A Few

Review of Basic MRI Artifacts in the Clinical Realm

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Clinical MRI Artifacts: "Beyond Bushberg"

- Introduction
- Clinical MR Artifacts
  - Don't recognize it clinically or never heard of it
  - Only see it in specific clinical applications
- New mitigations
  - Fat Suppression (Dixon, Improved B0 Shimming)
  - Metal Artifacts (MAVRIC/SEMAC/VAT)
  - Motion Artifacts (Fast Scans, Motion Resistant Scans)

MRI Artifacts in Bushberg

I will assume you know these at the level of Bushberg

- Magnetic Field Inhomogeneities
- Susceptibility Artifacts
- Gradient Field Artifacts
- RF Coil Artifacts
- RF Artifacts
- K-space Artifacts
- Motion Artifacts
- Chemical Shift Artifacts (1st Kind)
- Chemical Shift Artifacts (2nd Kind)
- Ringing Artifacts
- Wraparound Artifacts
- Partial Volume Artifacts

MRI Artifacts in Bushberg

- Magnetic Field Inhomogeneities
- Susceptibility Artifacts
- Gradient Field Artifacts
- RF Coil Artifacts (Coil "hot spots", Fat Saturation???)
- RF Artifacts (Zippers)
- K-space Artifacts ("bad pixel"???)
- Motion Artifacts
- Chemical Shift Artifacts (1st Kind)
  - "fat shift"
- Chemical Shift Artifacts (2nd Kind)
  - "water-fat cancellation bands"
  - Useful in abdominal MR
- Ringing Artifacts
- Wraparound Artifacts
- Partial Volume Artifacts

MRI Artifacts in Bushberg

Some tidbits to add

- Magnetic Field Inhomogeneities
  - Fat Suppression Failure (even worse near susceptibility source)
  - EPI Geometric Accuracy Failure (even worse near susceptibility source)
  - Moiré Artifact (more on that later…)
- RF Coil Artifacts (Coil "hot spots")
  - Can happen when you don't use the pads velcroed to the RF receive coil.
  - Use homogeneity correction (e.g. CLEAR, PURE)
- K-space Artifacts ("RF noise spike")
  - Possibly due to electrical arcing (e.g. DWI when humidity is too low)

Bushberg is Just the Beginning

There is not enough space in a general intro textbook to cover

- Recognizing "common" artifacts in a variety of unfamiliar settings
- Artifacts across a wide variety of applications
- Newest mitigations developed recently

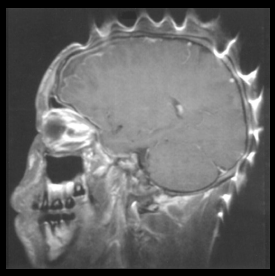
In clinical MRI, the basic artifacts will commonly be caught be techs and radiologists.

The physicist is more often brought in for the less obvious artifacts.

And 25 min is not enough time everything!

MR Artifacts are Endless!

- But learning basic principles can help you solve these mysteries



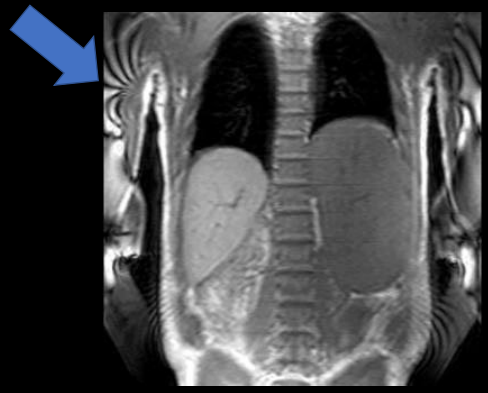
McKinstry, AJR 2004

The culprit:
Iron oxide tint in bees wax hair product!

Courtesy Robert Mulkern

The culprit:
Ferromagnetic Dye!

Moiré Artifact



AKA, "Zebra Artifact"

Artifact Mechanics

Cause:
The static magnetic field far from the isocenter of the magnet (often near the end of the bore for large FOVs).

All MR physics falls apart here!

