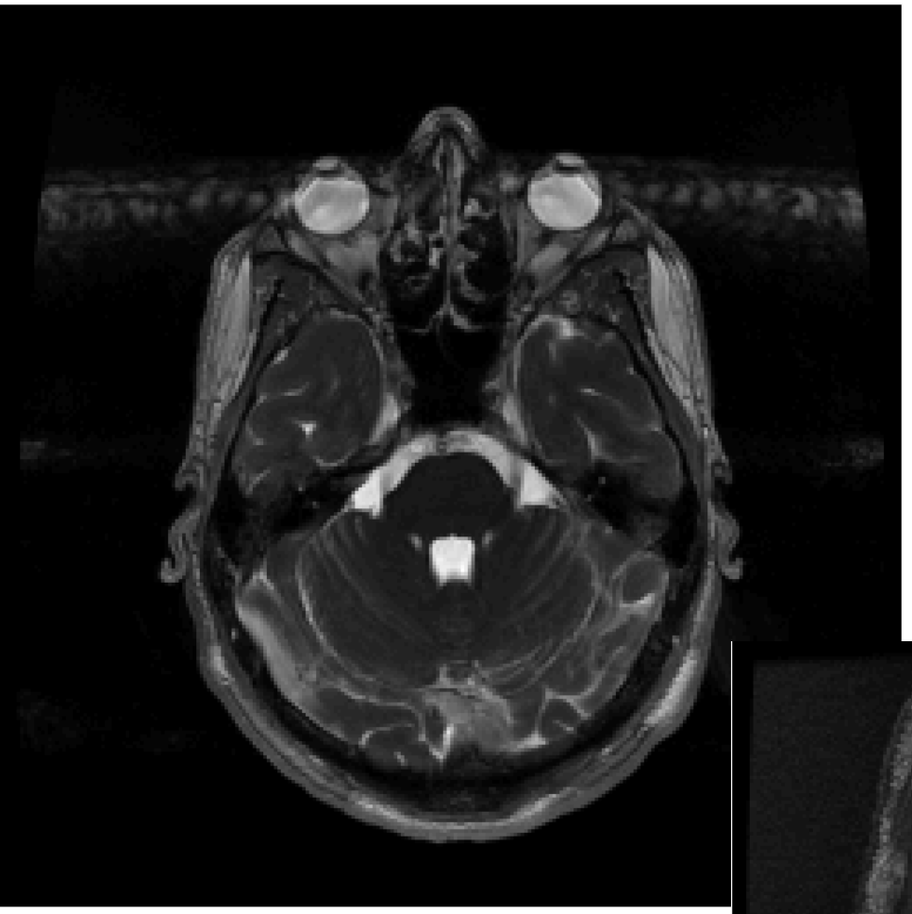
Patient or physiological motion

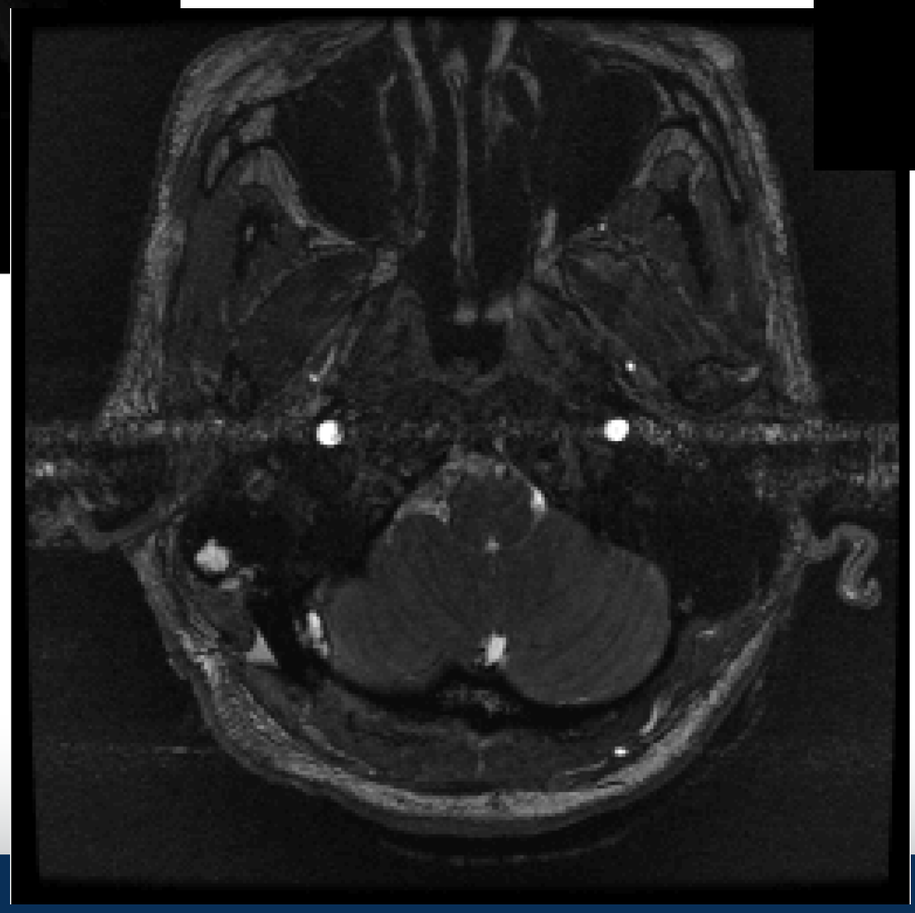
Pulsatile flow

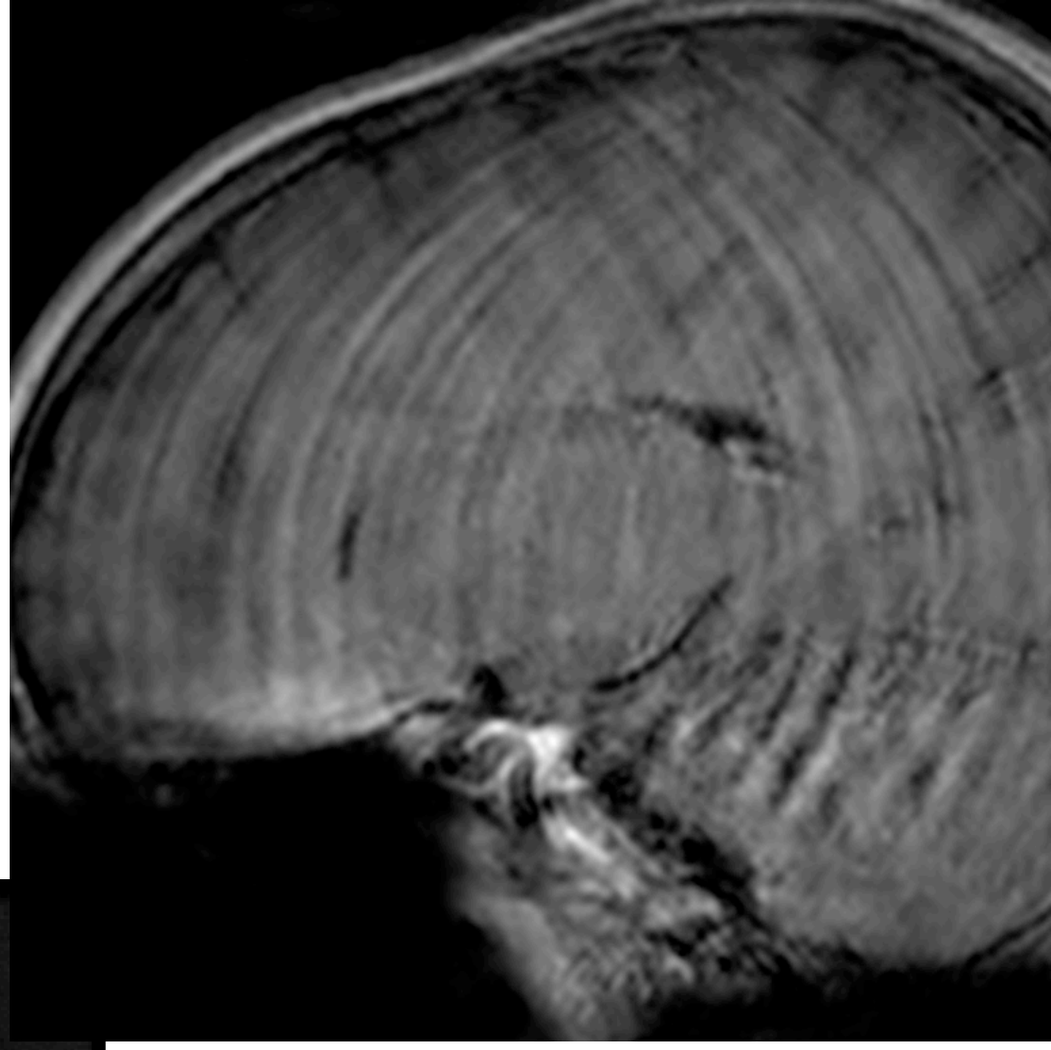
Other ghosing:

Errors in gradient performance (Nyquist)

Aperiodic Motion





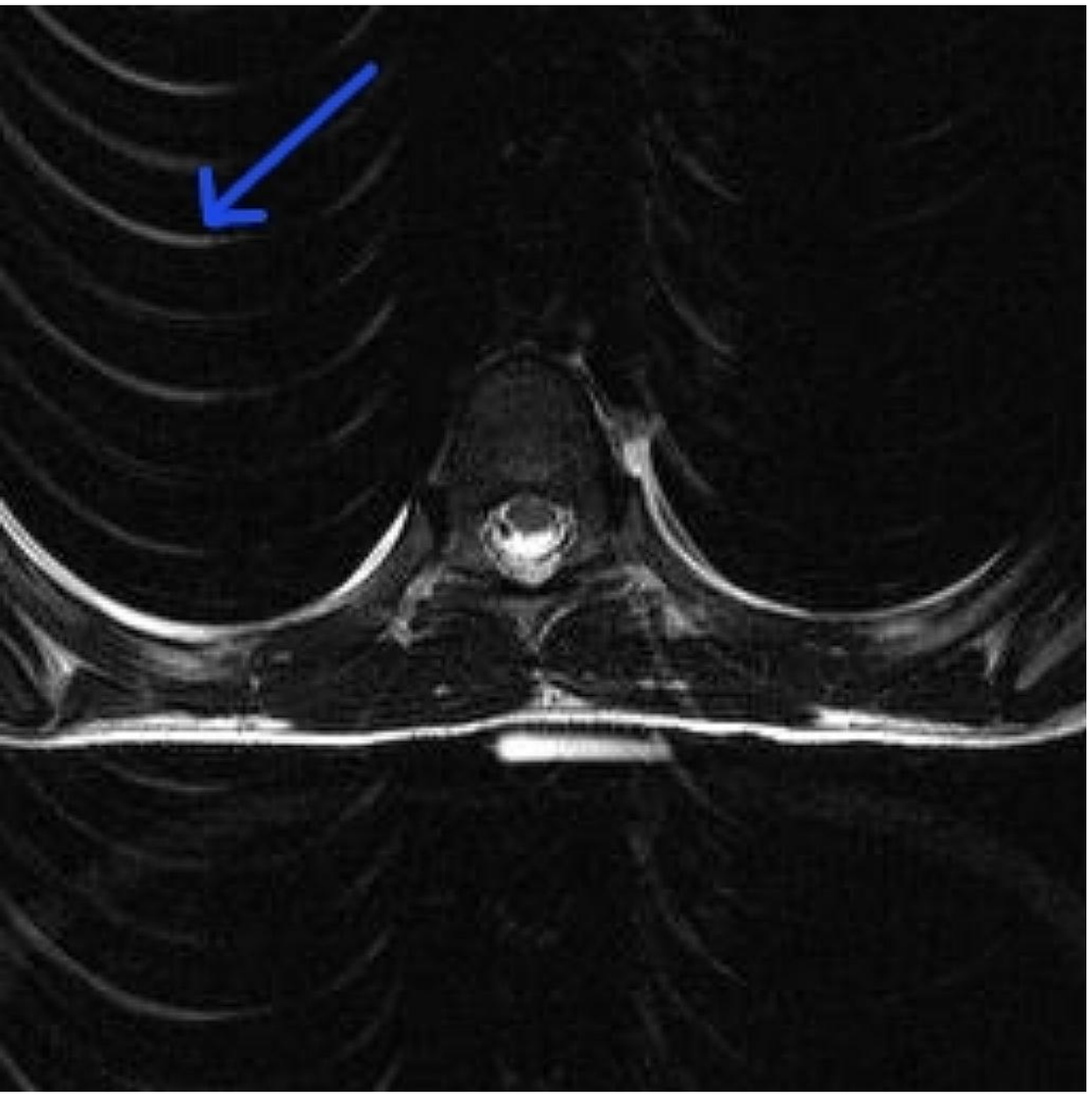


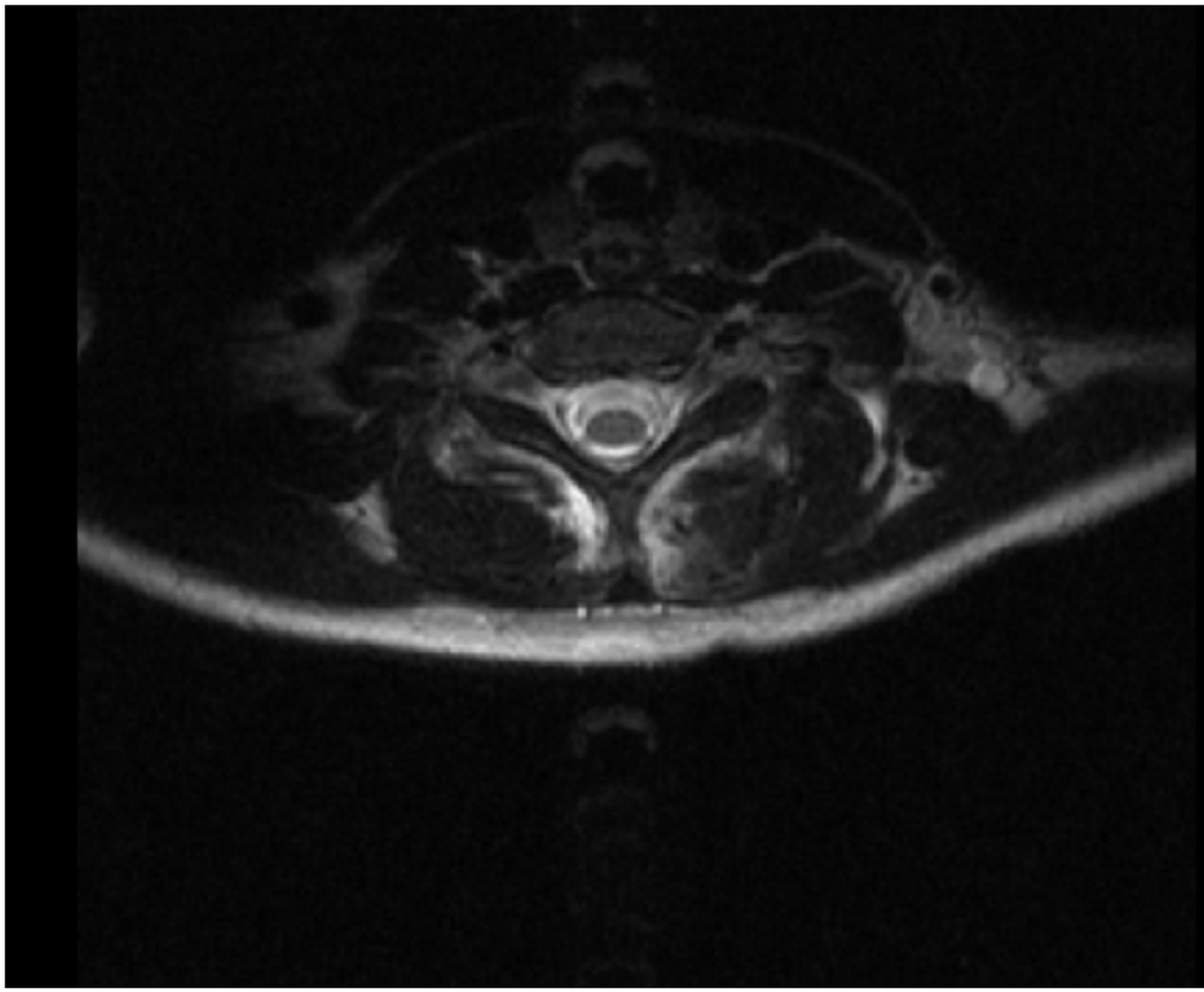
Pictures from Yanasak et al. (MRI: Artifacts RSNA web module)

Aperiodic motion leads to smear-like ghosting.

Trick question: what direction is the above patient moving?

