MRI Artifacts

Causes and Correction

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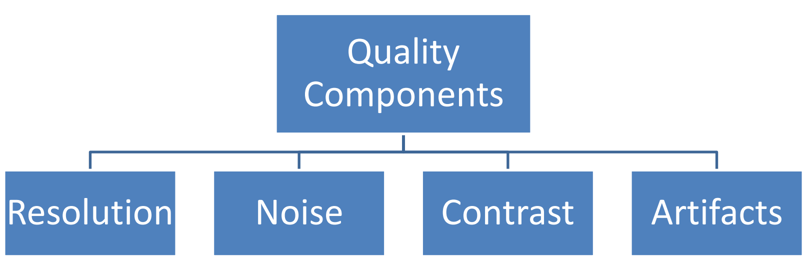
The components of image quality



Sources of Artifacts

- Physiological phenomena e.g. blood flow
- Physics limitations e.g. Gibbs and susceptibility
- Hardware Issues e.g. calibration, power stability
- Software problems e.g. programming errors

Types of artifacts based on their appearances

- Edge artifacts
  - (ghosting, chemical shift, ringing)
- Distortions
- Wraparound artifacts
- Artifacts by Special techniques
- Hardware related Artifacts

Ghosting and smearing by motion

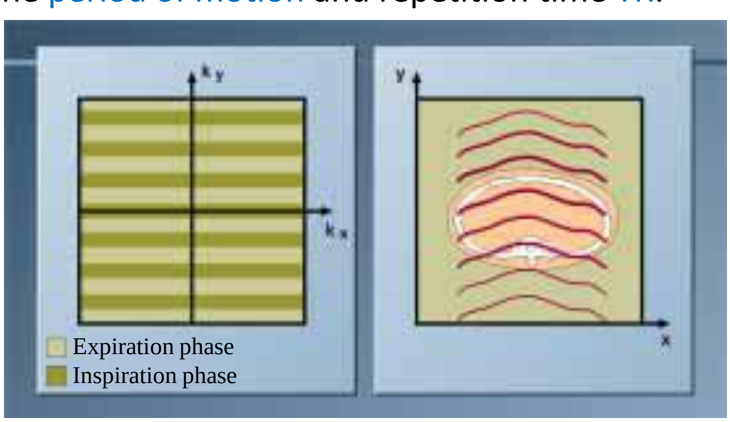
Artifacts are frequently caused by random or involuntary movements

1. Respiratory motion (the most frequent source for motion artifacts)
2. Cardiac motion and blood flow
3. Ocular motion, swallowing
4. Patient movement

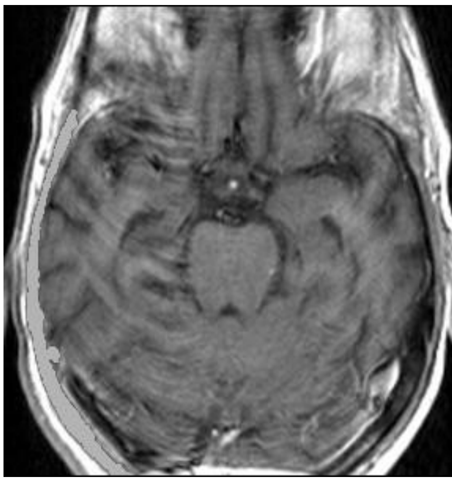
Motion artifacts are visible only in the phase-encoding direction

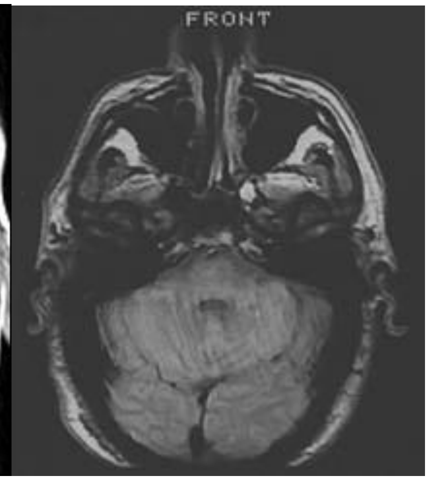
Respiratory motion

- Structures with high signal intensity, in particular subcutaneous fat, generate ghost .
- The interval between the ghost images depends on the period of motion and repetition time TR.



Motion Artifacts





Smearing (لکه ای)

- Non-periodic physiological movement such as eye motion leads to smears in phase direction.
- Pulsatile blood flow from enhancement of vessels perpendicular to the image plane can produce Ghost or smeared images.