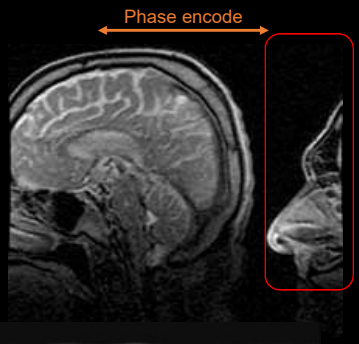
How to Fix

Who?	Does What?	Consequences
MR Tech	Use fewer slices (axials) (Other artifacts may limit before that)	May increase scan duration
Purchasing	Buy new scanner	Expensive!
Purchasing	Software upgrade • B0 mapping based with Dixon • ENCASE	Some expense Modest improvement Only limited applications

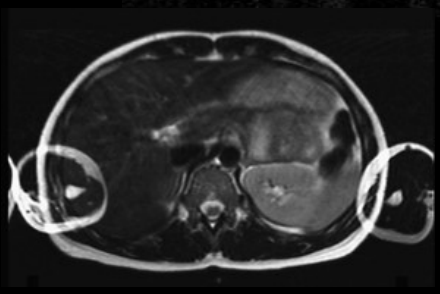
Aliasing Artifact

AKA, "Wrap-around" Artifact

Tissue seems to wrap around to the opposite side of the image if outside the FOV **in the phase encode direction.**



Warning !
"Textbook" Example



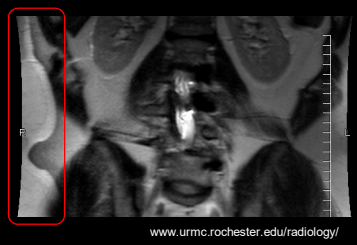
"Real world" Example

Axial Abdomen
Wrap in arms

Appearance

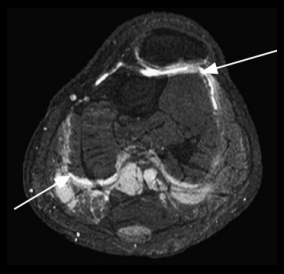
Clinical variations:

Coronal Abdomen/Lumbar
Wrap in lateral tissue



www.urmc.rochester.edu/radiology/

Axial of knee
Wrap in other knee!

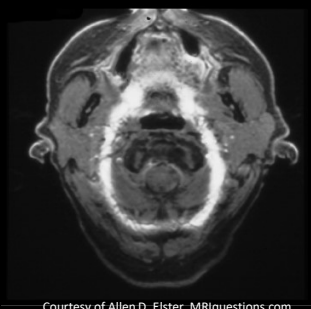


Appearance

Clinical variations:

- 3D scans have a 3D image volume.
- FOV in each of 3 directions.
- Uses “phase encoding” in PE and “slice” directions.
- If tissue extends beyond FOV in either direction, you can get aliasing

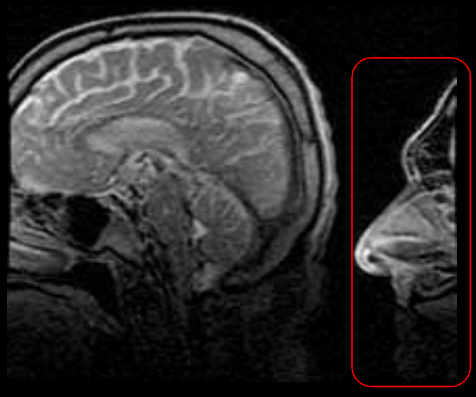
3D Axial Scan of Brain
Wrap in the “slice direction”



Courtesy of Allen D. Elster, MRIquestions.com

Artifact Mechanics

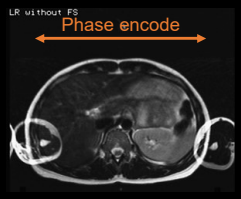
Cause:
Phase values from phase encoding are the same for tissue in different places.