Periodic Motion





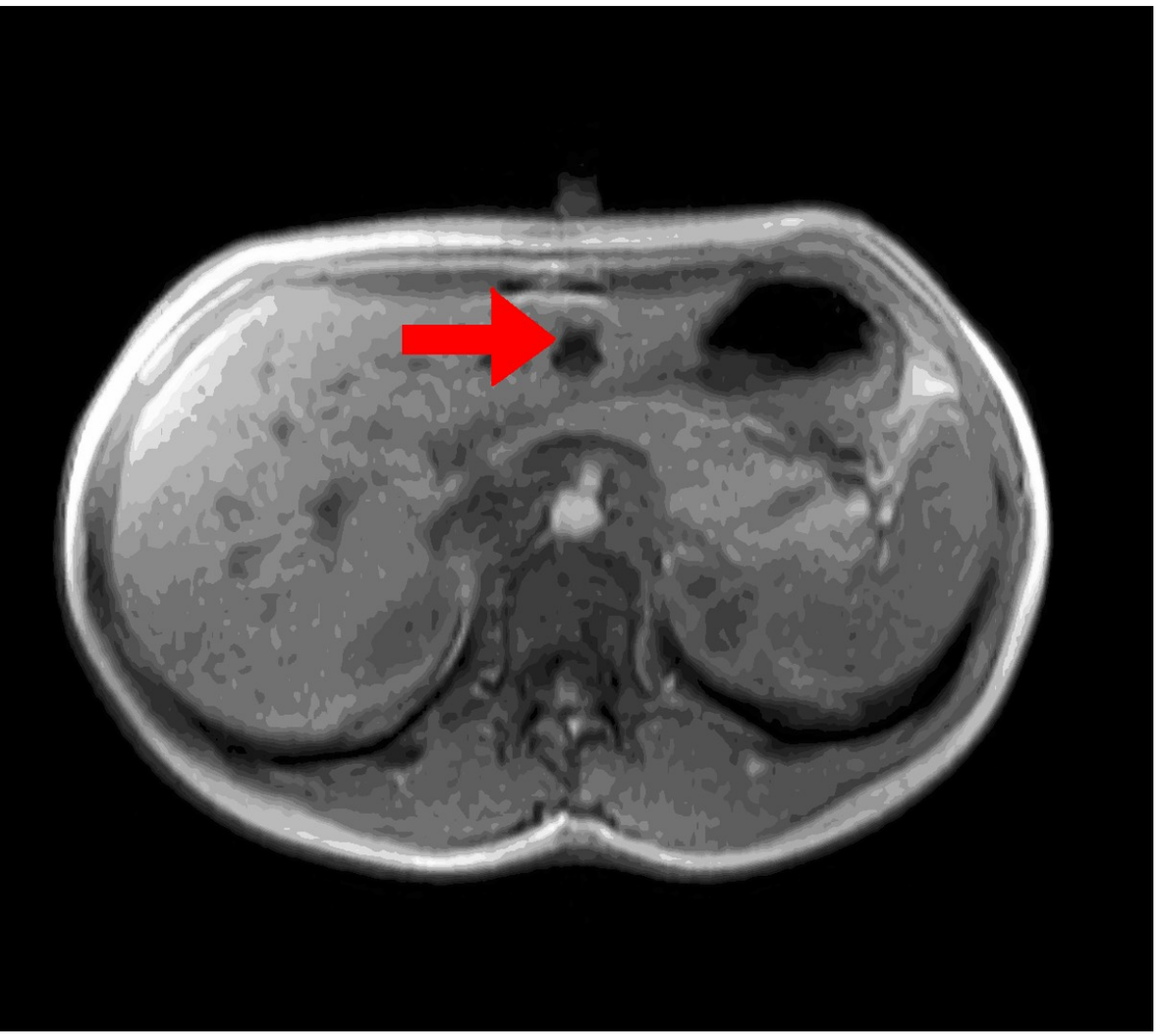
Pictures from Yanasak, et al. (MRI: Artifacts RSNA web module)

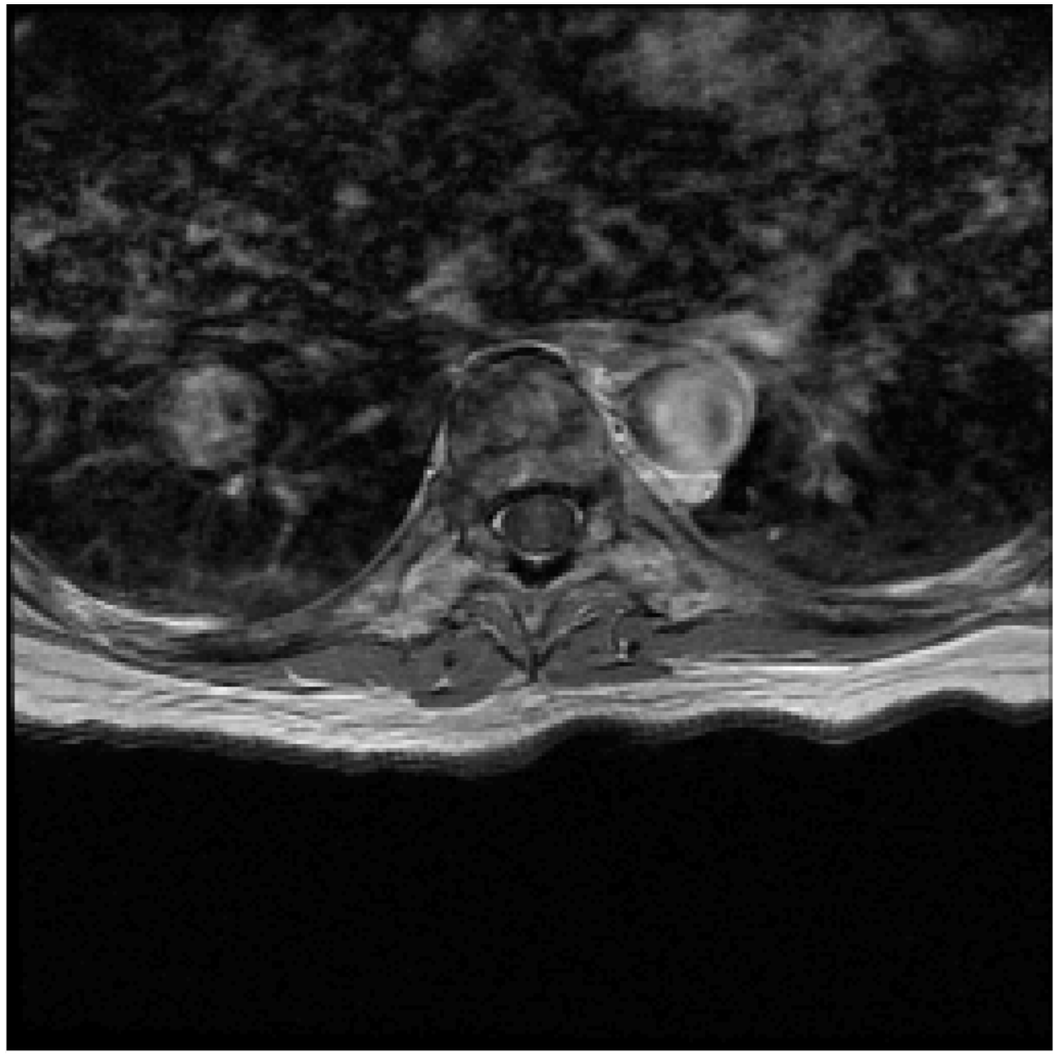
Periodic motion leads to duplicate ghosts across the image.

Can use spatial saturation upstream of the vessel or tissue to help.

Pulsatile Flow

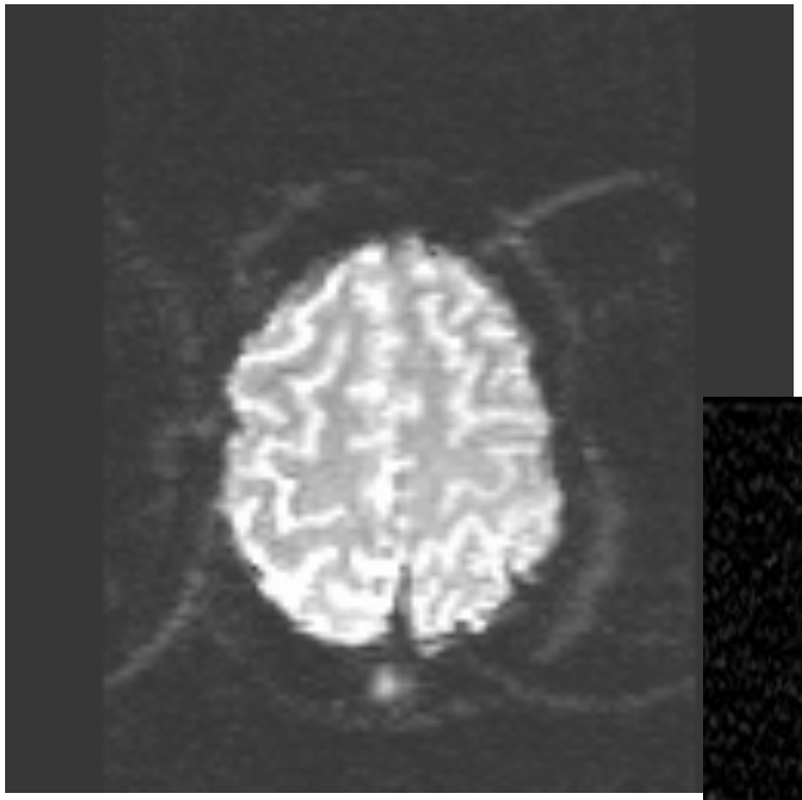
Pictures from Yanasak, et al. (MRI: Artifacts RSNA web module)



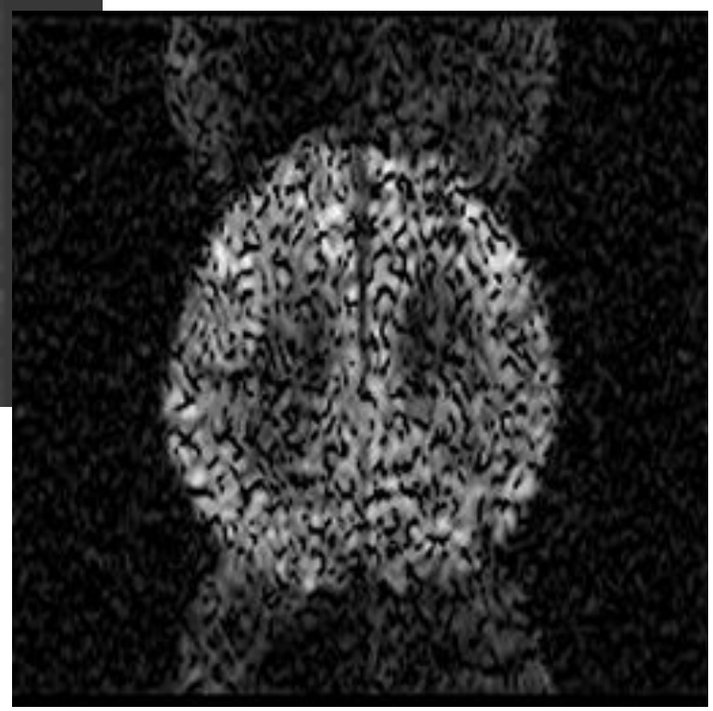


Pulsatile flow will result in strong, coherent image duplicates, along the phase-encoding direction.

N/2 Nyquist Ghosting

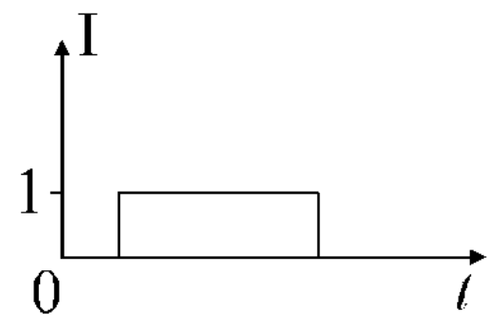


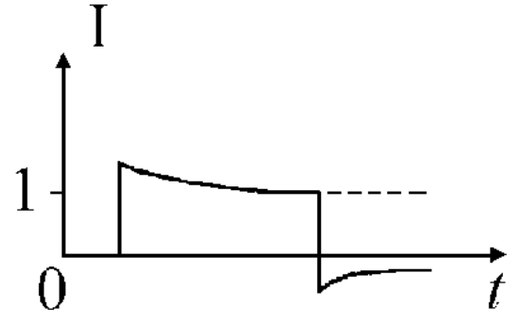
From http://www.mr-tip.com/serv1.php?type=art&sub=Eddy%20Current%20Artifact

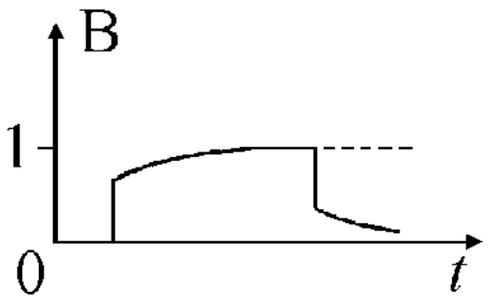


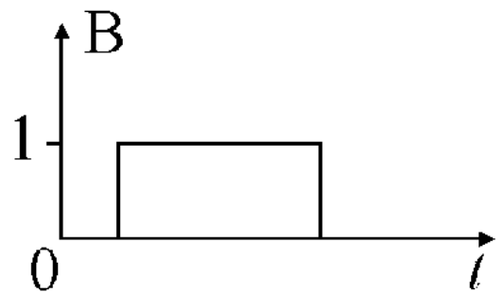
Without eddy current compensation

With eddy current compensation









Eddy currents: Electrical currents running in the superstructure of the MRI can counteract the gradient fields. Occurs when the switching is fast and the gradients are strong (e.g., EPI, diffusion, etc)

Ghosting

Common Occurrences:

Imaging of heart or major blood vessels

Scans where the patient must lie still for a long time

Sequences that switch gradients quickly (e.g., EPI)

Remediate:

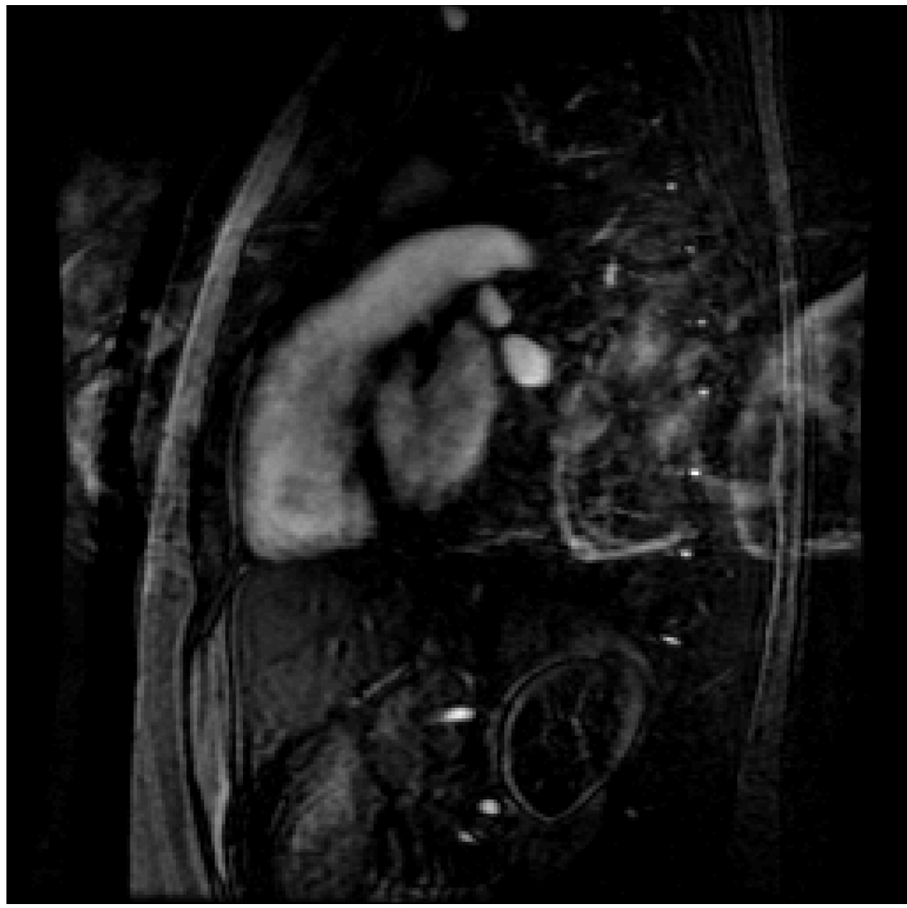
Switch frequency and phase encoding to rotate the artifact.

Use flow compensation or saturation bands

Ask the patient to be still.

Use motion-resistant sequences (SSFSE, or propeller).

Use respiratory or cardiac gating, or breath-holding.

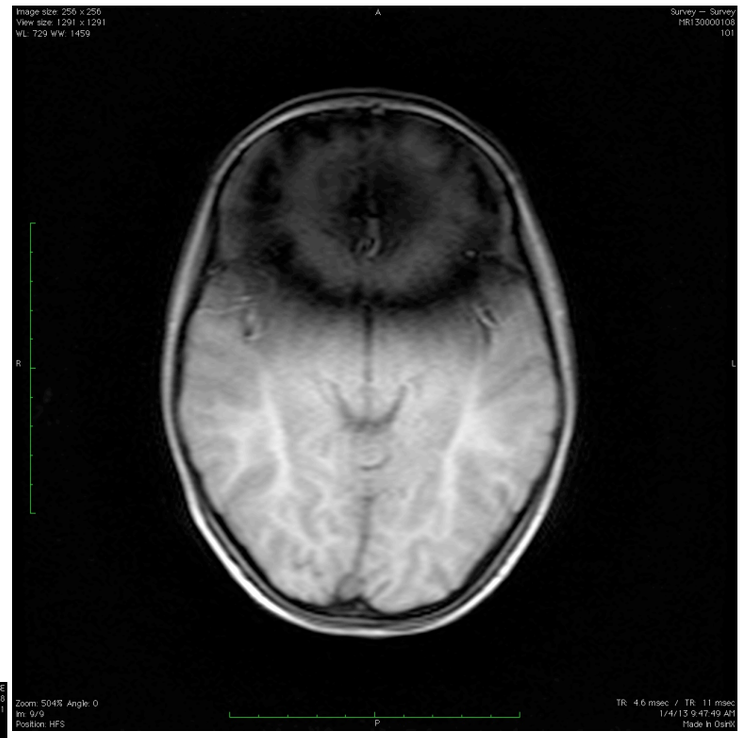


Artifacts of Special Origin

Susceptibility and Pulse Sequences

Susceptibility and artifacts … different in appearance from one sequence to another… here is some dental work.