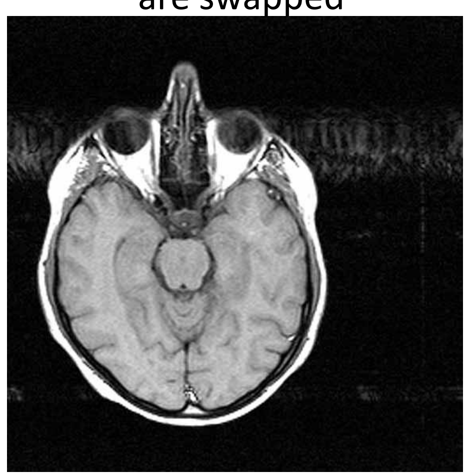
Correction of motion artifacts

- Swap the phase and frequency-encoding gradients
- Use sequences with flow compensation (GMR)
  - GRADIENT MOTION REPHASING
- Define pre-saturation slices.
  - Parallel to the image plane for the inflowing blood
  - In the image plane for Sagittal images of the spine
    - Artifacts caused by respiratory or peristaltic motion.
    - Artifacts caused by swallowing in cervical spine
- Use sequences with fat suppression
- Use physiological synchronization.
- Use pseudo-gating
  - Make the value of TR a multiple of the heart rate
- Increase the number of averaging

Swapping phase and frequency-encoding gradients

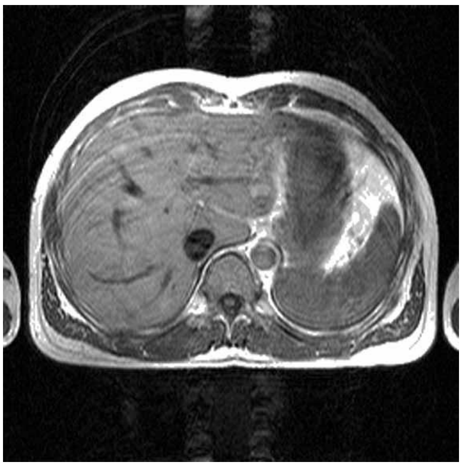
Standard phase-encoding direction

Phase and frequency axis are swapped

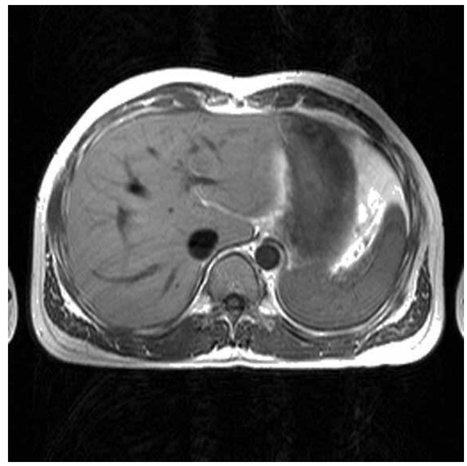


Averaging to suppress motion artifact

1 averaging

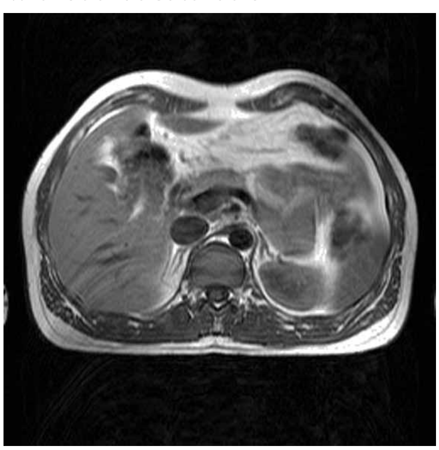


4 averaging

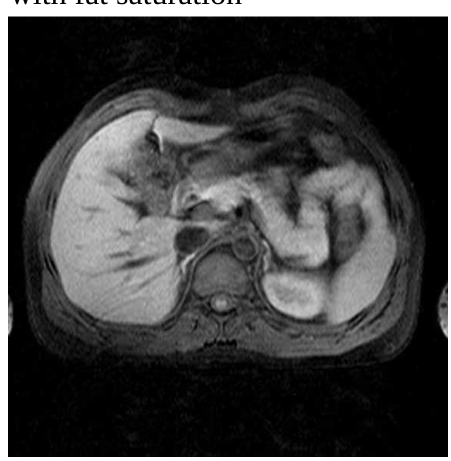


Fat saturation to suppress Motion artifacts

T1-weighted image of the liver without fat saturation



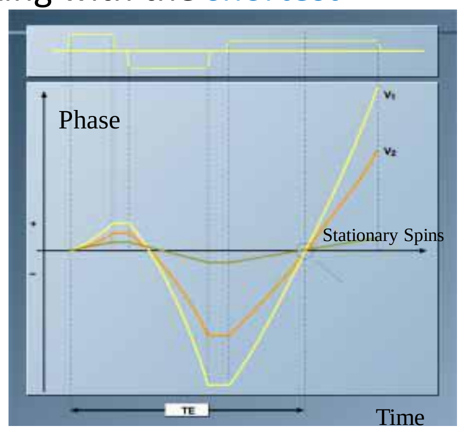
T1-weighted image of the liver with fat saturation