SAME SAME

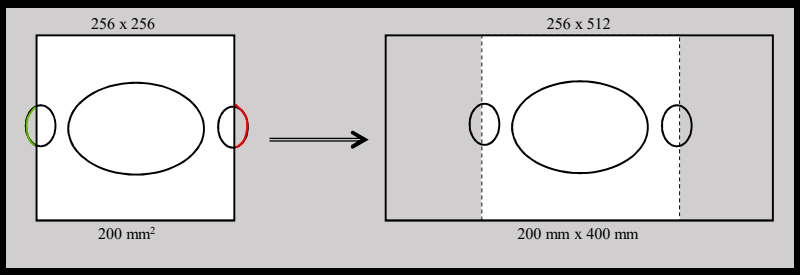
Is it 12am or 12pm?

How to Fix



Simple solution: Increase # of PE samples (increase FOV)

Foldover Suppression:
Increase # of PE samples (increase FOV) and throw out unwanted portion of image



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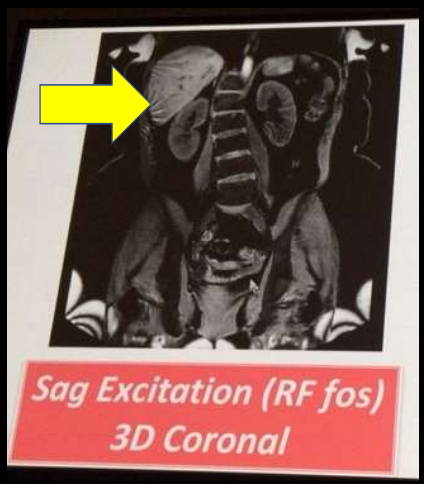
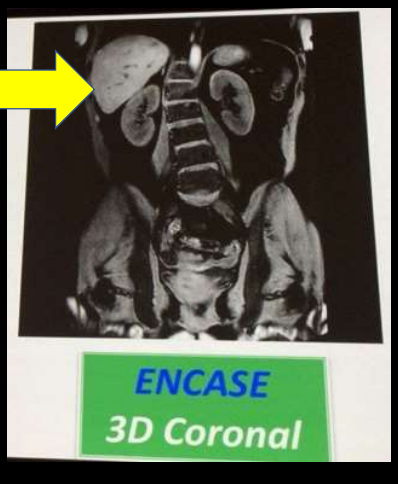
How to Fix

Who?	Does What?	Consequences
MR Tech	Use Foldover Suppression	Increased scan duration
MR Tech	Make FOV cover all tissue	Increased scan duration
MR Tech	Change foldover direction to avoid wrapping	Not always possible
MR Tech	Use saturation bands	Increase SAR (possibly scan duration); Not always effective
MR Tech	For 3D: Use Slab Select excitation	Vary by vendor/application

Combination Artifacts: Example (Aliasing & Moiré)





AKA, "Flame Artifact"

Possible Mitigations:

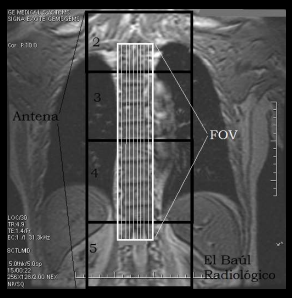
- Solve Aliasing Artifact and accept Moiré (e.g. in a coronal)
  - Long breath holds…
- Specialized scan (ENCASE, Philips)

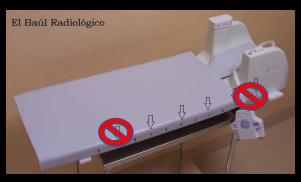
An Easter Egg App

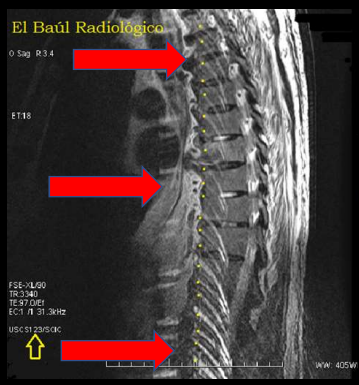
Dumolin, Philips lunch talk, ISMRM 2015.