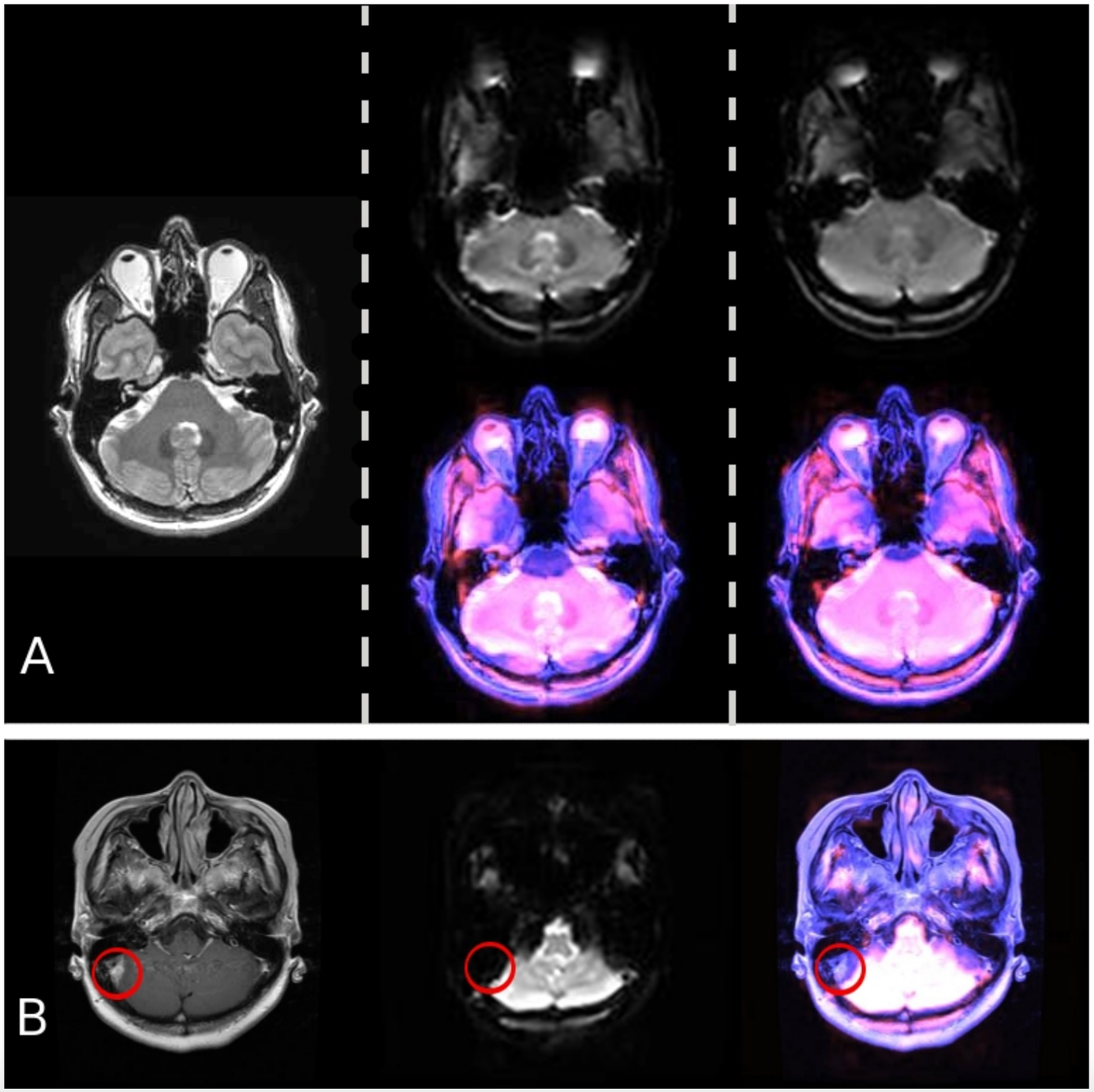
FSE -- very little



GRE—more so, over sinuses

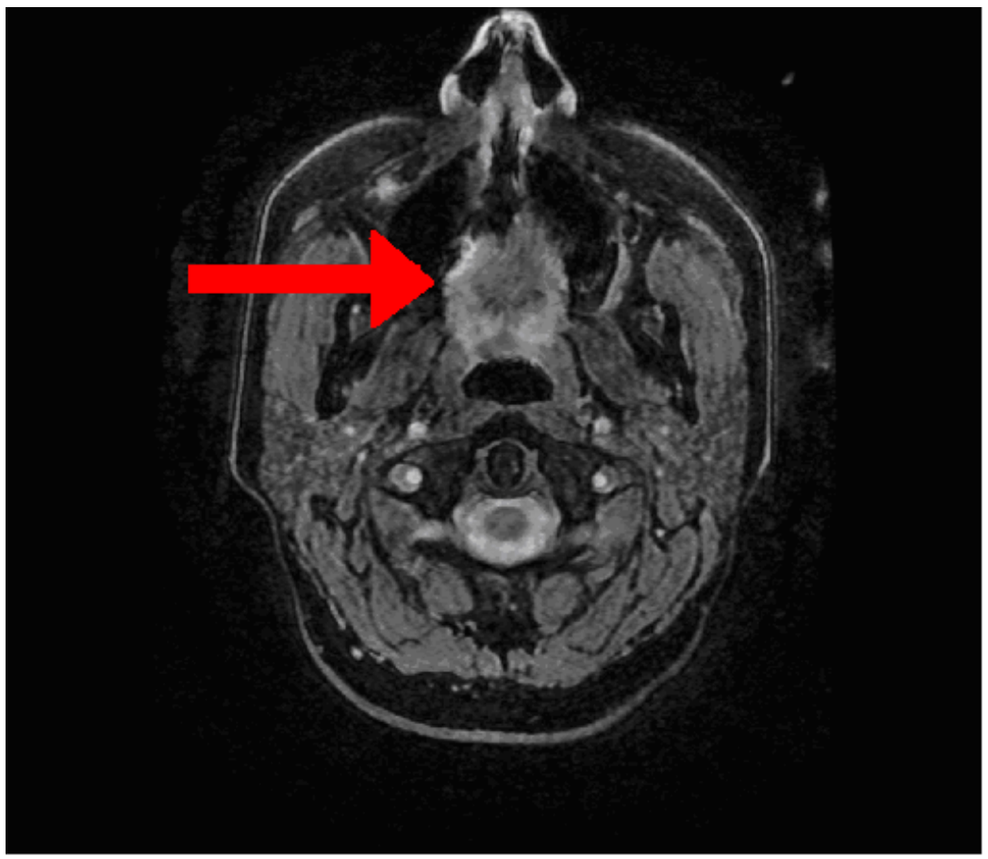
EPI -- disaster

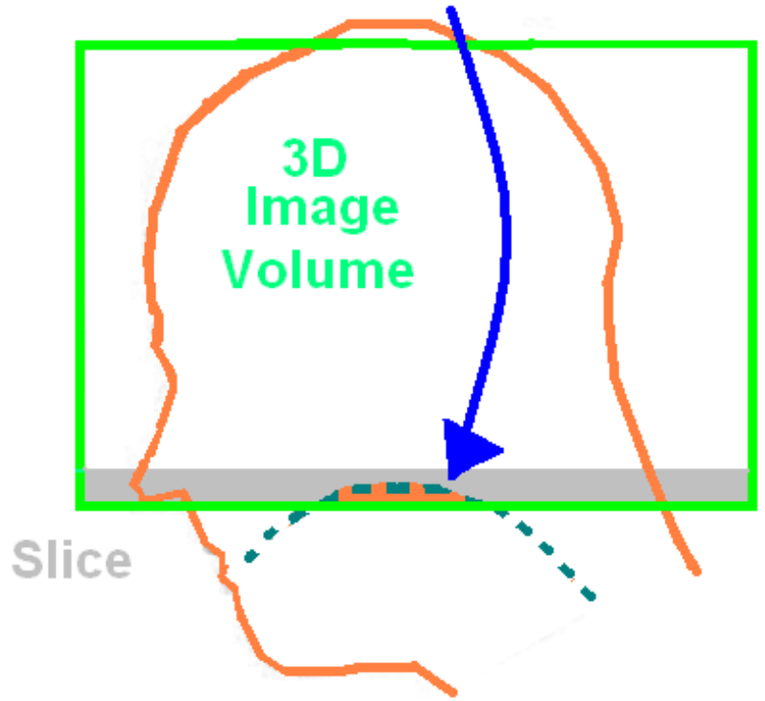
Susceptibility and Pulse Sequences



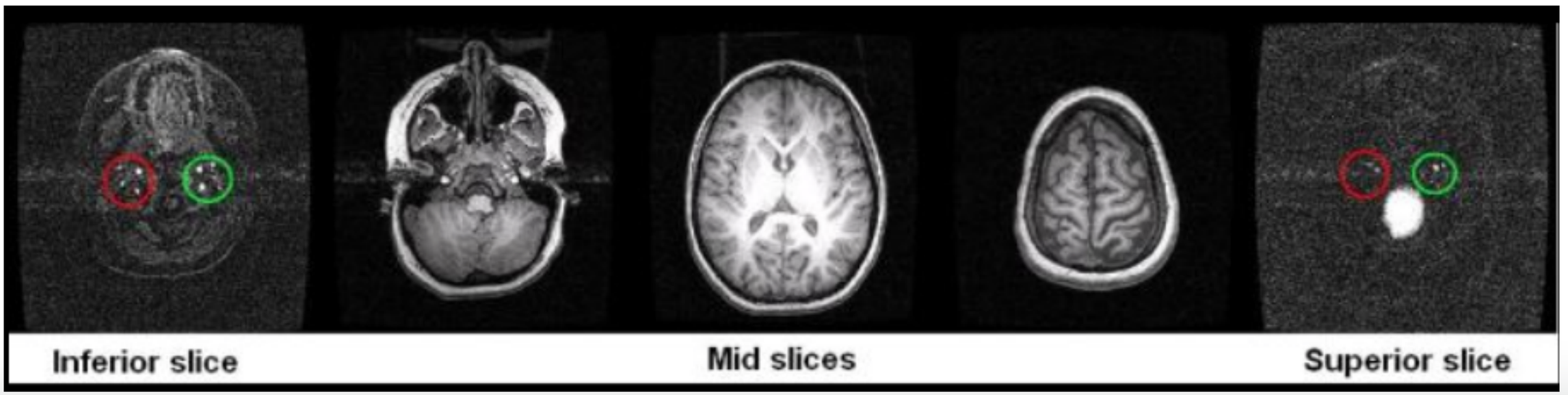
Susceptibility distortion in EPI can eliminate anatomically useful data.

2D vs. 3D Sequences: Aliasing

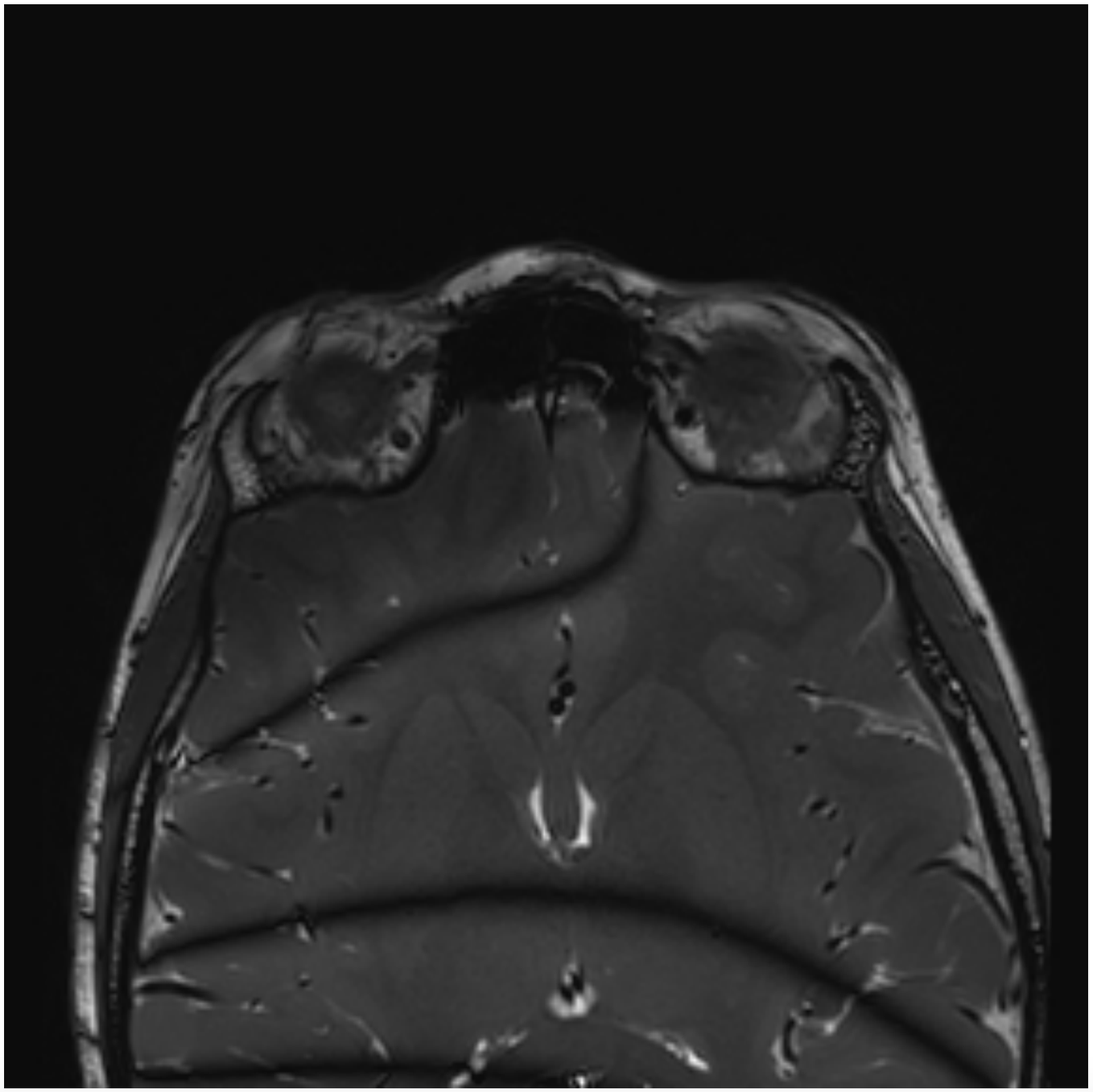




Schematic of aliasing



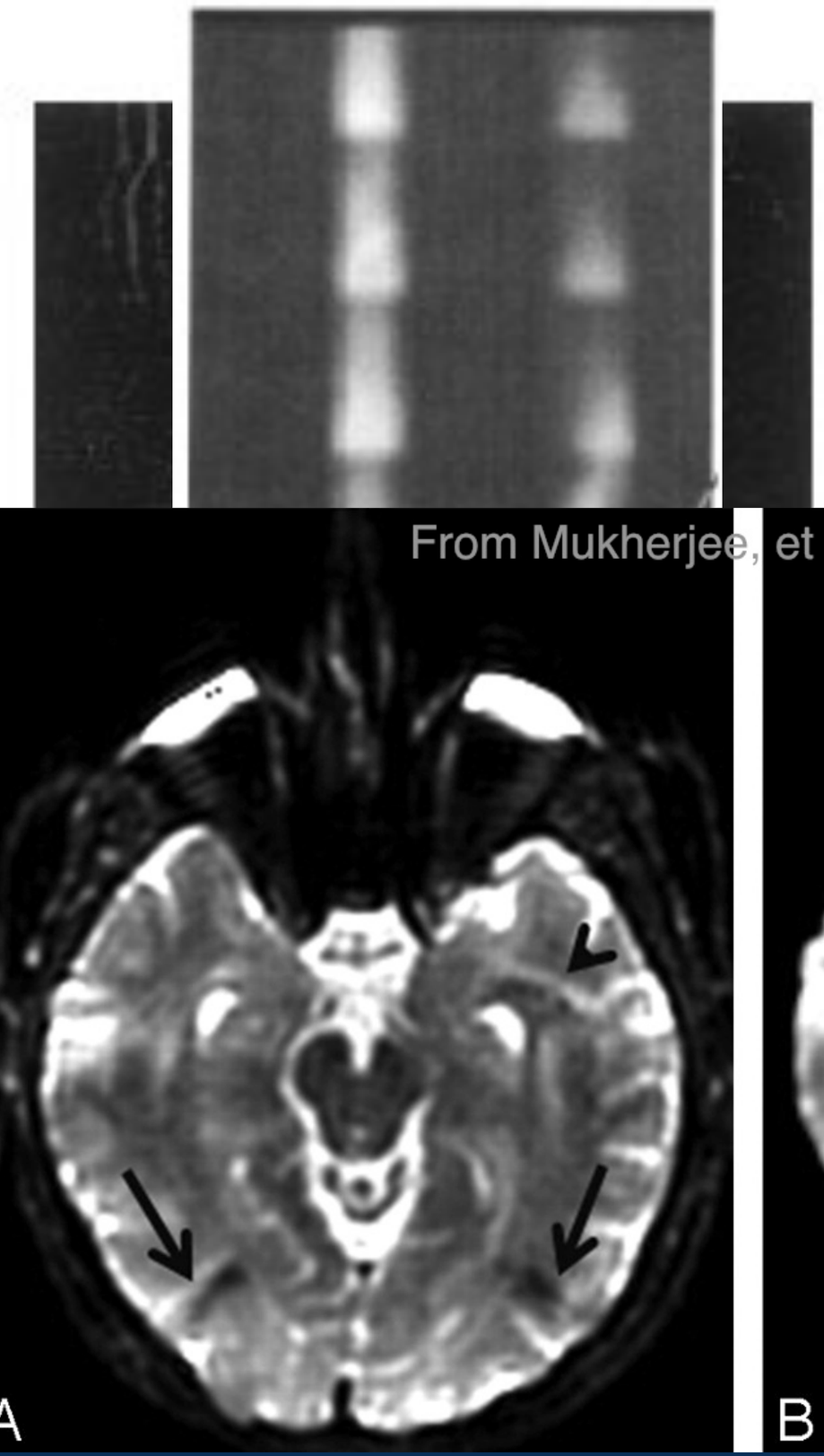
Special sequences



SSFP sequences in particular suffer from off-resonance effects.