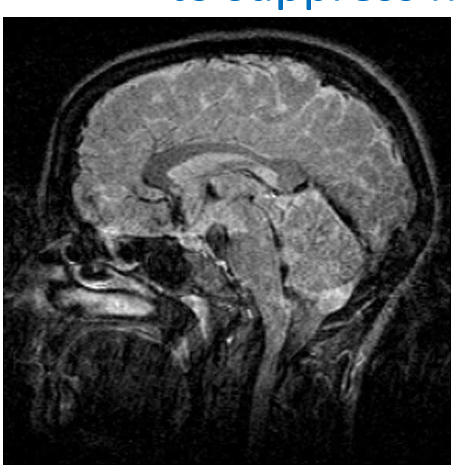
GRADIENT MOTION REPHASING (GMR) to suppress Motion artifacts

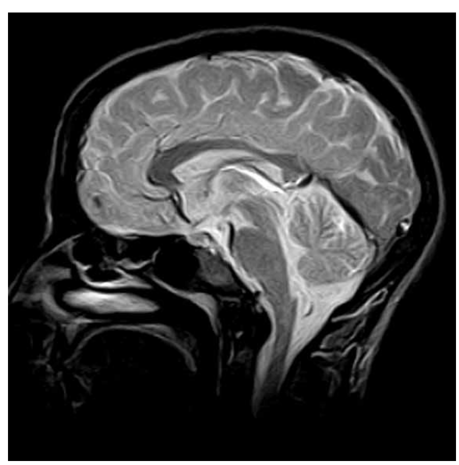
- Additional gradient pulses of the appropriate size and duration are applied.
- Optimal results are obtained by compensating for constant velocities and working with the shortest possible echo time.

- Use in imaging the thoracic spine, cervical spine, and head, because the effects of blood and CSF flow are very high



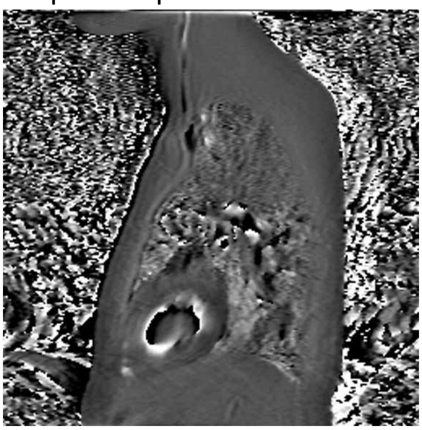
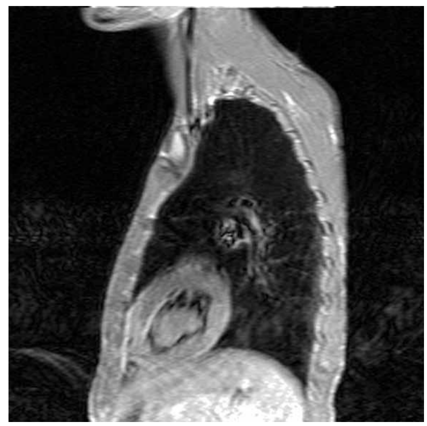
GRADIENT MOTION REPHASING (GMR) to suppress Motion artifacts


Without GMR

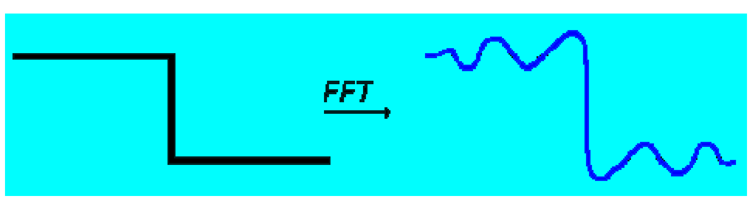

With GMR

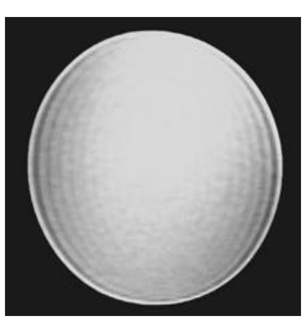
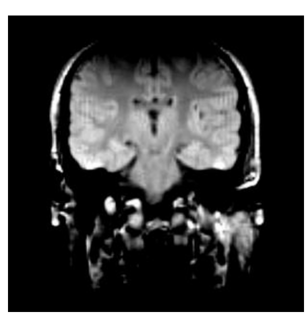
Motion artifacts in Phase images

- Motion artifacts are easily detected in the region of the cervical vessels, the aortic arch, and in the ventricle.
- Stationary spins have a uniform phase relation while the phase relation of flowing spins differ depending on the speed of flow
- In the phase image, the pixel grey scale value represents the respective phase relation between –180° and +180°

Gibbs or Truncation Artifact



TRUNCATION ARTIFACT (Ringing artifacts)

- Bright or dark lines, parallel & next to borders of abrupt intensity change
- It is technical in nature, result from the principles for sampling and digitizing an analog signal.
- In theory, an infinite bandwidth should be sampled,
- However, in practice a finite bandwidth is sampled, meaning that some data is truncated