Combination Artifacts: Example (Aliasing & Moiré)

Variation on an Annefact Artifact







Fix: Turn off coil elements away from your slices

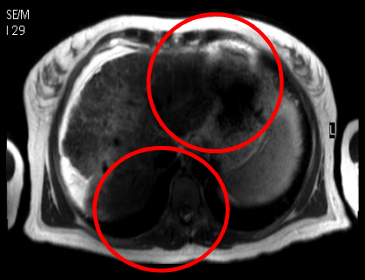
RF Shading Artifact

RF shading artifacts primarily at 3T or higher, mainly in chest/abdomen

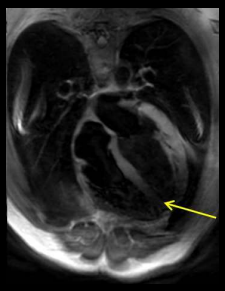
Classic example: ascites or fetal

"Dielectric artifact" (not really)

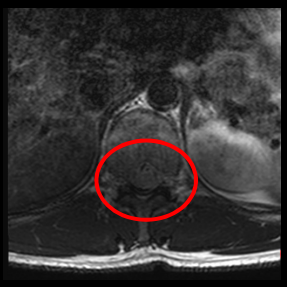
Commonly mistaken for poor coil placement or coil maintenance issue.



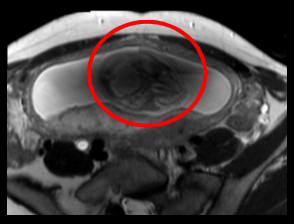
Liver ascites



Cardiac



T/L junction of spine

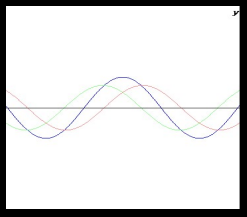


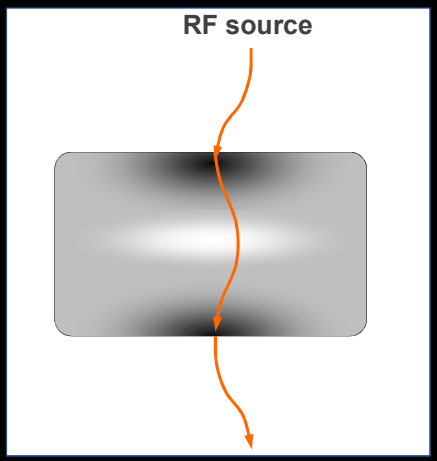
Fetus

Andrews T, IACSM, 2009
Andrews T, ISMRM, 2011

Artifact Mechanics

RF transmission reflects in body creating "standing waves"(see blue wave below)



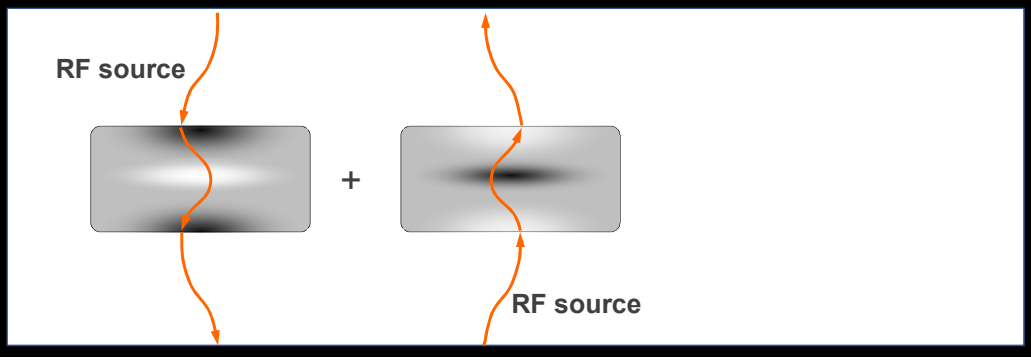


How to Fix

Analogous to noise cancelling headphones

- "RF shimming" (AKA, "parallel transmission" or "parallel transmit")
- Change phase and amplitude of at least 2 RF transmissions
- Makes RF transmit field more uniform.

http://mriquestions.com/uploads/3/4/5/7/34572113/mr_achieva_tx_whitepaper_multitransmit.pdf