Need good shimming (or, lack of metal in the surrounding area)

Special sequences



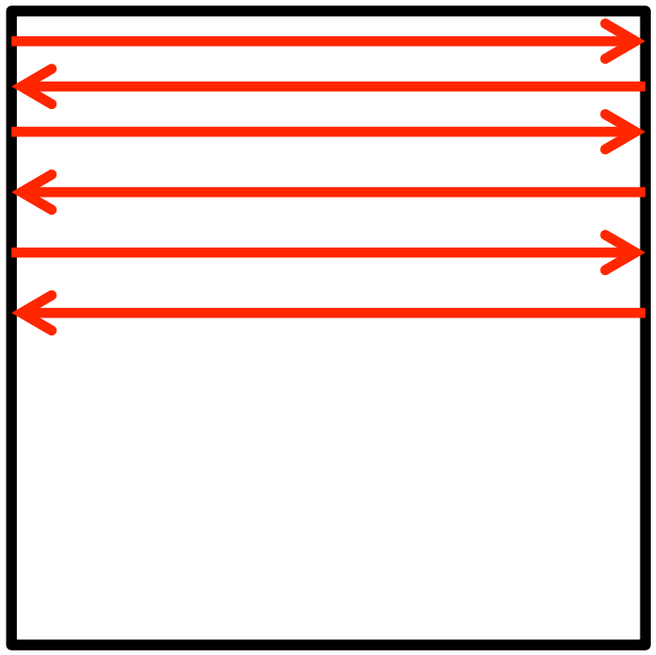
Diffusion, MRA, PC-MRA are other examples of techniques with special artifacts…each requires some attention to detail.

From Mukherjee, et al. AJNR, 2008

Spin-Warp vs. Non-Cartesian

Non-cartesian readout in k-space

- phase/frequency encoding doesn't occur in rows/columns of k-space
- Direction of readout = frequency encoding
- Artifacts occuring along particular directions change in appearance.



Cartesian

Non-cartesian

Spin-Warp vs. Non-Cartesian

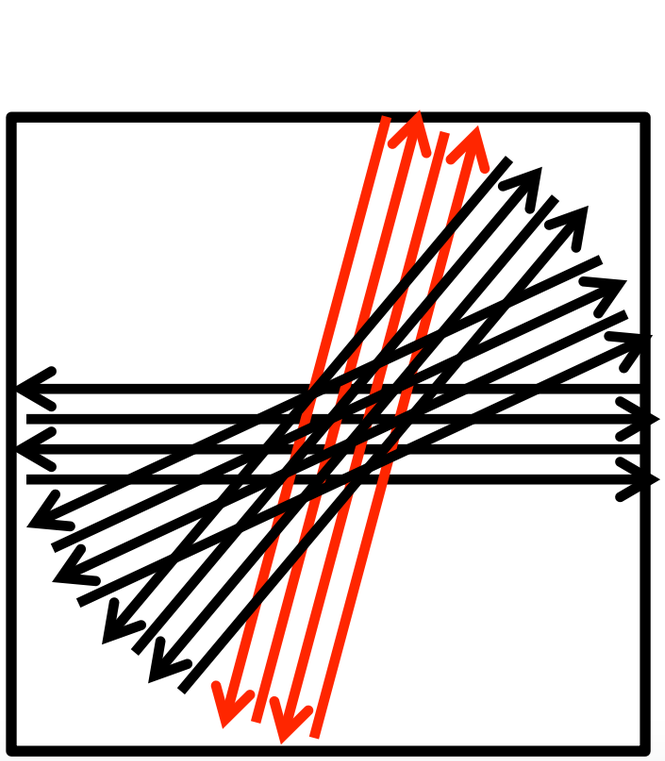
Propeller/Multi-vane/Blade

Rotating sections of FSE-like traditional cartesian

Sometimes called “radial”…although not strictly the same.

Bestows some ability to correct for motion.

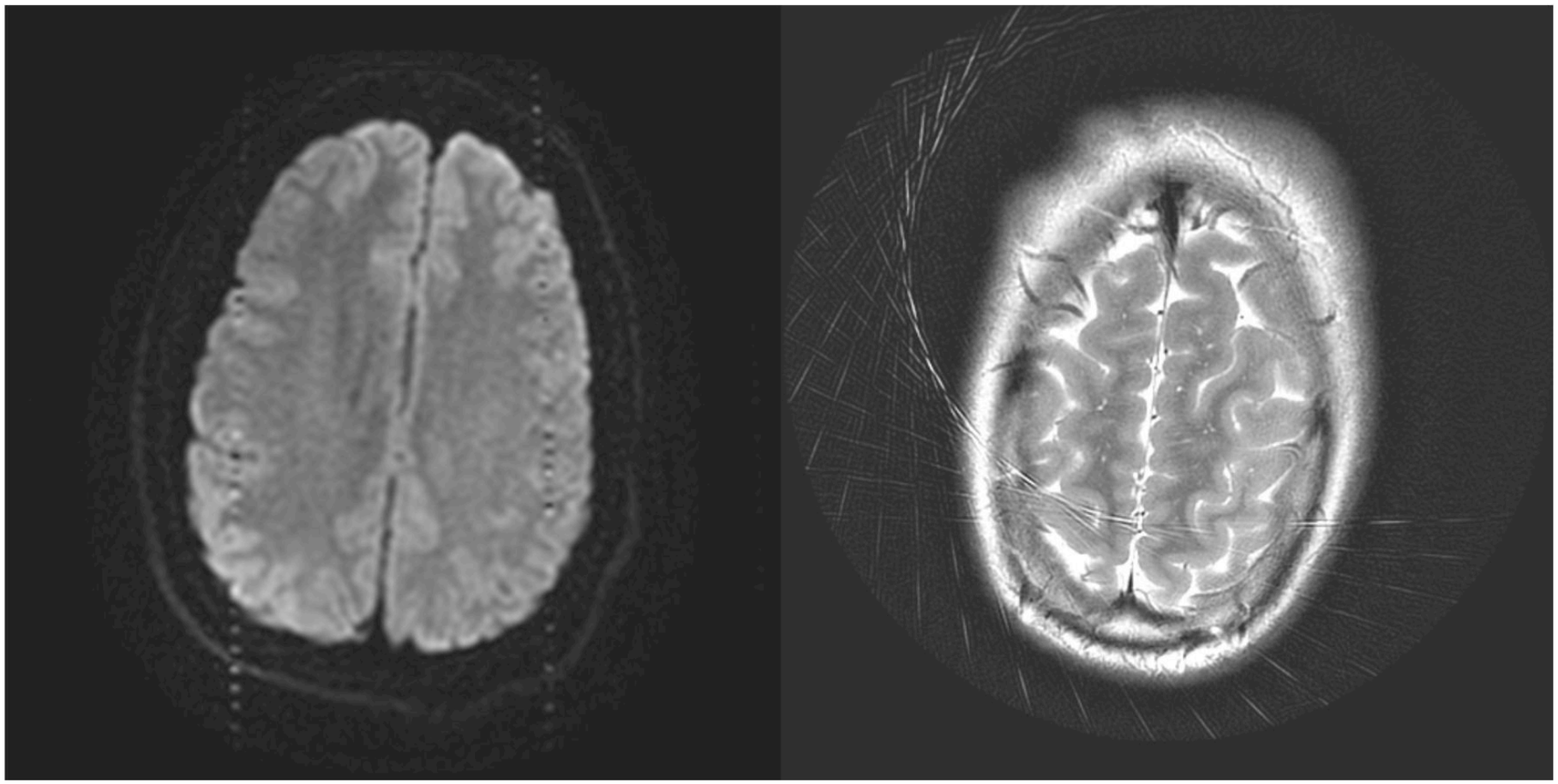
Rotation of encoding directions, so … artifacts look accordingly.



Propeller

Spin-Warp vs. Non-Cartesian

Rotation of encoding directions, so … artifacts look accordingly.



Left picture from Yanasak, et al. (MRI: Image Formation RSNA web module)

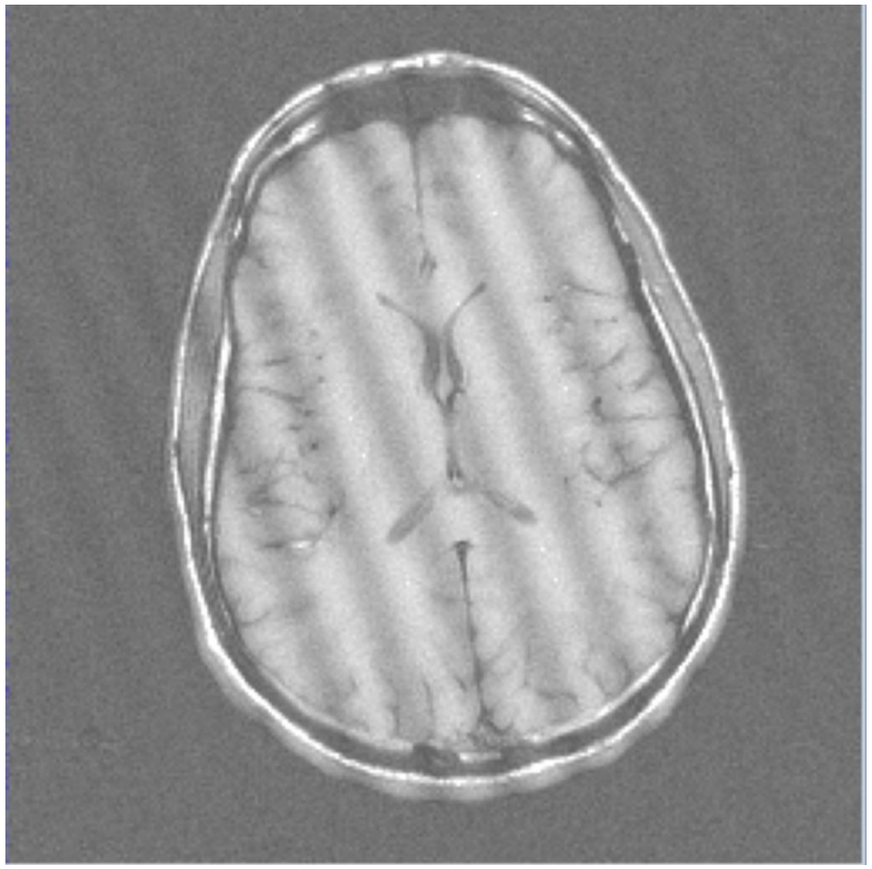
Spin-Warp vs. Non-Cartesian

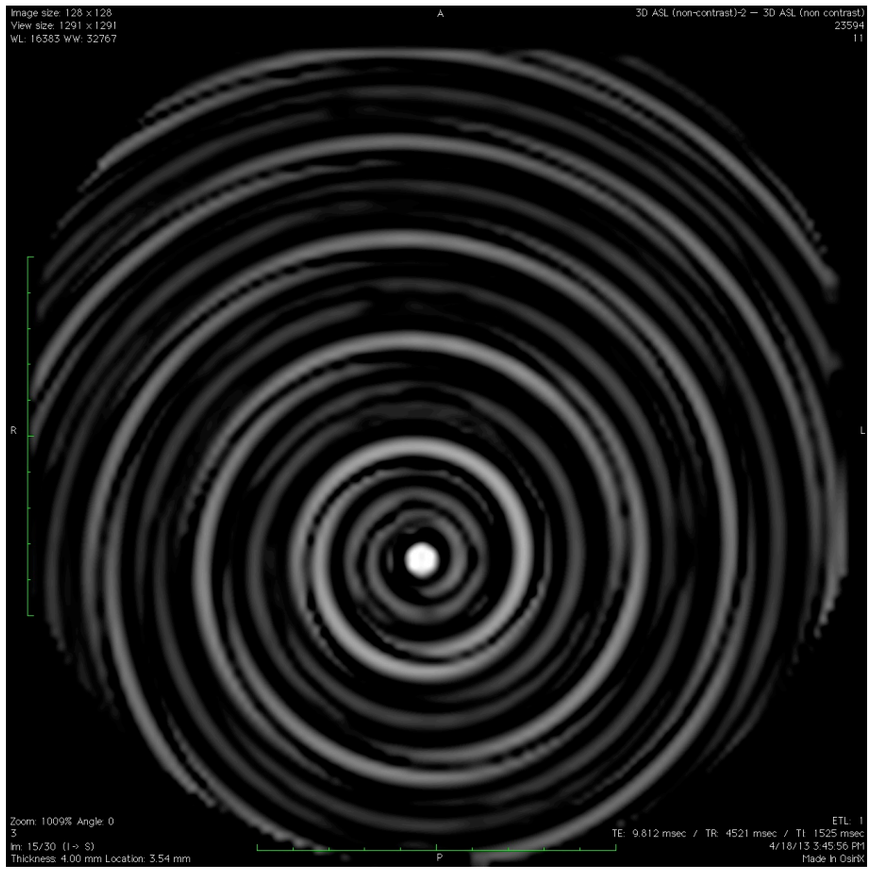
Each readout is a spiral through k-space.

Frequency and phase encoding point throughout k-space.

Uses: EPI-type sequences (e.g., Arterial Spin Labeling, fMRI)

Left picture from Yanasak, et al. (MRI: Image Formation RSNA web module)

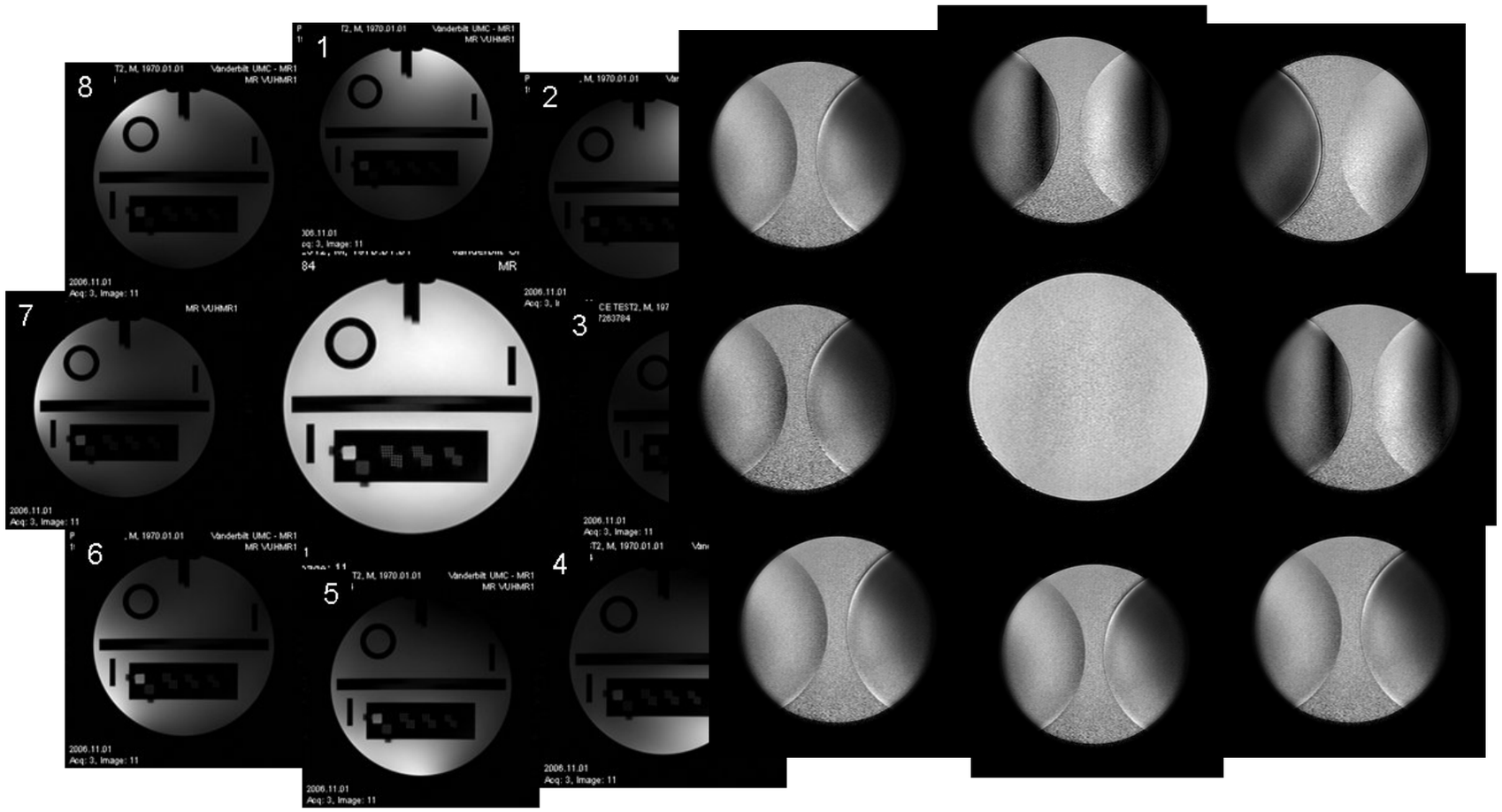




Parallel Imaging-Based Artifacts: An Epidemic… ...turning benign artifacts into monsters!

Parallel MR Imaging

Spatial sensitivity varies for each element → can use this in conjunction with undersampling.