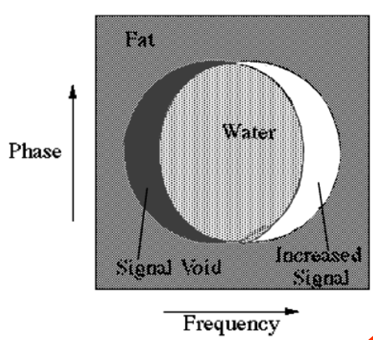
Correcting Ringing artifacts

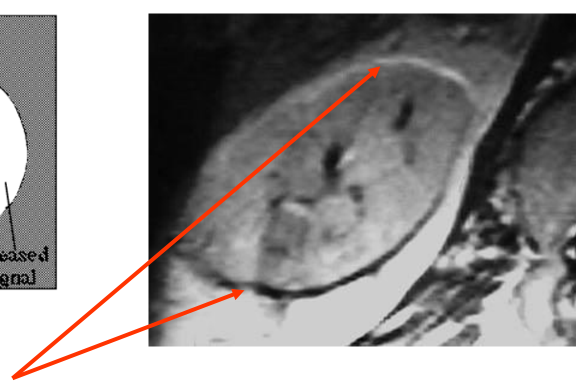
1. Use a raw data filter (HANNING filter)
2. Decreasing Pixel size by increasing the imaging matrix or decreasing the field of view

Chemical Shift Artifact

- The different resonant frequency of fat & water is transformed into spatial difference.
- Appears in Frequency-encoding direction
- Common in vertebral bodies, orbits, solid organs surrounded by fat.
- Worst at higher field strength, less with stronger gradients.

Chemical Shift Artifact





Kidney example)

The shift is 3.5 ppm, corresponding toapproximately 147 Hz at 1.0 Tesla. For a pulse sequence with a readout bandwidth of 78 Hz/pixel, there is a shift of 2 pixels

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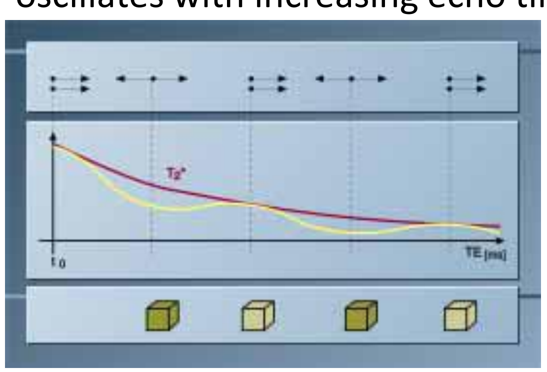
Correcting Chemical Artifacts

- Use a sequence with a wider bandwidth
  - Higher readout gradient, causes less pronounced chemical shift artifact, but Less SNR
- Swap the phase and frequency encoding
- Use a STIR sequence
- Use fat/water suppression

Chemical shift contours (Black Line Artifact)

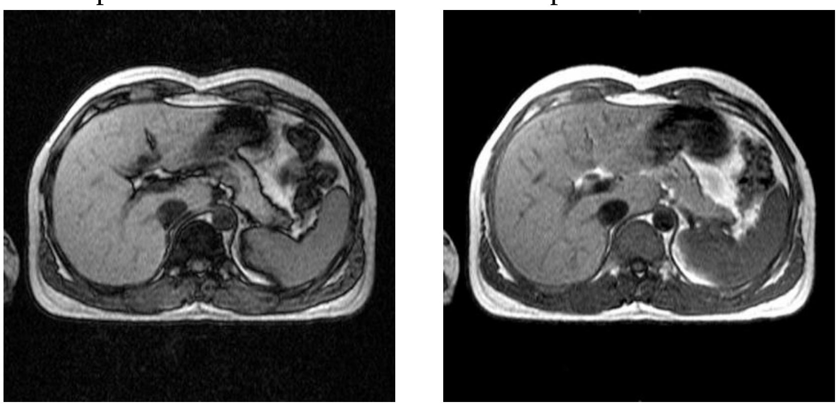
- Since Lipid and water protons precess at different frequencies, there are in-phase every 4.8ms (1.5T) and 2.4ms (3T), and totally out-phase every 2.4 and 1.2 respectively.
- Therefore, the signal intensity of a voxel containing fat and water oscillates with increasing echo time TE.



Correcting CS contour artifacts

- Use only echo times where the fat and water spins are in-phase.
- Fat suppression
- Increase bandwidth or matrix size.