How to Fix

Who?	Does What?	Consequences
MR Tech	Avoid 3T for cases where this is a likely problem (e.g. ascites)	Lose advantages of 3T
MR Tech	Use RF shimming	May not be completely effective
Purchase & MR Tech	Use dielectric pads	May not be effective May be awkward & uncomfortable

Vibration Artifact

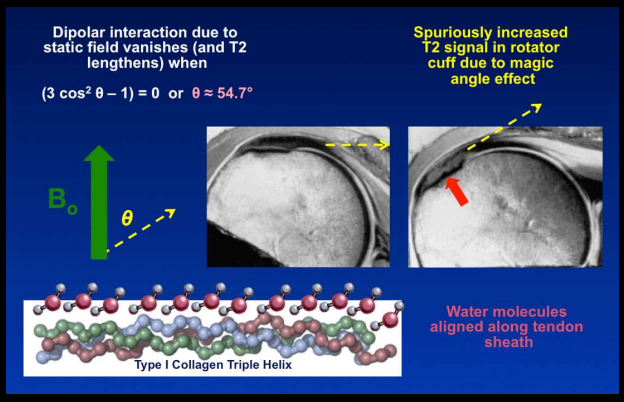
- Vibrations near (or even from) the scanner can contribute phase variations similar to patient motion.
- "Ghosting", reverberation artifacts
  - Looks like patient motion, but can be seen in a phantom
  - Addressed in Report 100 on MR Acceptance Testing:
    - Possibly due to:
      - large ventilation systems (e.g. w/ unbalanced fan)
      - Aging patient table mechanics (esp. with lighter subjects such as children and babies)"
    - To mitigate:
      - Best addressed at installation
      - Field service should address later
      - Might use quieter scans (if caused by scanner)

"Application Specific" Artifacts

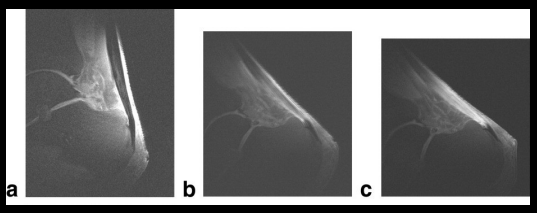
- Some artifacts are rarely or never seen outside of very specific clinical applications (e.g. cardiac cine scans)
- Use this as a clue for addressing the problem

"Magic Angle" Artifact

Most commonly seen in MSK MRI.
Can simulate connective tissue pathology.



Courtesy A Elster



Bydder M "Magic Angle Effect" JMRI (2007)

Mitigations:

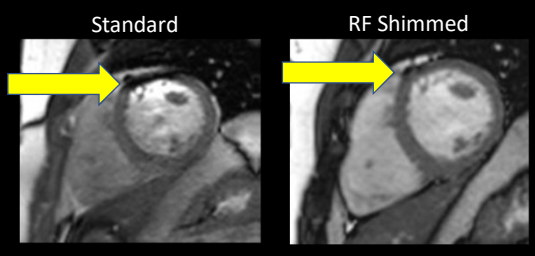
- Position affected tissues far from magic angle
- Use longer TE values (>37ms, 1.5T)
- Focus on T1 scans for tendon pathology

Banding Artifact (for SSFP)

- Steady State Free Precession (SSFP) is a "workhorse" sequence for cardiac cine scans (showing cardiac contraction at different timepoints)
- Very sensitive to B0 inhomogeneity, leading to dark bands

Saremi, "Optimizing Cardiac MR Imaging", RadioGraphics 2008; 28:1161–1187

- Mitigations:
  - Switch to using a longer more flat GRE
    - Useful near CIEDs (pacemakers, ICDs, CRTs)
  - B0 Shimming
  - Decrease TE
  - Keep TR about double the TE
  - RF shimming (directly increases FA; reduces SAR, so you can decrease TE)
  - Patient-specific frequency offsets, etc, etc



Andrews T, ISMRM 2010

Troubleshooting: Some Starting Questions

- Is this really a clinical problem? What is a "good enough" solution?
- What kind of pulse sequence is it?
  - Some have special artifacts OR are particularly sensitive to some things (EPI, SSFP, T2 TSE, FLAIR, SWI)
- Is the artifact pointed in a direction?
  - Phase-encoding or readout direction? Does it change if you swap directions?
- Are there any recognizable anatomical features in the artifact?
  - Maybe a "ghost". Is there motion? Is parallel imaging used (e.g. SENSE)?
- Is there signal pile-up and voids?
  - Maybe susceptibility related. What could be causing it? Nearby metal? Air?