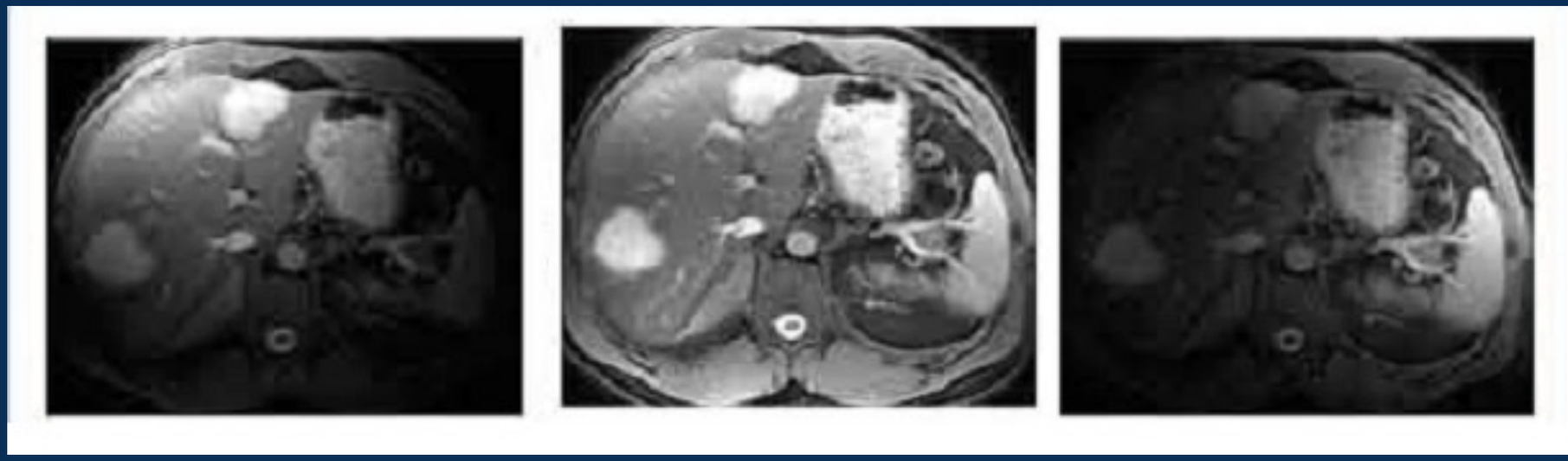
Conventional use of phased-array (unaliased)

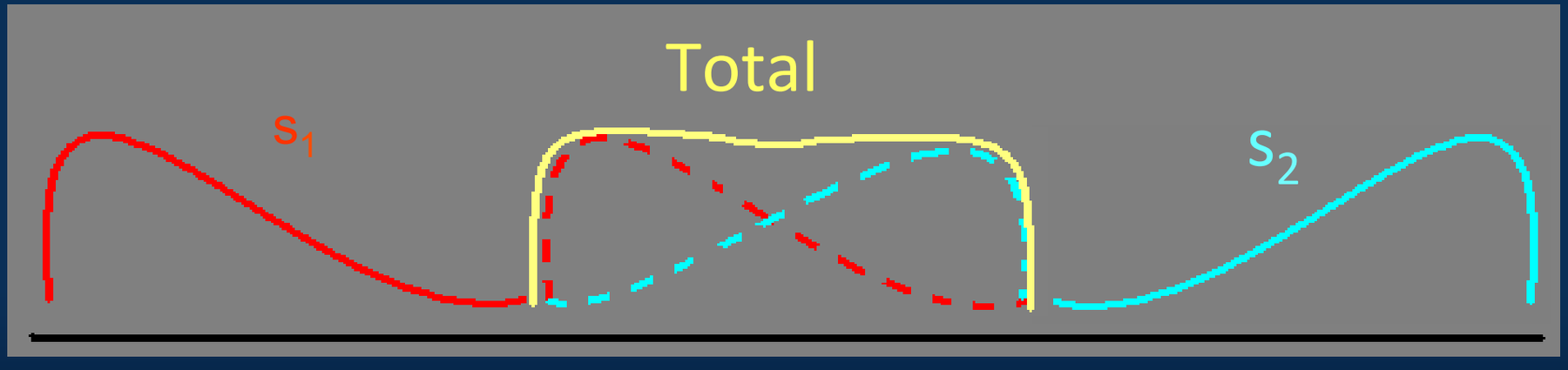
Parallel reconstruction of data (aliased)

Sensitivity Map

The spatial sensitivity of each coil element = sensitivity map.

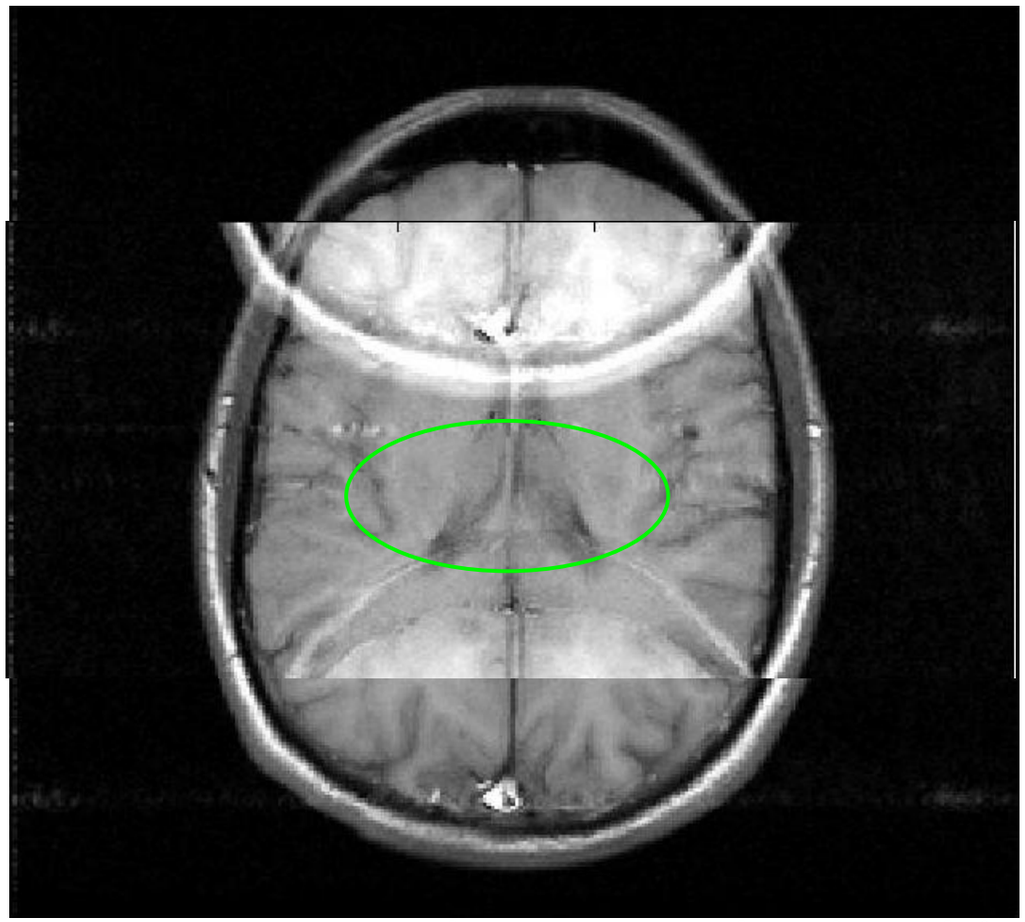
A ***calibration scan*** is usually required to calculate this.



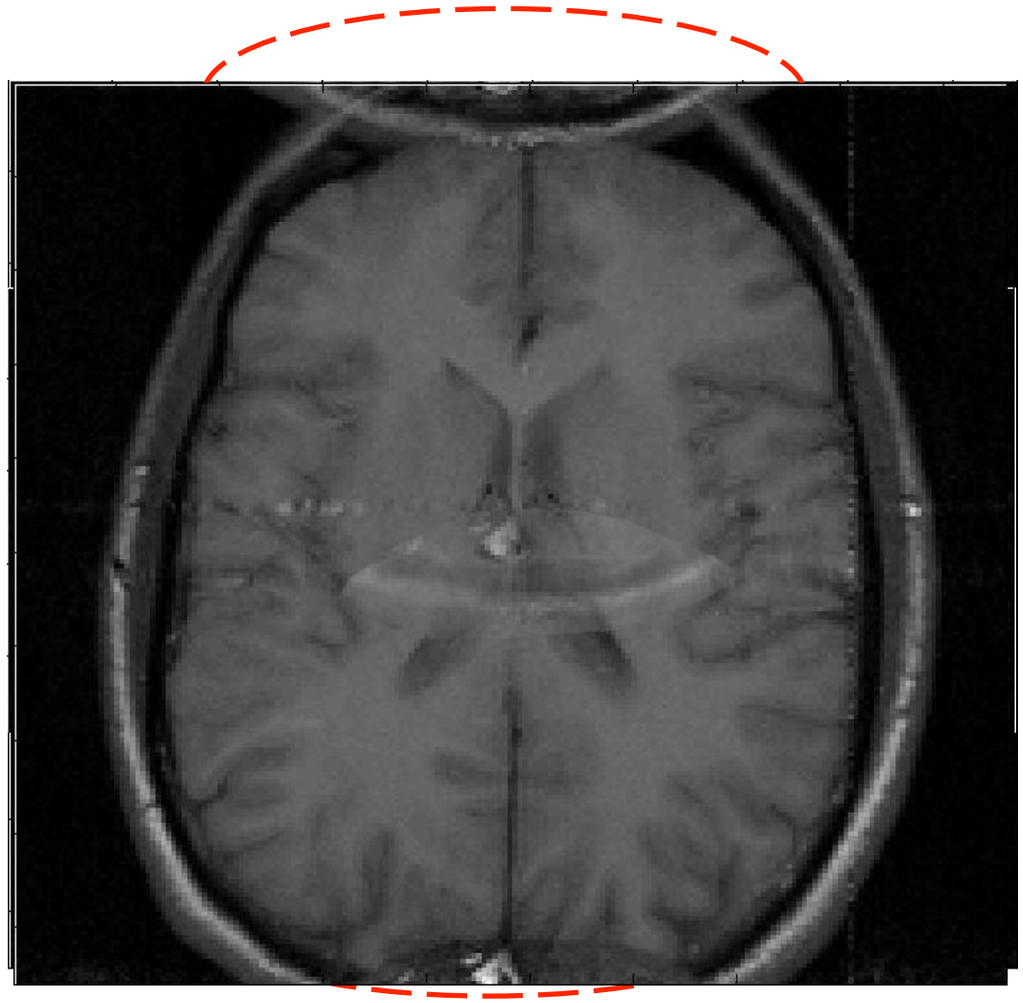


Artifact #1: Tissue Outside of FOV (SENSE)—Wrap-around artifact

What happens when the FOV is too small?



Center region in this example should be unaliased, for acceleration R=2.

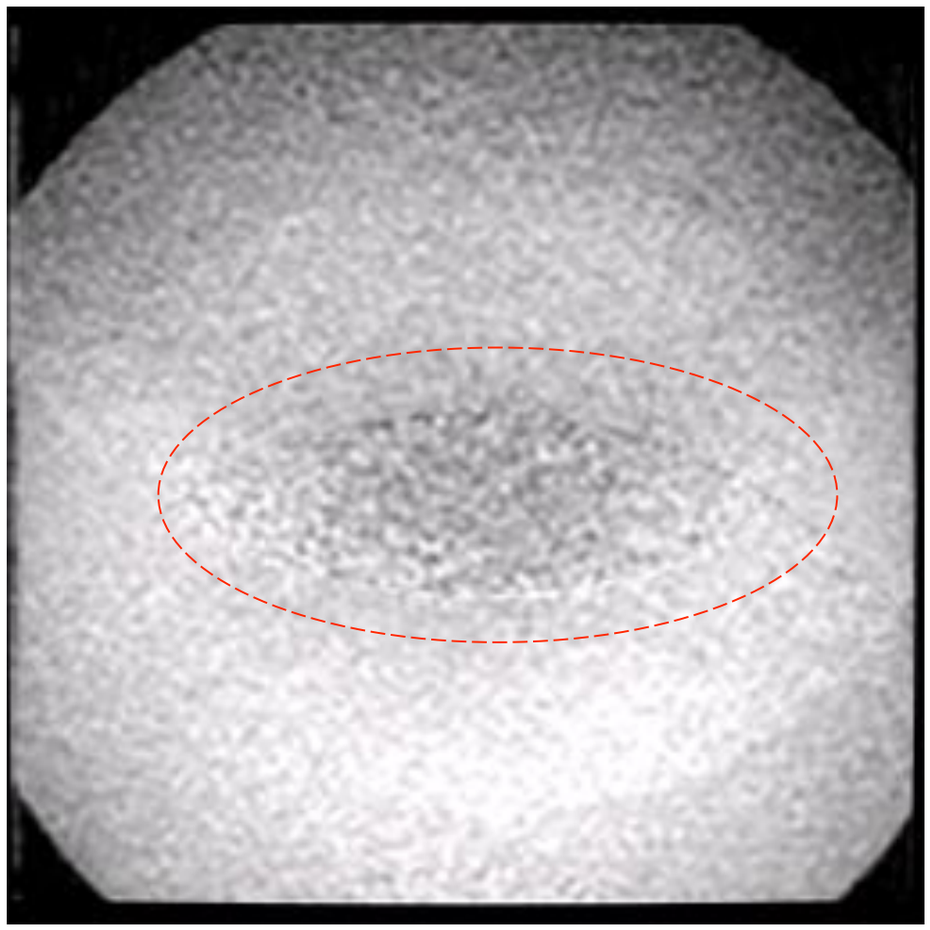


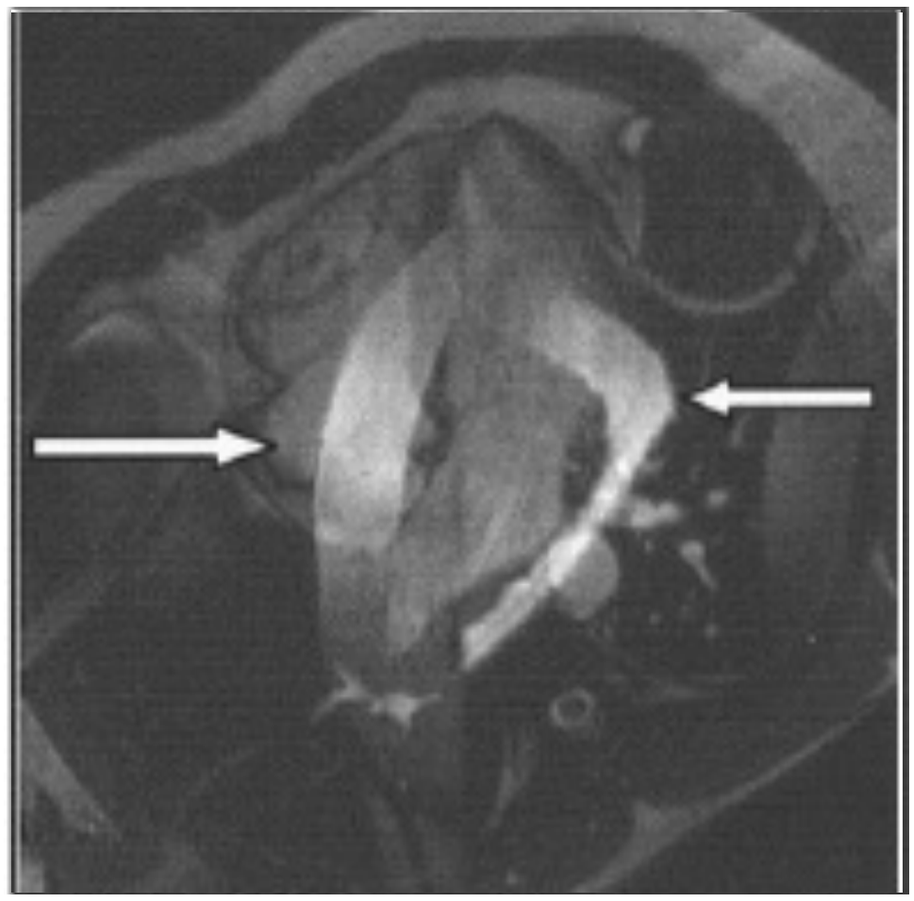
Treated as non-aliased tissue during reconstruction.

Artifact #1: Tissue Outside of FOV

- With SENSE-based technique, tissue outside of the FOV yields “wrap-into” artifact

Goldfarb, JMagn Reson Imag. 2004

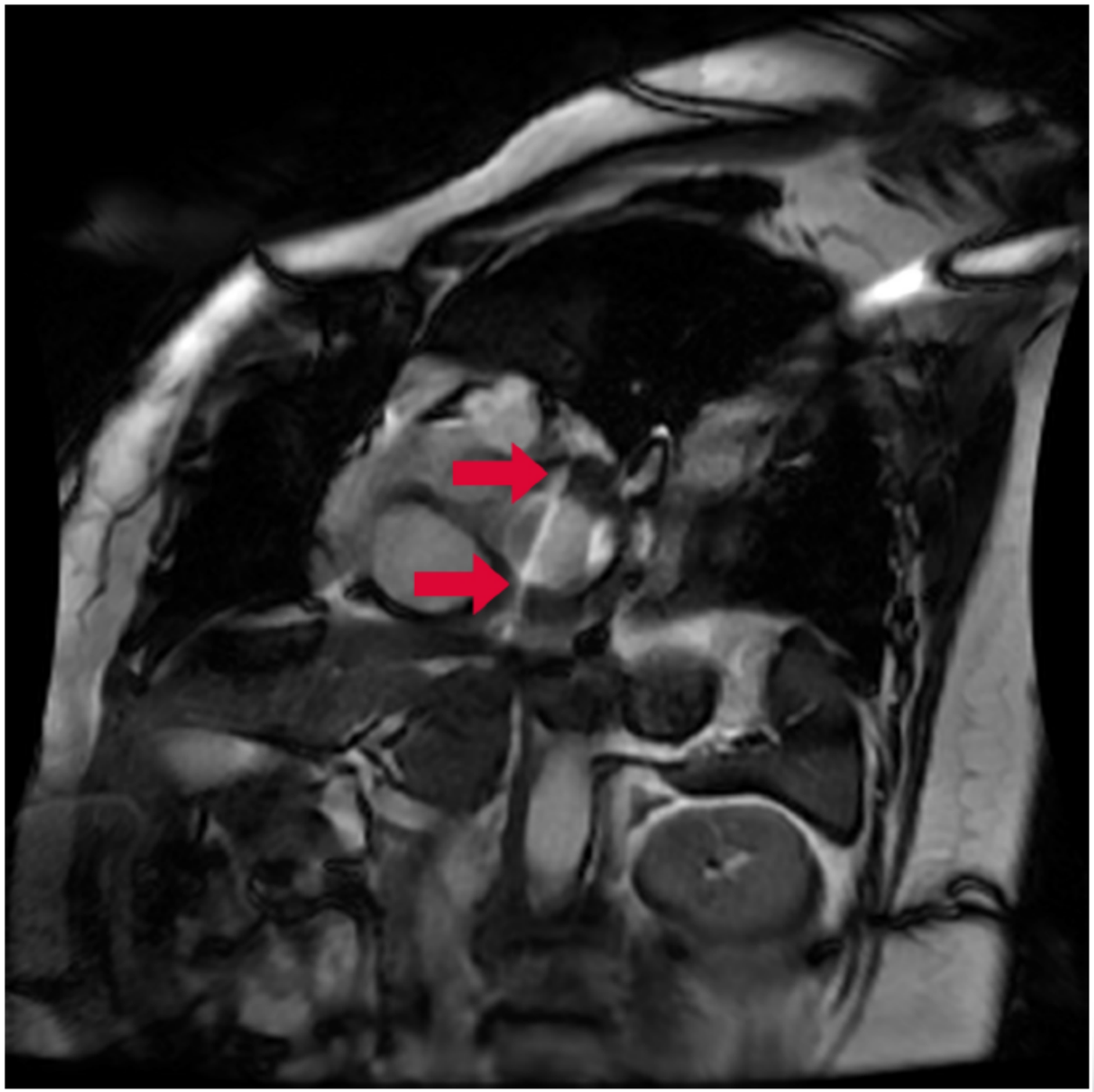




SENSE FOV

Signal outside FOV

Artifact #1: Tissue Outside of FOV

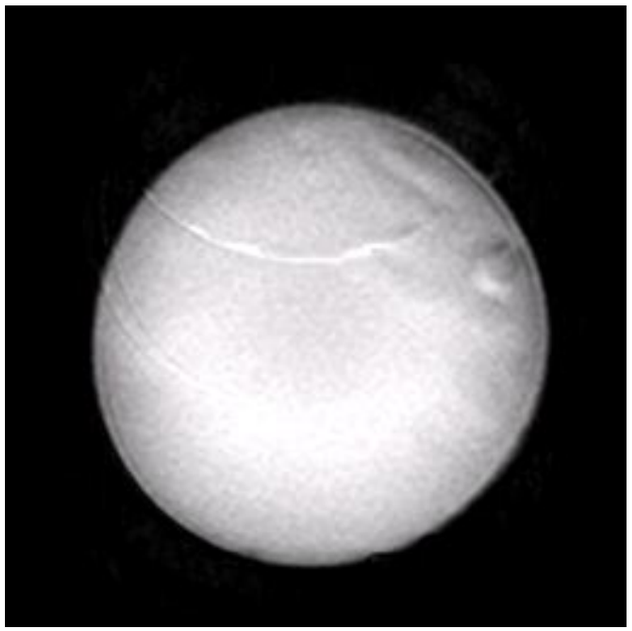


- Must open up the field of view, or potentially need to use a different angle.