Out-phase at TE=7.2 In-phase at TE=4.8



Types of artifacts based on their appearances

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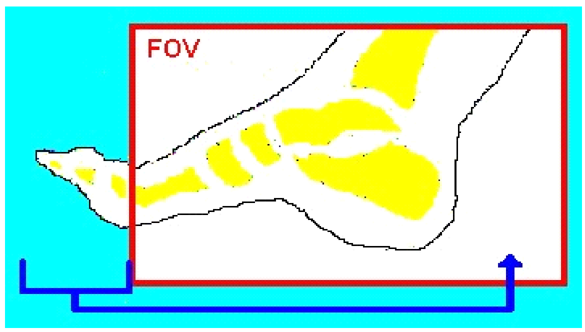
Aliasing or "Wrap-around“ Artifact

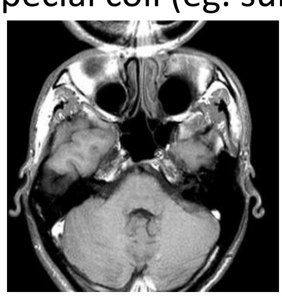
- Occurs when the field of view (FOV) is smaller than the body part being imaged causing the region beyond to project on the other side of the image.
- Caused by undersampling in the phase or (rarely) frequency direction.
- May occur in end slices of a 3D acquisition.



Correcting Aliasing artifact

1. Increase sampling rate, which in turn increases the dimension of the image; the pixel size remains the same
   - oversampling is always used in the readout direction
   - increasing phase steps in the phase-encoded direction
2. Define the saturation slices
3. Swap the phase and frequency-encoding directions
4. Use a special coil (eg. surface coil)

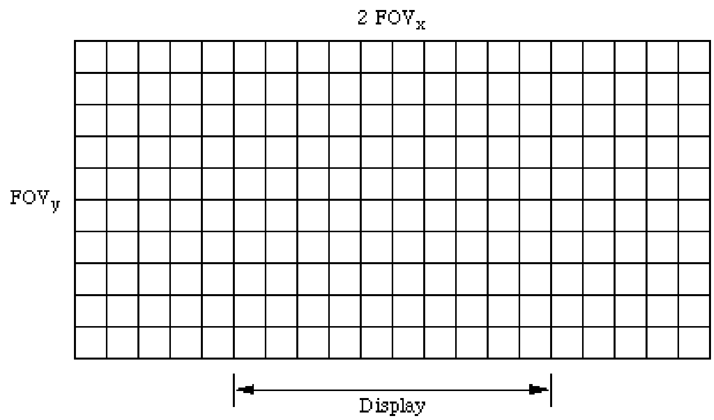
Without oversampling



With oversampling

Oversampling in the frequency encode direction

- Siemens: doubles the number of points sampled.
- -GE: Oversampling is always utilized.
- This does not change image acquisition time (or number of slices or echo time).



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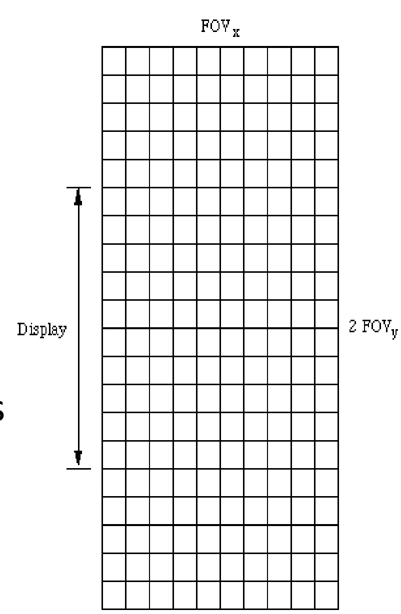
Oversampling in the Phase-encode direction

- ” Oversampling ” by Siemens:

increases the number of phase encodes by a user selectable percentage.

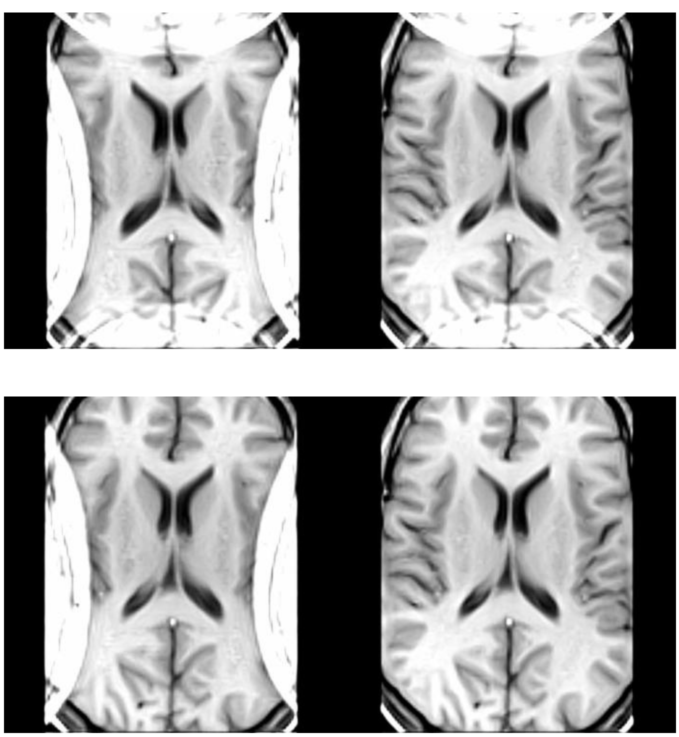
- ” No Phase Wrap” by GE:

doubles the number of phase encode samples (and halves the number of excitations).