Big New Technical Improvements

Sounds overwhelming, but there are reasons to be hopeful.

Scanner upgrades often "hide" many artifact mitigations, so check the documentation.

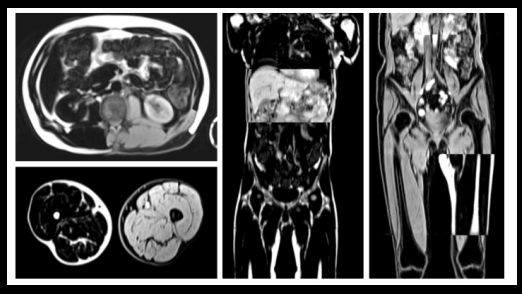
Some of the bigger recent improvements……..

https://enterprise.press/archive-wealth/year-wasnt-bad-news/

Improvement 1: Fat Suppression

<u>More robust fat sat method</u>

- DIXON Method
  - Generally more robust fat sat (esp. post-Gd injection)
  - Possible "water-fat swap" artifact
    - Easy to spot and increasingly uncommon



Glocker, et al "Correction of Fat-Water Swaps in Dixon MRI" MICCAI 2016

<u>Make B0 more uniform</u>

- Image-Based High-Order Shimming
  - Originally for Breast MR
- Coil-based Shimming
  - Newer Head/Neck Coils

Varies from vendor to vendor
(More Easter Eggs!)

Improvement 2: Metal Artifact Suppression

<u>View Angle Tilting</u>

- <u>In-plane distortion</u> improvement; for smaller artifacts
- Some blurring potentially
- Minimal effect on scan duration

<u>MAVRIC/SEMAC</u>

- <u>Through plane distortion</u> improvement; for larger artifacts
- LONG scan duration potentially
  - Now CS can help

Improvement 3: Motion Artifacts

- Motion Insensitive Scanning
  - Non-Cartesian scanning
    - Propeller
    - Golden Ratio "stack of stars"

Covered Later Today

- Accelerated Scanning
  - Compressed Sensing (CS)
    - Esp. for shorter breath hold scans
  - Simultaneous Multi-Slice (SMS)
    - Vendor names: HyperBand, MultiBand, SMS (w/ "blipped CAIPI")
    - Simultaneously excite multiple slices (commonly fMRI/DTI; large stacks)
    - Small SNR penalty
    - BUT may be high SAR or have artifacts similar to parallel imaging

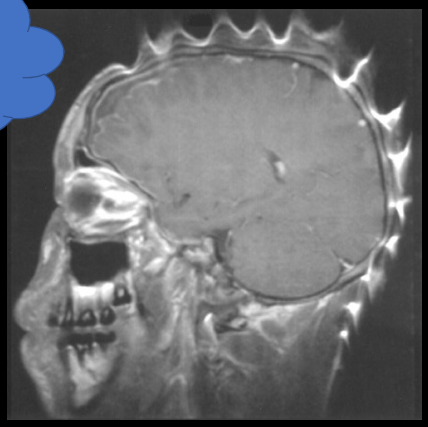
Covered Later Today

Improvement 4: Everything else! (Actually DL/AI)

- Deep Learning /AI in reconstruction is starting to help with other artifacts
- Example: Gibbs ringing artifact in spinal cord due to small matrix size in perpendicular direction

GE Healthcare

Pile up and voids.
Maybe susceptibility.
Is there metal nearby?
Iron in hair product!