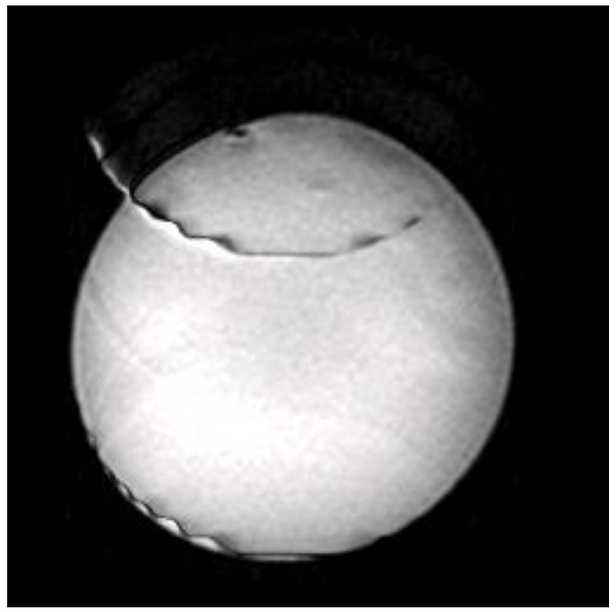
Yanasak and Kelly, Radiographics, 2014

Artifact #2: Motion After Calibration Scan (any non-auto-calibrated sequence)

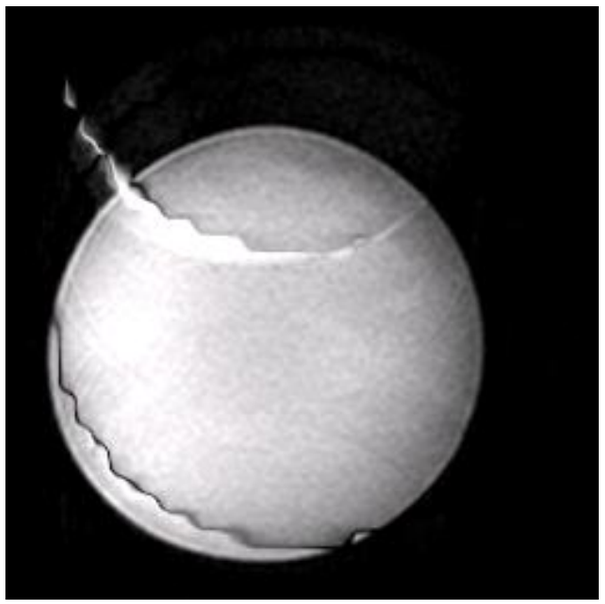
Calibration scan must accurately represent tissue position.



Small displacement



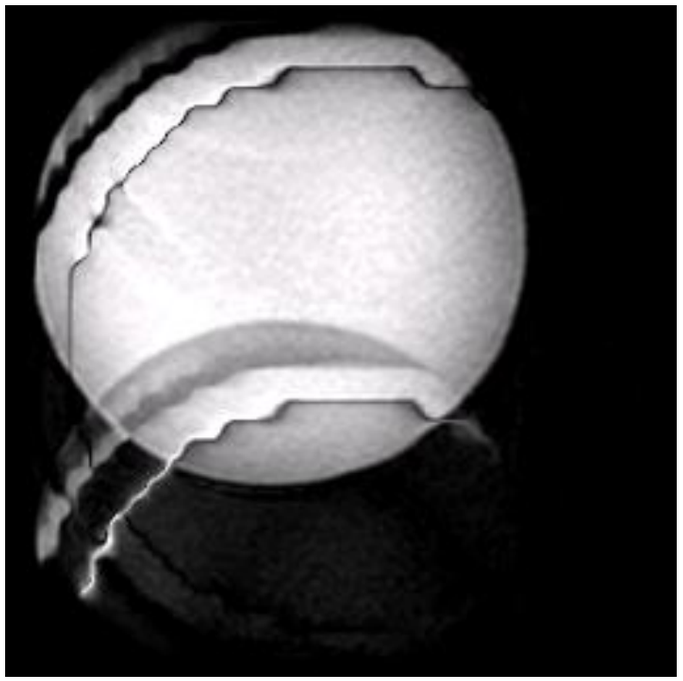
Medium displacement



Large displacement

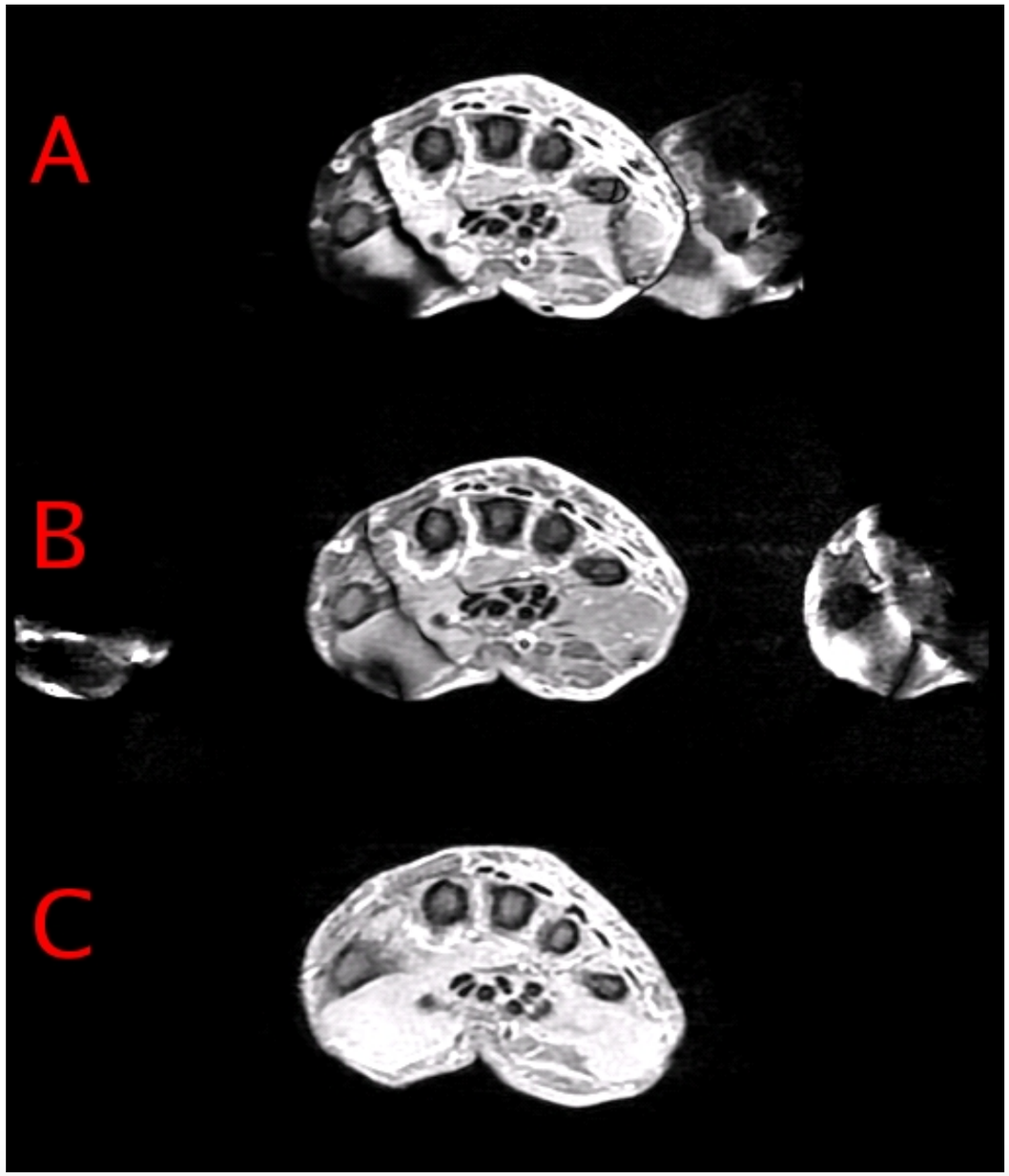
Artifact #2: Motion After Calibration Scan (any non-auto-calibrated sequence)

Affected by FOV choice as well.



Small FOV

Large FOV



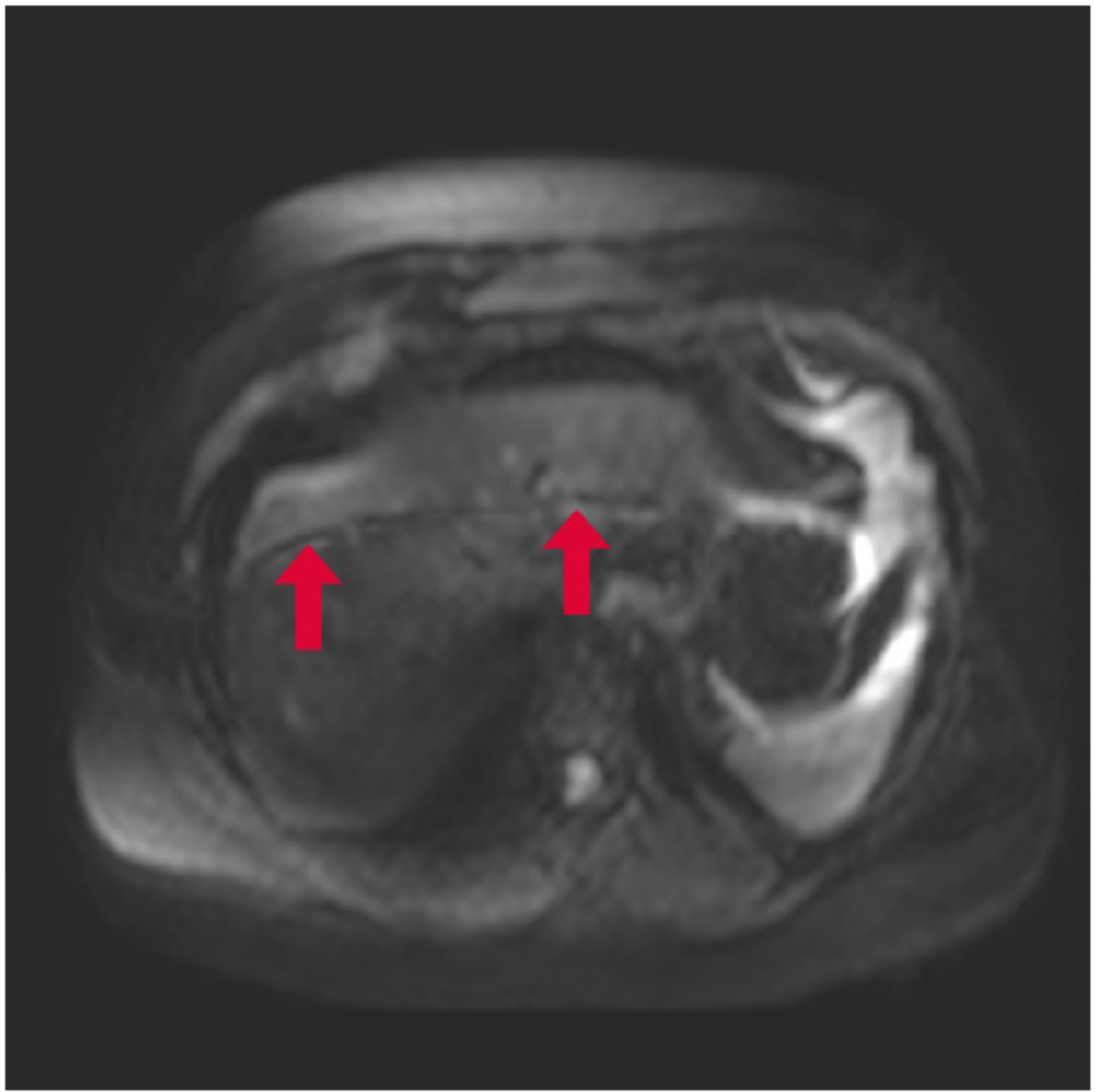
Artifact #2: Motion After Calibration Scan (any non-auto-calibrated sequence)

Yanasak and Kelly, Radiographics, 2014

This happens most often in abdomenal scans.

If the patient's chest is not in the same location as it was when the calibration was scanned, YOU WILL GET AN ARTIFACT.

Inhale vs. exhale?



Artifact #2: Motion After Calibration Scan (any non-auto-calibrated sequence)

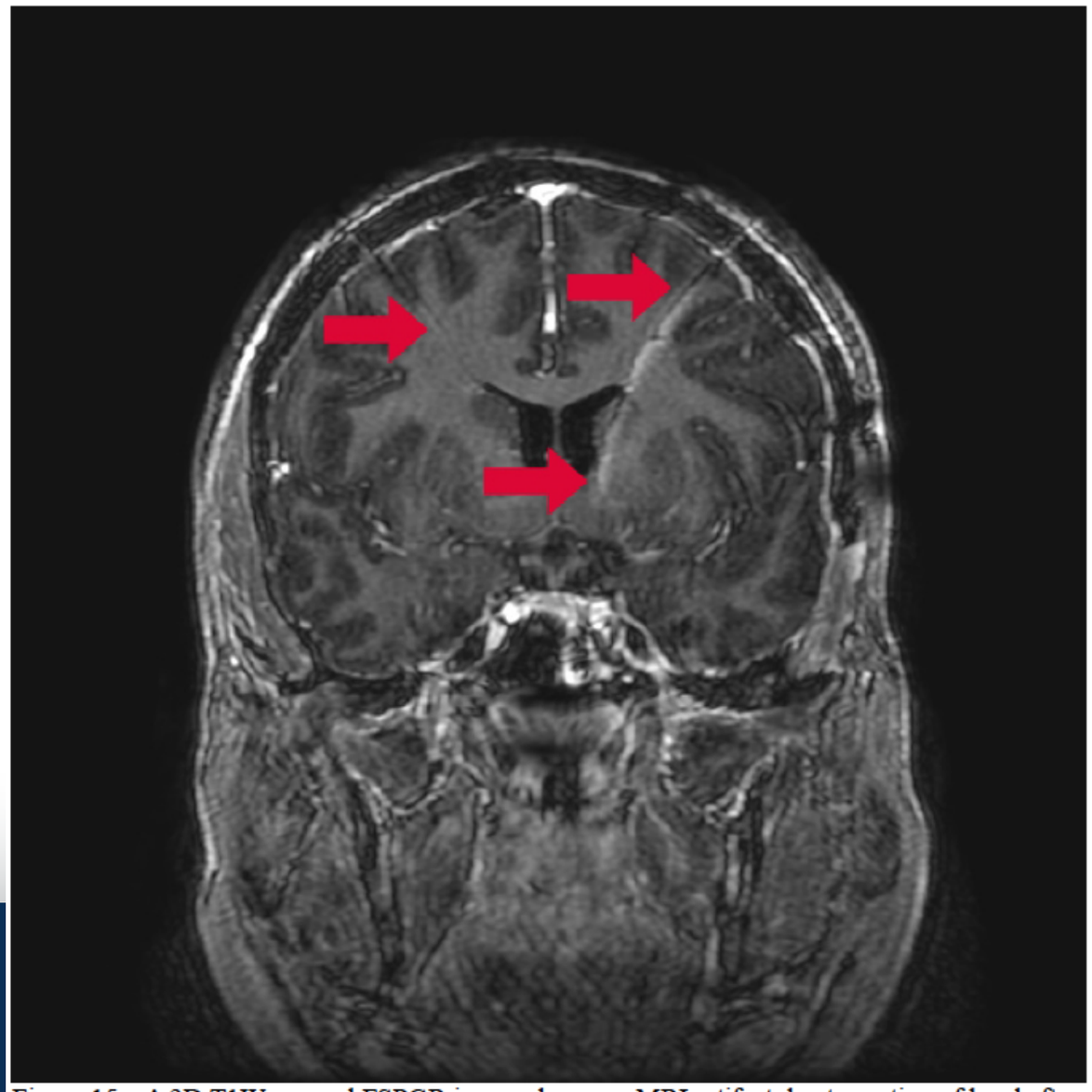
What to do about these?