Aliasing in the slice encoding direction

- This happens in a 3D data set.
- GE routinely discards the four outermost slices in a 3D data set (acquire 128 slices; displays 124 slices)
- Aliasing or wrap-around in the slice encoding direction is often still visible in the outermost slices.



Artifact with no oversampling

Read oversampling

Phase oversampling

Read and phase oversampling

Types of artifacts based on their appearances

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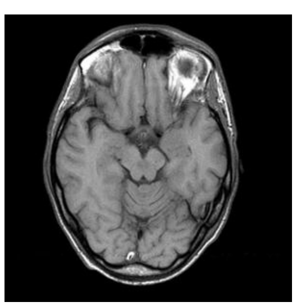
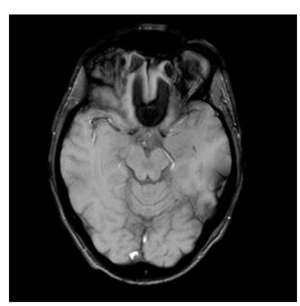
Susceptibility Artifact

- At all interfaces between tissues with different magnetic susceptibility, a local field gradient will be present.
- It happens for gradient-echo sequences because they do not compensate for field inhomogeneities

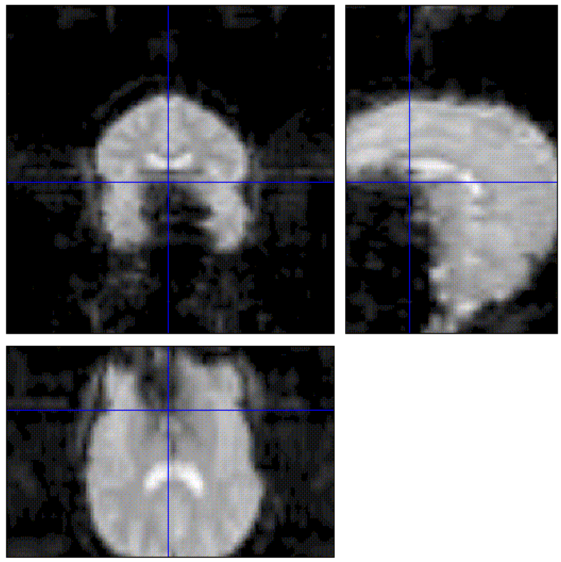


Spin-echo sequence



Gradient-echo sequence

Susceptibility Artifact in Orthogonal T2* (EPI) images

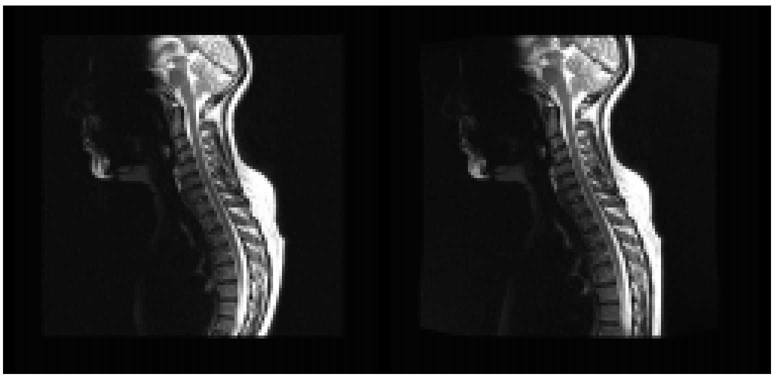


Correcting Susceptibility artifacts

1. Use spin-echo sequences
2. Decrease the voxel size (The differences in magnetic fields across the voxel will be reduced)
3. Decrease the echo time (shorter the time in which the spins can be dephased)
4. Use sequences with wider bandwidths

Distortions due to non-linear gradients

- Large FoV's may lead to geometric distortions in the periphery of MR images
- Excited slices are curved at the edge of image.
- Use the **Large FOV-Filter** to correct



Distortion correction using the **large Fov filter**

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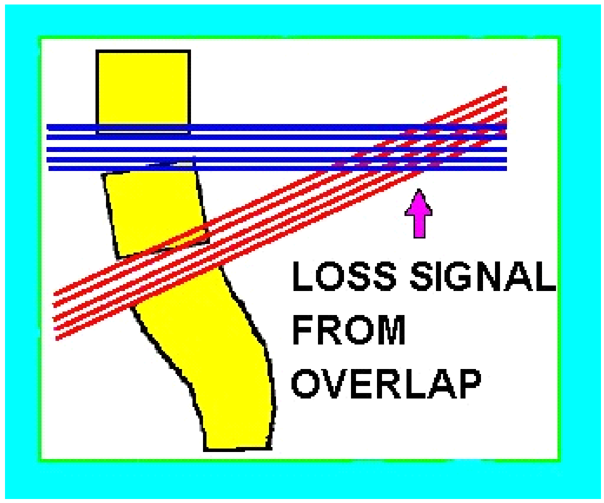
Slice-overlap (cross-slice) Artifacts