Acknowledgments:
Robert McKinstry (hair artifact)
Dave Hitt (ENCASE)

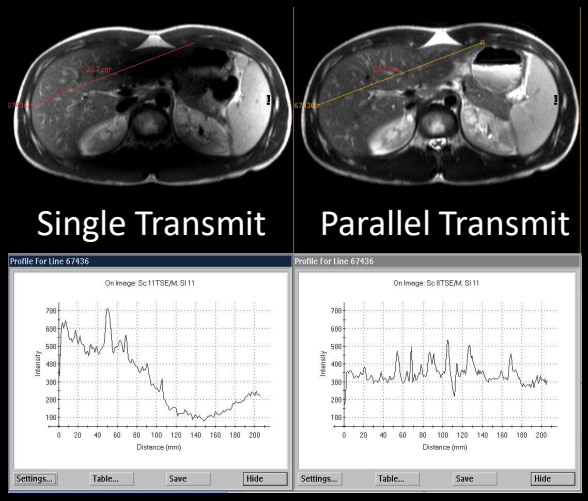
Thank you for your attention!

BONUS SLIDES !

How to Fix

Is this a window/level trick?

Corrected an 85% signal drop in left lobe of liver.



Andrews T, Ghostine J, Gonyea JV, Ebert GM, Braff SP, Filippi CG, "Reduction in Dielectric Shading in Liver on Clinical 3T Parallel Transmission MR System", ISMRM Proc., 2010.

Simultaneous MultiSlice (SMS)

Excite multiple slices (2-4) at the same time.

Unlike parallel imaging, there is little SNR penalty for SMS acceleration!

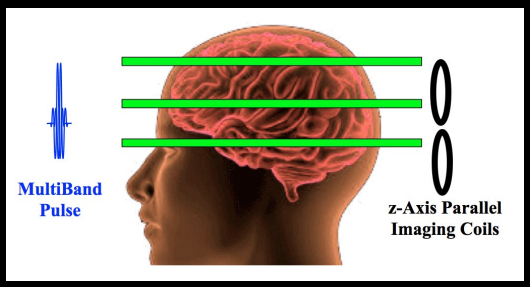


Image courtesy of Allen D. Elster, MRIquestions.com

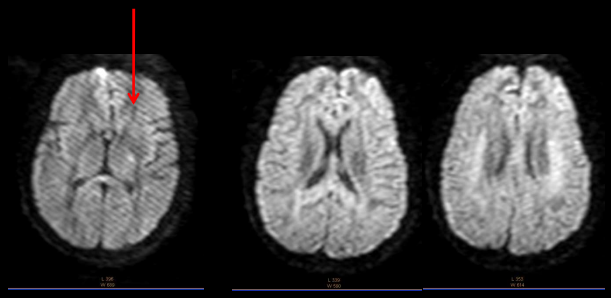
Initially introduced for speed improvements for EPI-based scans (e.g. DTI and fMRI)

Can potentially be used
- For long 2D scans (e.g. axial t-spine)
- With parallel imaging acceleration (depending on coil)

Limitations:
- Often use high SAR pulses
- May produce ghost artifacts (similar to SENSE)

Appearance

"Corduroy" Artifact



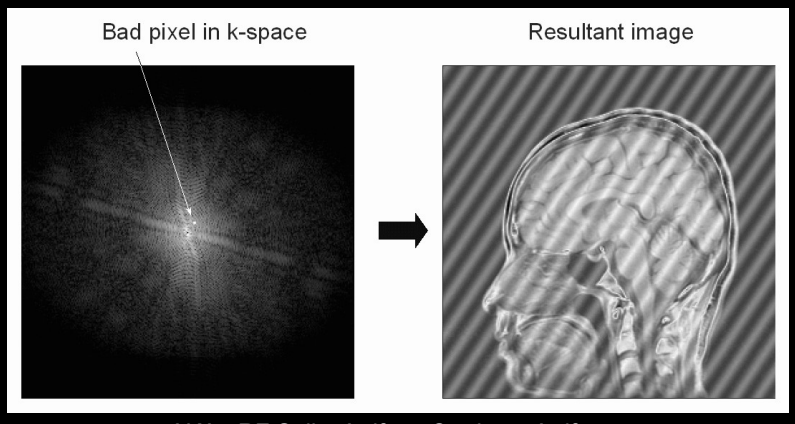
Extreme example

More typical examples

Most commonly seen for DWI scans especially in low humidity.