Rescan the calibration scan, then rescan the sequence again.

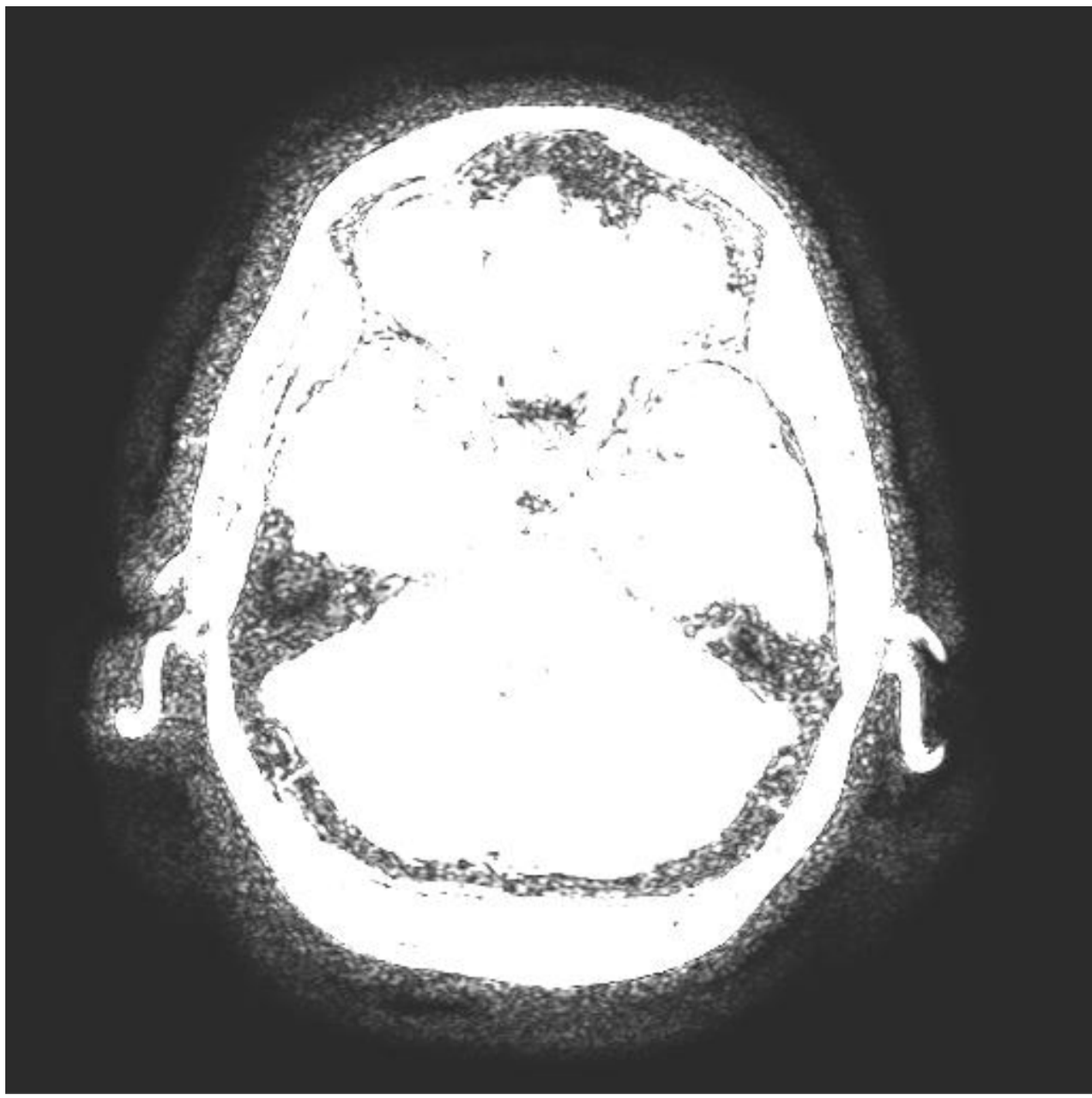
Or, use GRAPPA if you can.

If a patient moves all the time, ***parallel imaging may not be for you.***

Yanasak and Kelly, Radiographics, 2014



Sensitivity Map Mismatch Artifacts



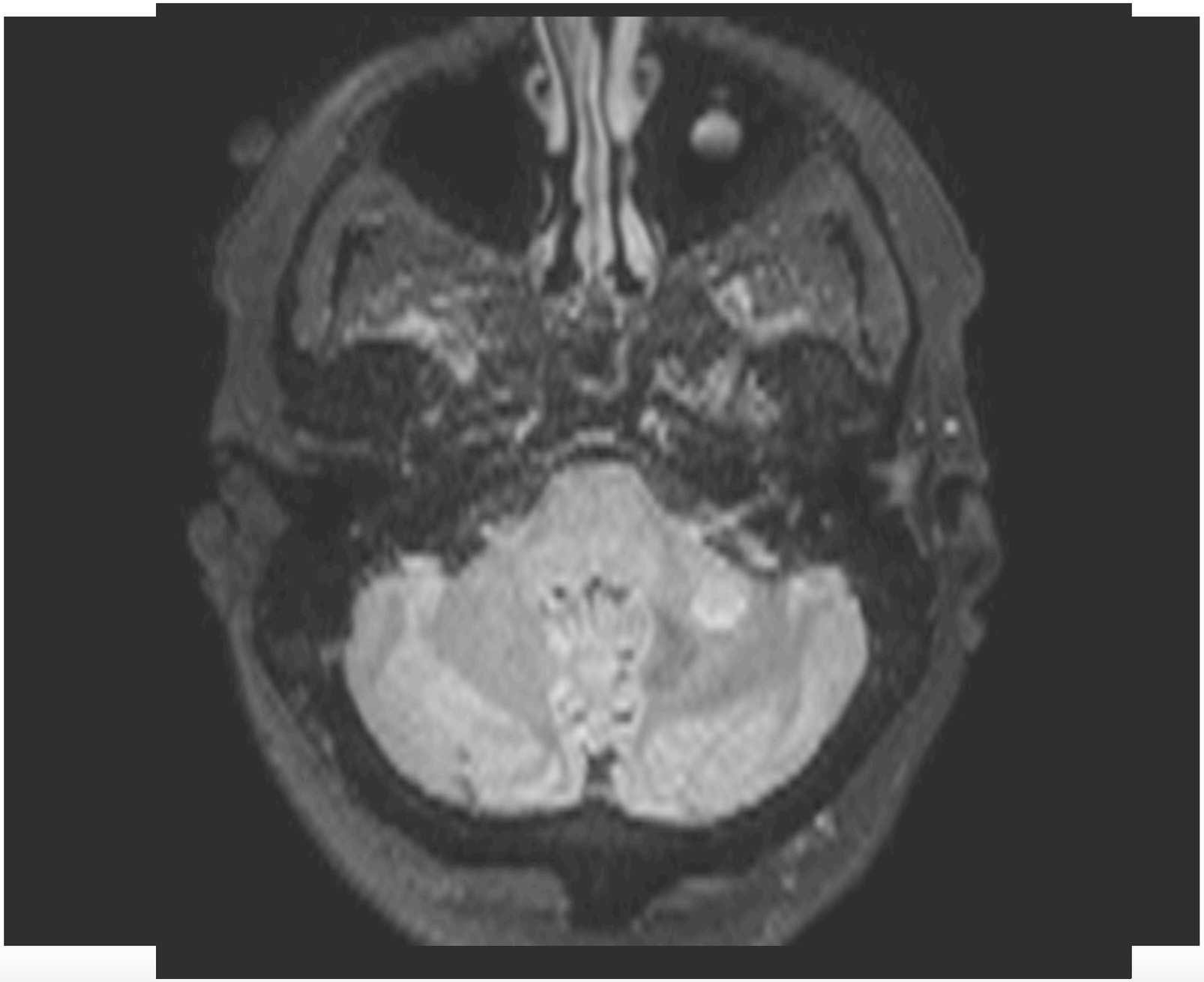
Thin, bright structures in the periphery of sensitivity map—mismatch between sensitivity and anatomy.

2D Acceleration and Sensitivity Map Mismatch Artifacts

Cerebellar lesion?

No … sensitivity map mismatch, projected in slice direction (PE #1),

...and in-plane phase-encoding direction (PE #2)

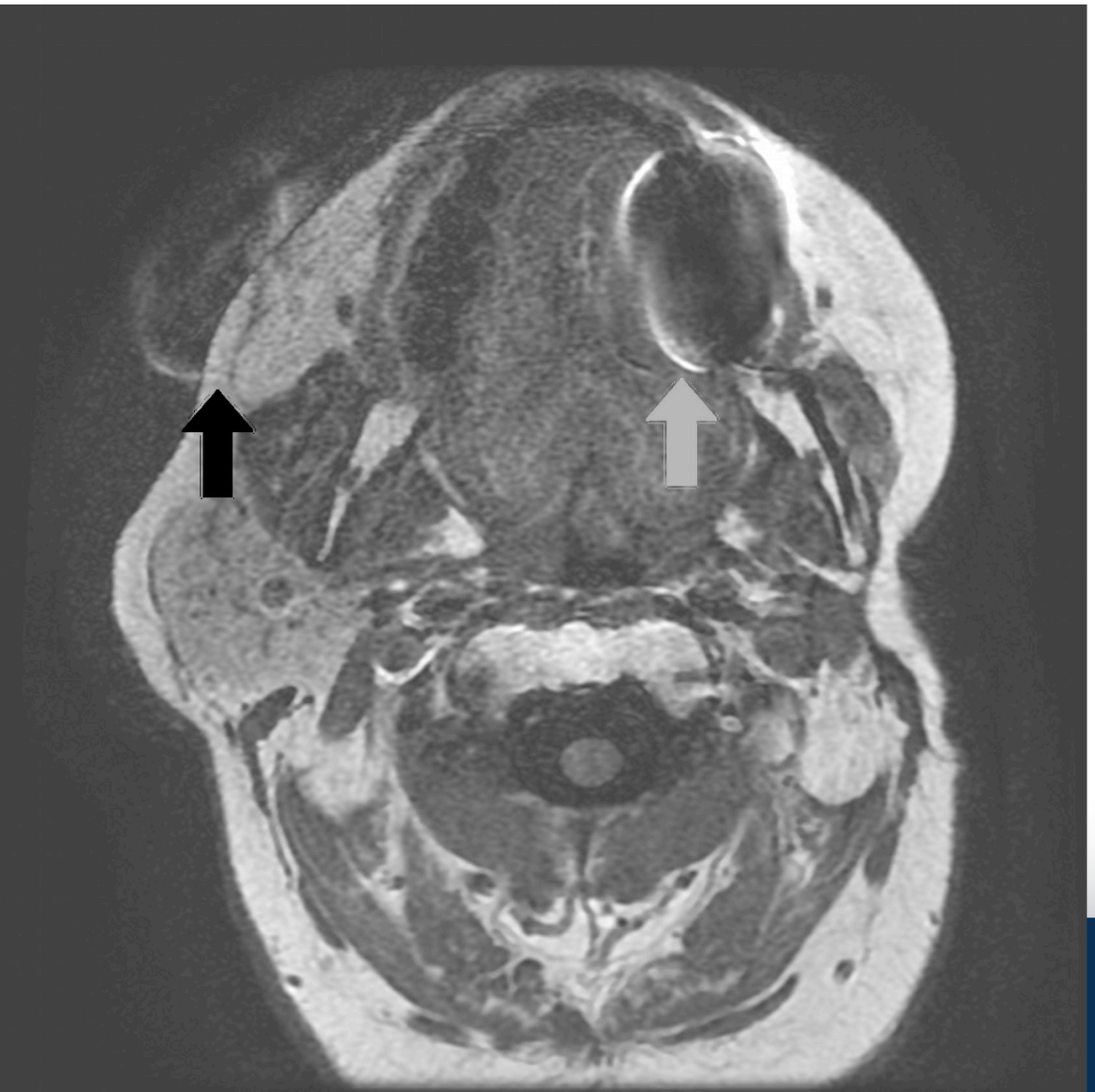


pMRI and Traditional Artifacts

Appearance of traditional artifacts may be modified by pMRI

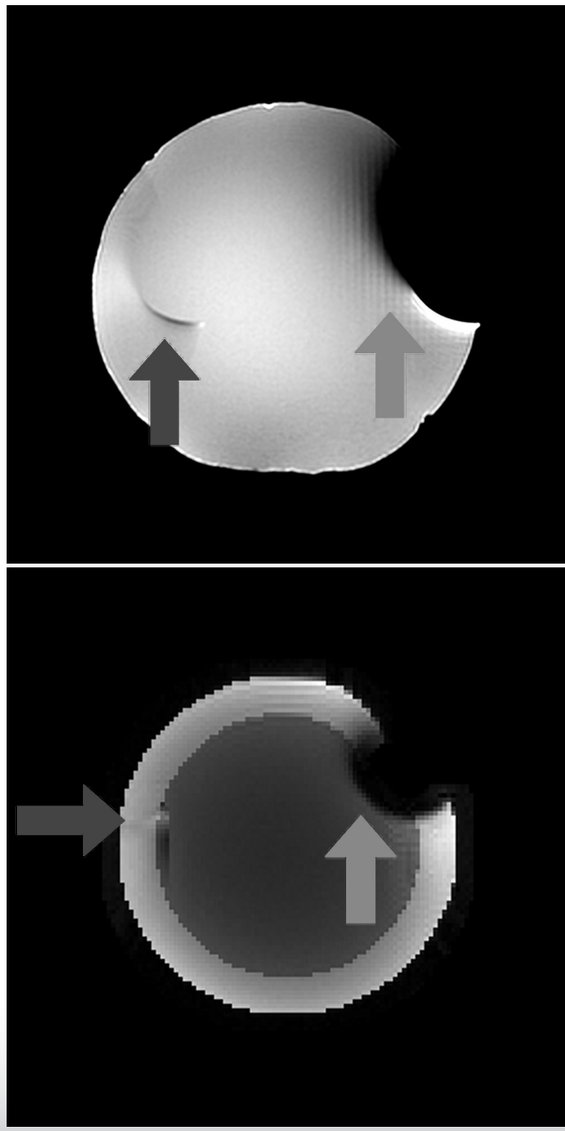
Susceptibility (artifact not perfectly represented on sensitivity map)