Slice-overlap (cross-slice) Artifacts

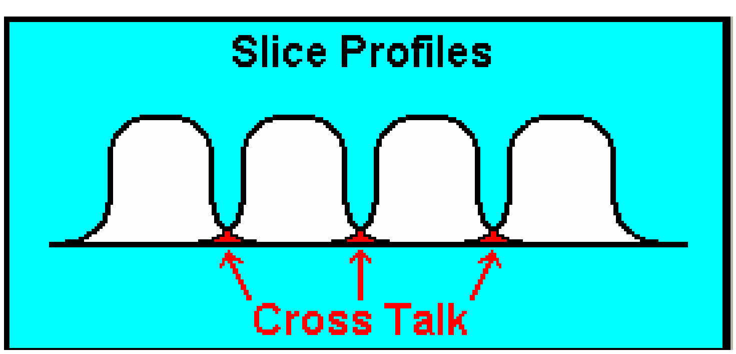
- Loss of signal seen in an image from a multi-angle, multi-slice acquisition.
- Same mechanism as spatial presaturation for reduction of motion and flow artifacts.
- Example: Two groups of non-parallel slices in the same sequence, e.g., L4-5 and L5-S1.

Correction of Slice-overlap Artifacts

- Avoid steep change in angle between slice groups.
- Use separate acquisitions.
- Use small flip angle, i.e. GE sequence

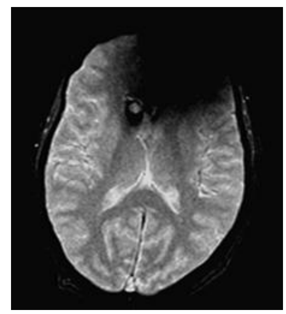
Cross-talk Artifact

- Result of imperfect slice excitation, i.e. non-rectangular, of adjacent slices.
- Causes reduction in signal over entire image.
- May be reduced by using gap, interleaving slices and optimized (but longer) rf pulses.



Metallic artifacts (magnetic field perturbations)

- Ferromagnetic metals distort the static field due to the alignment of many magnetic "domains".
- This artifact is worse with GE than with SE sequences.
- The effect of metallic objects is signal loss and image distortion
- Example:
  - Cosmetics (Fe, Co)
  - Metal Implant fillings



Non-ferromagnetic metal Artifacts

- Non-ferromagnetic metals can distort the static magnetic field due to smaller magnetic susceptibility effects.

- Eddy currents may also be induced in some metal objects resulting in induced magnetism.
- Example:
  - Non-ferromagnetic metal Shrapnel

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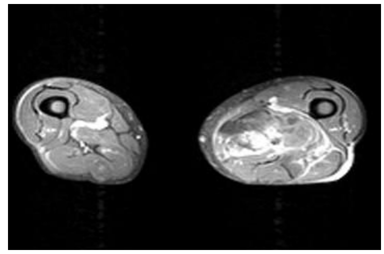
Field inhomogeneity Artifacts

1. Main magnetic field
2. RF coil inhomogeneity
3. Dielectric effects – worst at 3T+

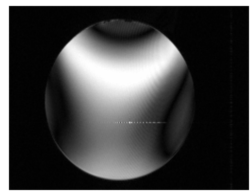
- May cause variation in intensity across image
- May cause non-uniform fat suppression

Field inhomogeneity – Bo

The only sign of the shim problem in SE is a tiny geometric distortion (viewed along the Z axis).



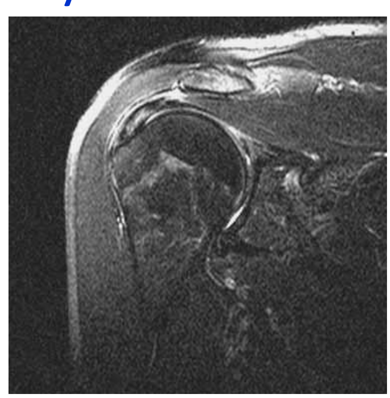
The Z (slice) component of the shim error now causes a tremendous signal loss (failure to refocus) in areas where it is large.