Artifact Mechanics

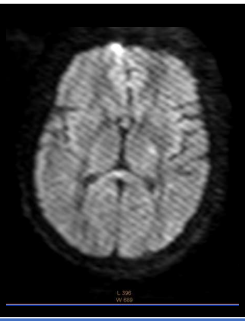
Spike in K-space



AKA: RF Spike Artifact, Corduroy Artifact
If you live in a dry climate, beware of this one!

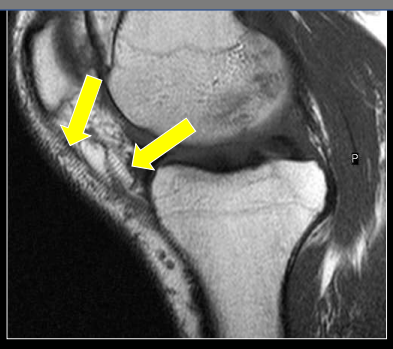
Warning !
"Textbook" Example

How to Fix



Who?	Does What?	Consequences
Service Engineer	Check for sources of noise spikes: Bad light bulbs, power injectors, (for DWI: low humidity)	Scanner downtime
Facilities Engineer	DWI: Maintain scanner room at correct humidity	Extra work and time to correct (esp. during winter)

Advanced



Most apparent with T1/PD TSE

Cause: Flip angle inaccuracy leads to **stimulated echoes** (which after the reconstruction look like fine structure)

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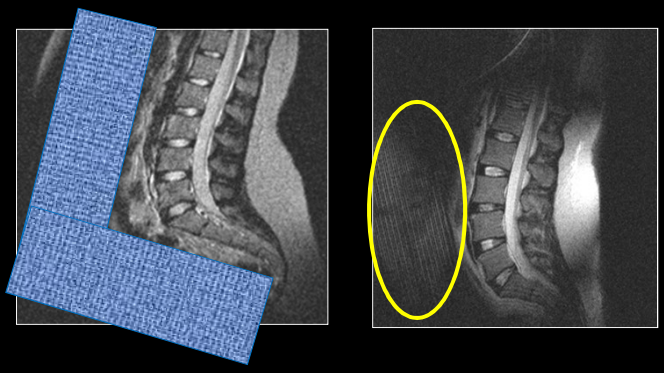
FID Artifact (focal stripes)

How to avoid:
1) Use 2 "real" NEX
2) Increase signal crushing gradients around refocusing pulse (possibly by turning on flow compensation gradients).

Advanced

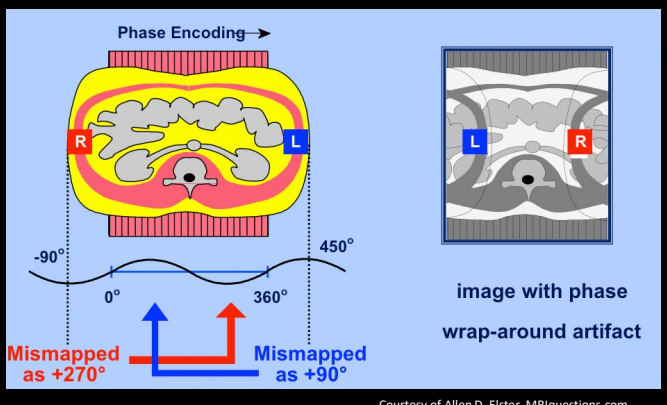
Cause: Intersecting Saturation Bands (AKA: REST slabs)

- Not to be confused with corduroy artifacts caused by spikes
- Those caused by REST tend to be localized
- Often associated with 3D FSE/TSE



Artifact Mechanics

Cause:
Phase values from phase encoding are the same for tissue in different places.



Courtesy of Allen D. Elster, MRIquestions.com

Like with an analog clock,
Confusing 12am with 12pm