Yanasak and Kelly, Radiographics, 2014



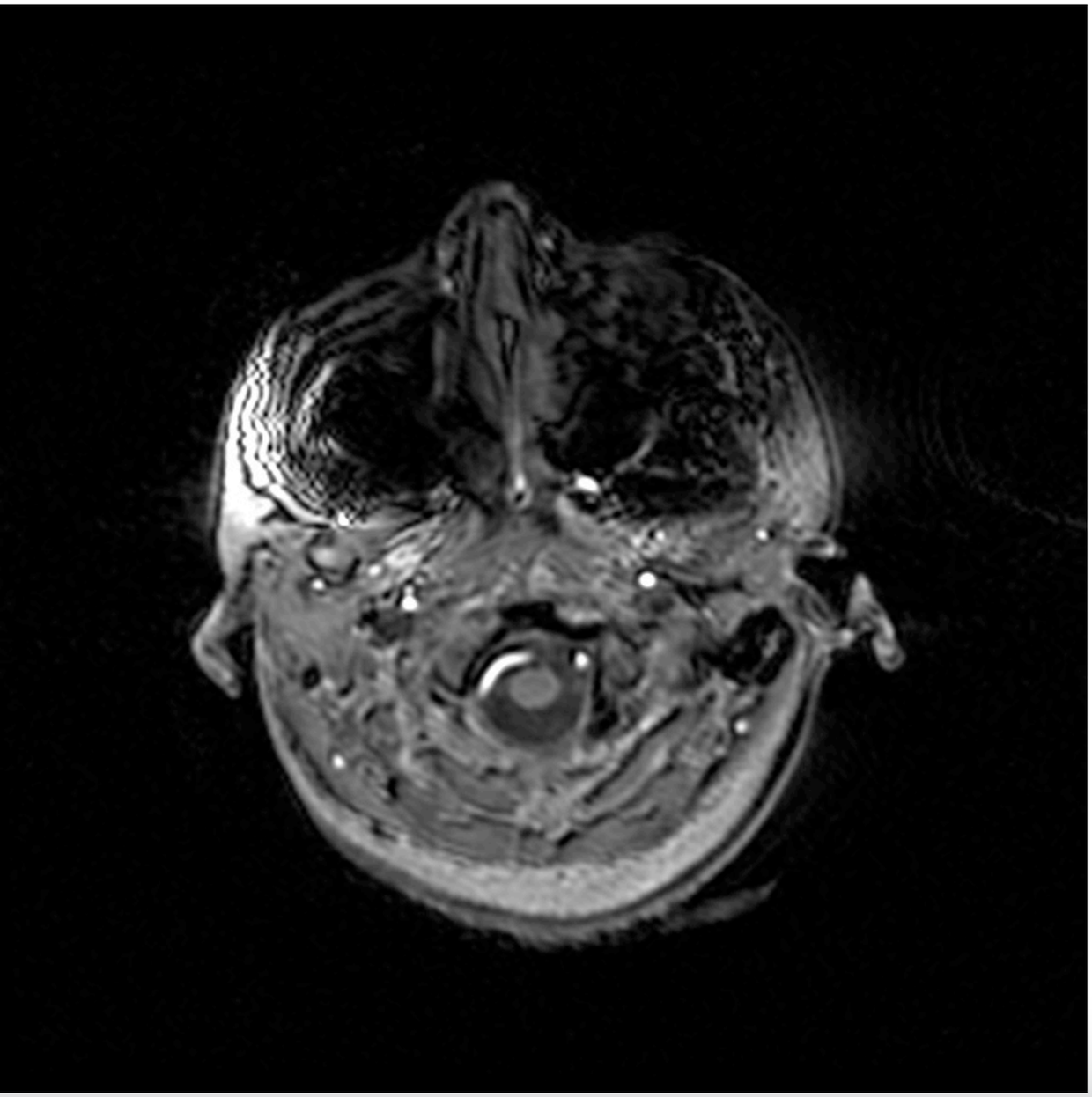
phantom

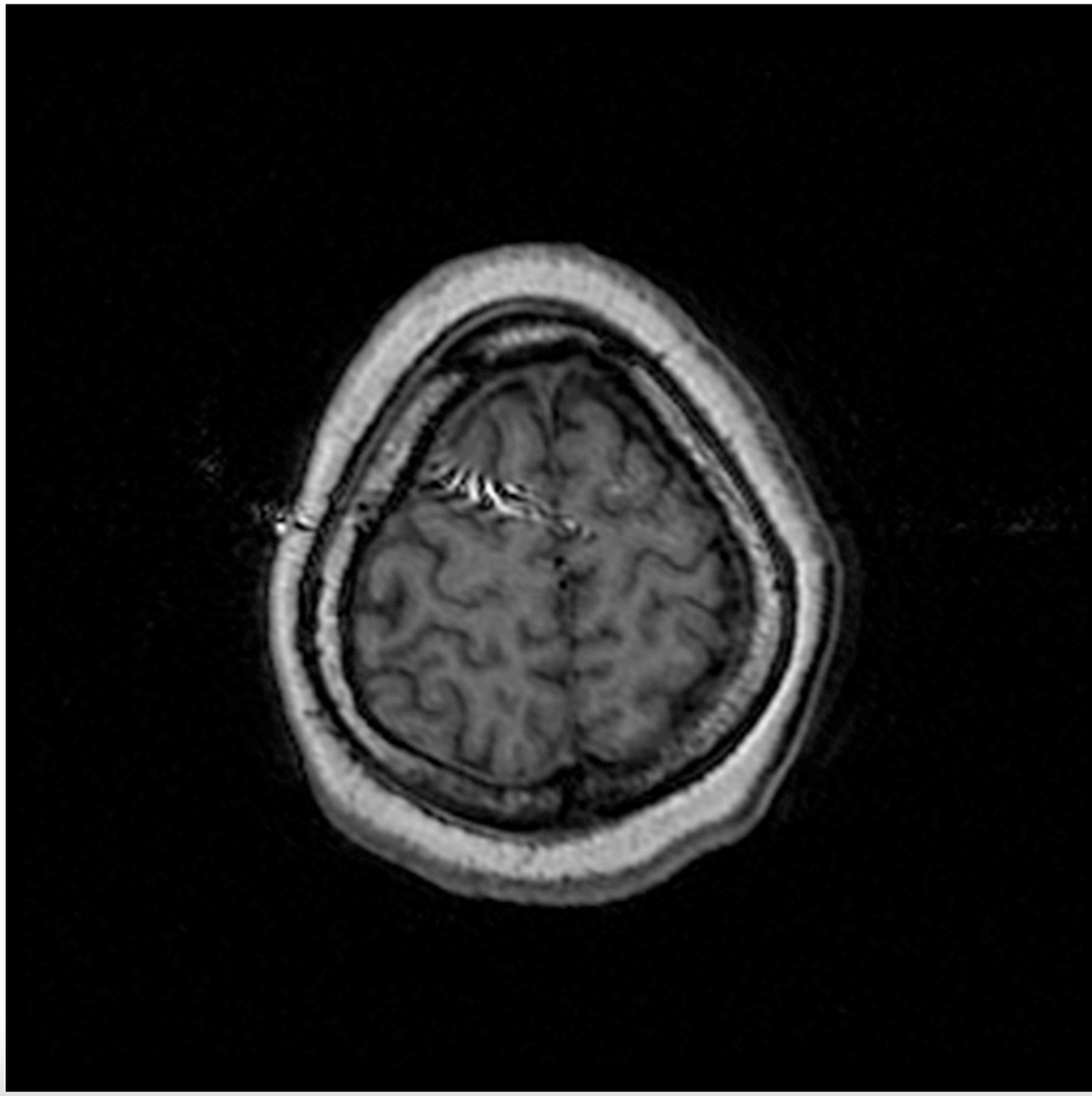
simulation



pMRI and Traditional Artifacts

Another susceptiblity artifact, affecting a GEM 2D acceleration scan.

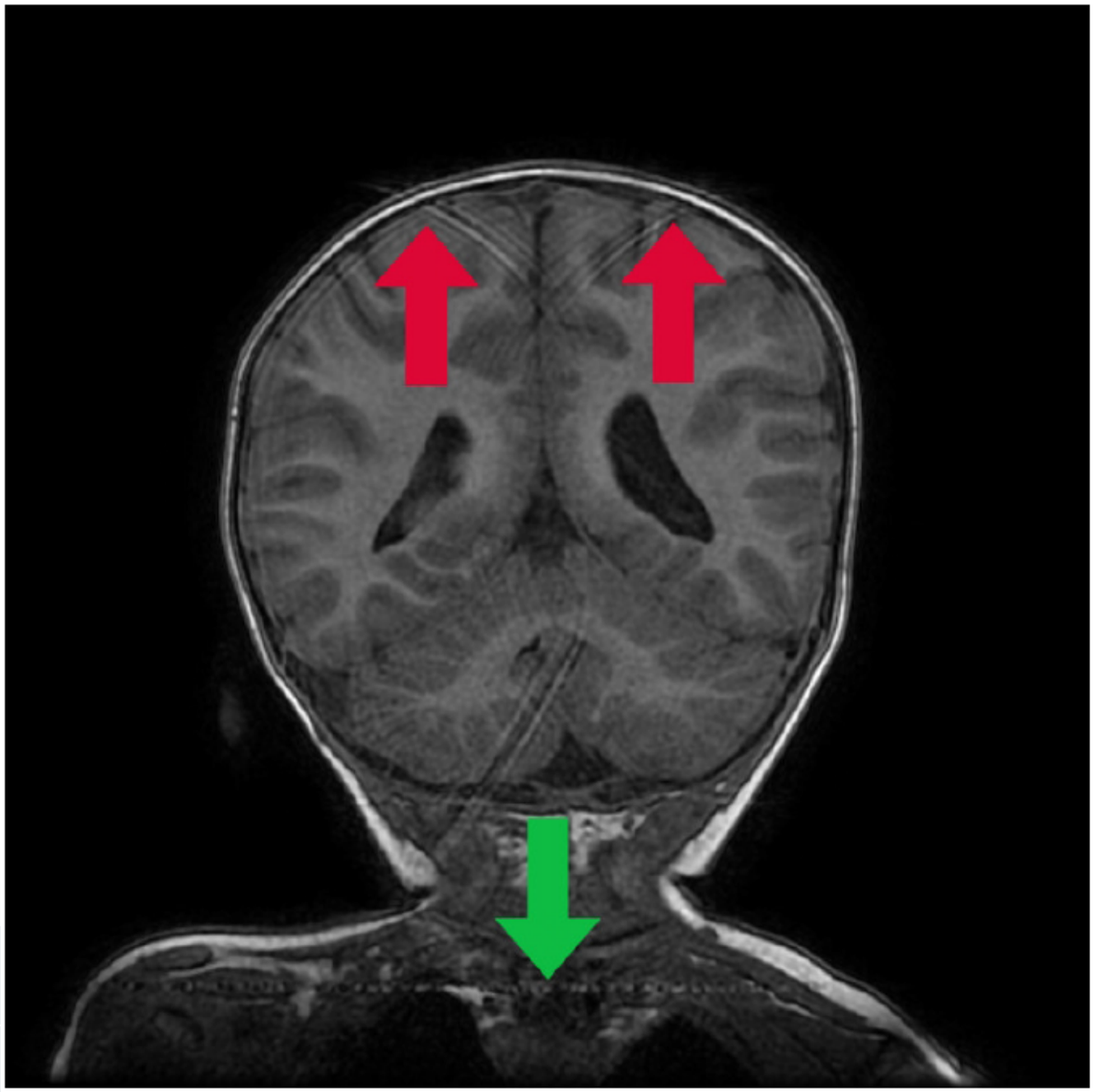




pMRI and Traditional Artifacts

Appearance of traditional artifacts may be modified by pMRI

Zipper causes poor reconstruction.

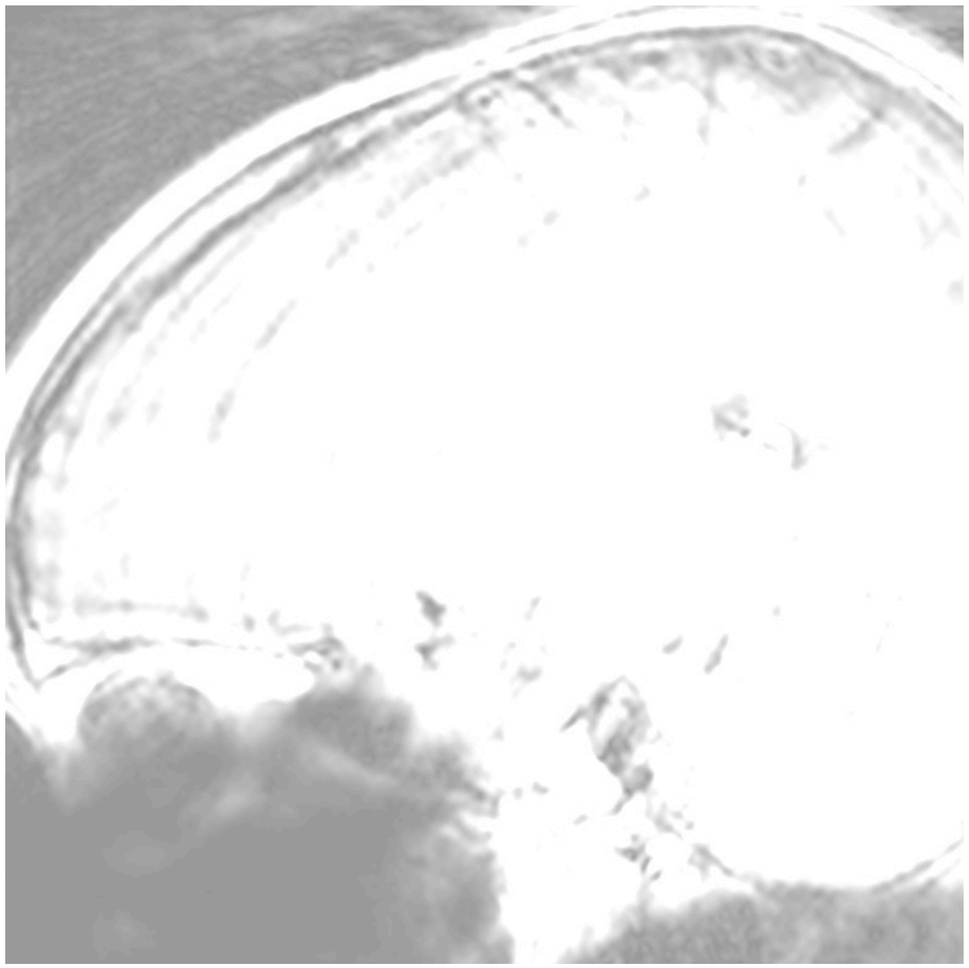


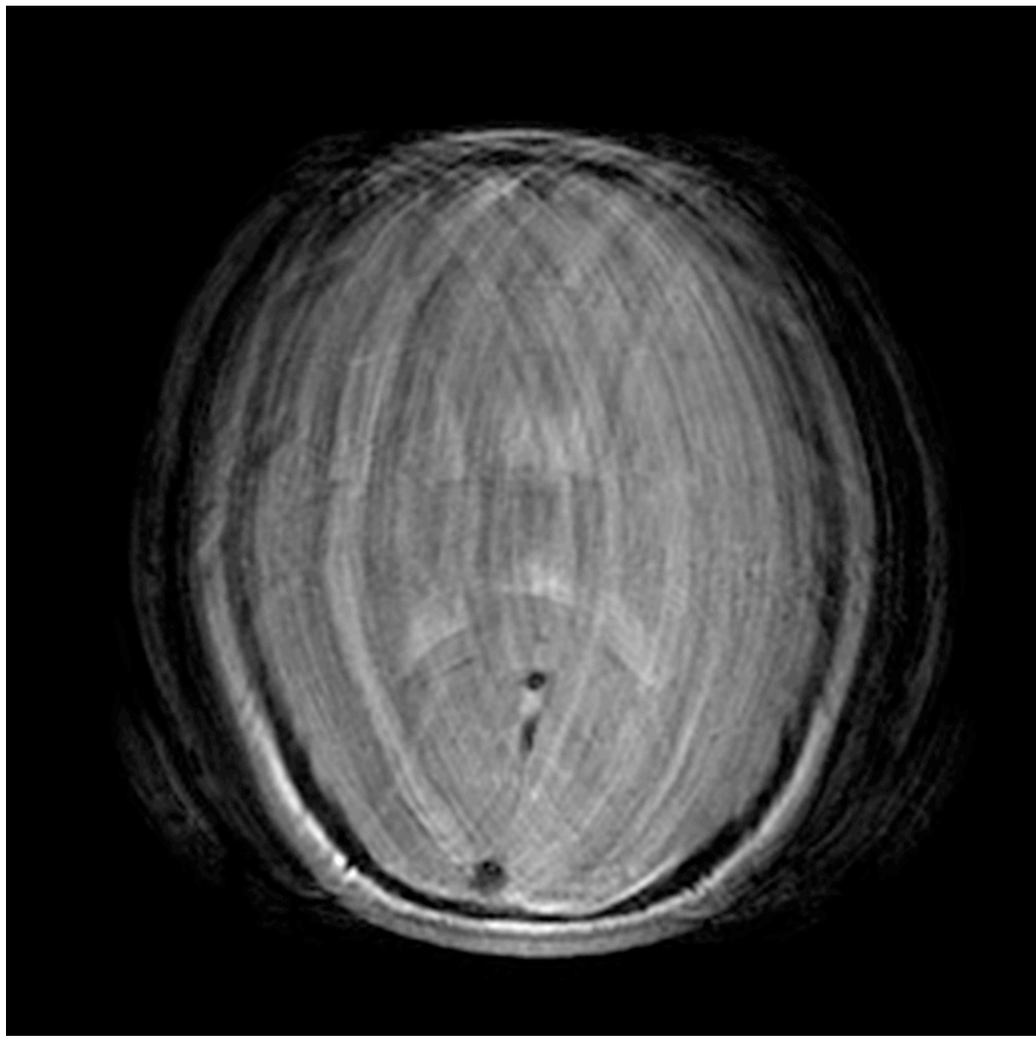
Yanasak and Kelly, Radiographics, 2014

pMRI and Traditional Artifacts

Appearance of traditional artifacts may be modified by pMRI

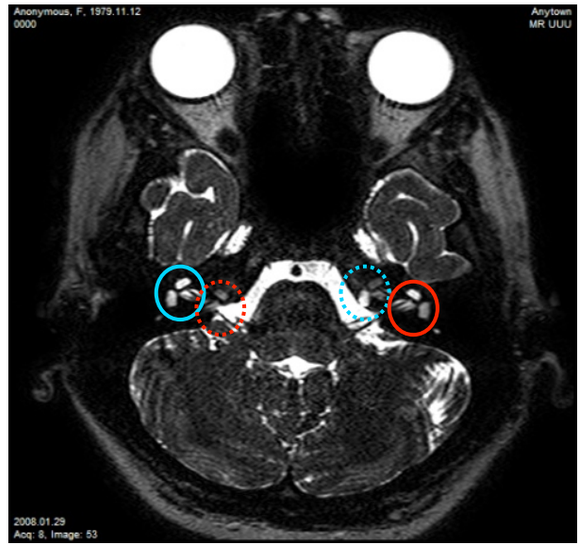
Profound motion is made much worse by pMRI.

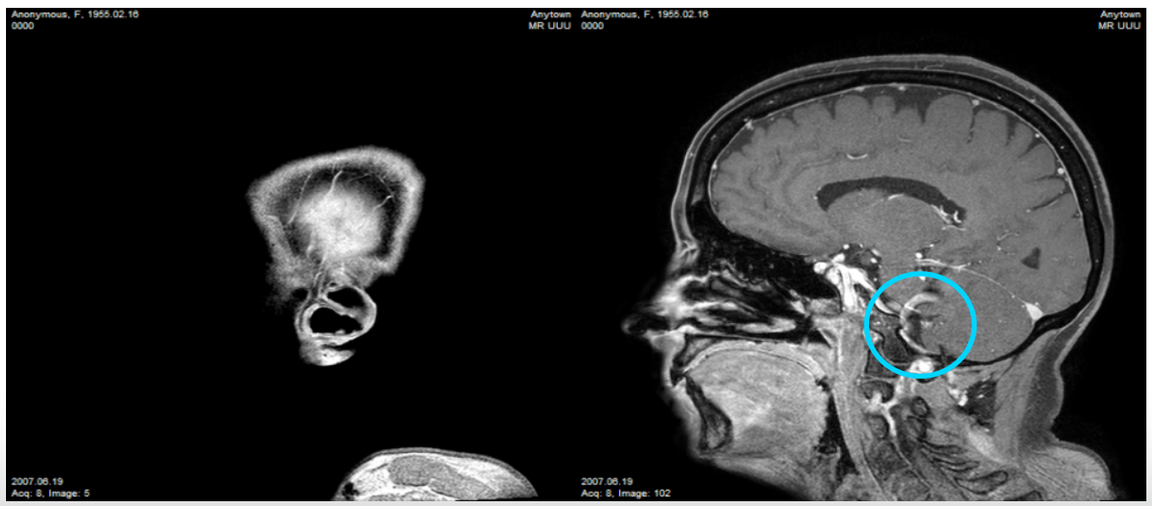




Yanasak and Kelly,
Radiographics, 2014

pMRI Clinical Artifact Examples





3D artifa ed volume (

Pseudo-"failure" of fat sat: Patie

IAC structure ghosting

nd SENSE scans

Summary

- Many different kinds of artifacts.
- Many are correlated with phase-/frequency-encoding axes by design (although, non-cartesian …).
- Some are of lesser issue to Radiologists (e.g., Gibbs, zippers).
- Some need more attention than they usually get (e.g., susceptibility, fat sat failure).
- Sequences and artifacts can be correlated.
- pMRI artifacts are becoming more common (and make a nuisance out of innocuous, traditional artifacts).
- QUESTIONS?