Correction:

1. Shimming
2. Area of interest in near isocenter
3. Use STIR for Fat sat vs. Chess

Field inhomogeneity- RF coil



1. Causes non-uniform image intensity
2. Causes non-uniform fat suppression

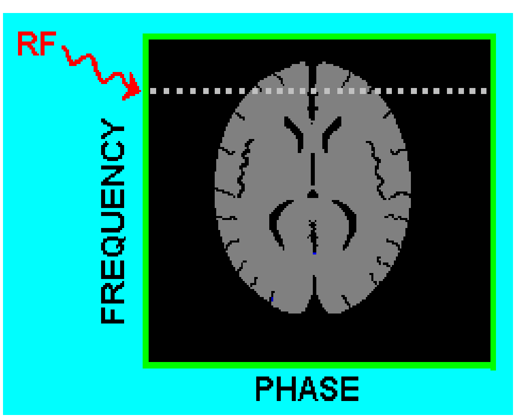
Correction:

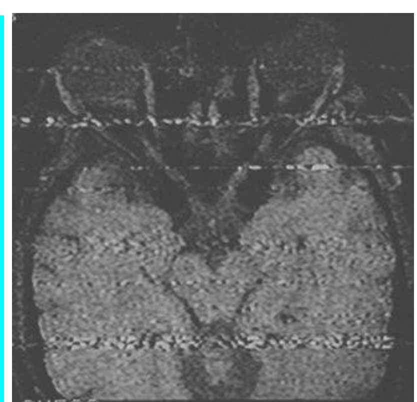
1. Use volume vs. surface coil,
2. allow space between coil and body.

Zipper Artifacts (Leaking RF shield)

- Most are related to hardware or software problems beyond the radiologist control.
- May occur in either frequency or phase direction.
- Zipper artifacts from RF entering room are oriented perpendicular to the frequency direction.

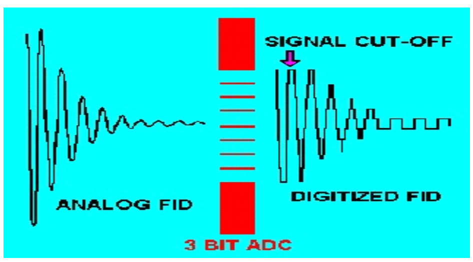
Zipper Artifacts

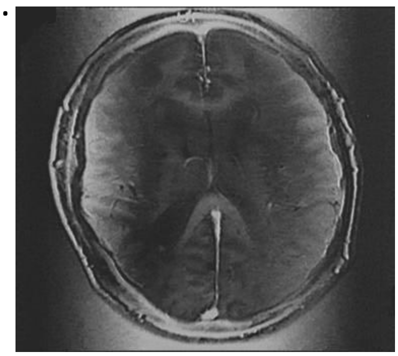




RF Overflow Artifacts (Clipping)

- Causes a nonuniform, washed-out appearance to an image.
- Occurs when the signal received from the amplifier exceeds the dynamic range of the ADC
- Correction: RF gain calibration by Auto prescanning usually adjusts the receiver gain.

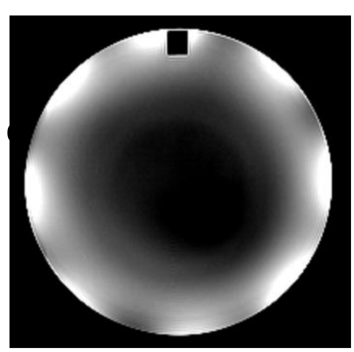




Surface coil artifact

- The sensitivity of surface coils falls off dramatically with distance from the coil. Tissues close to the surface coil will have higher intensity than tissues farther from the coil.
- This artifact is very apparent in T1 weighted imaging of the spine where subcutaneous fat produces very intense signal.

- -GE Signa has an option
"Image Intensity Correction" that is
reduce surface coil artifacts .

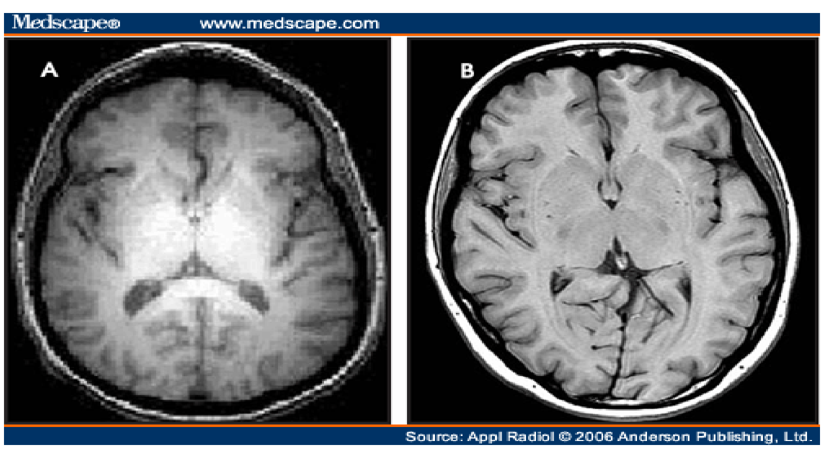


SNR variation across the FOV for an 8 channel (parallel) brain coil.

Quadrature ghost artifact

- Another amplifier artifact caused by unbalanced gain in the two channels of a quadrature coil.
- Combining two signals of different intensity causes some frequencies to become less than zero causing 180 degree "ghost."

Field inhomogeneity- Dielectric Artifact (Central brightening)



Correction:

1. use phased array coils, software compensation

Dielectric Artifact

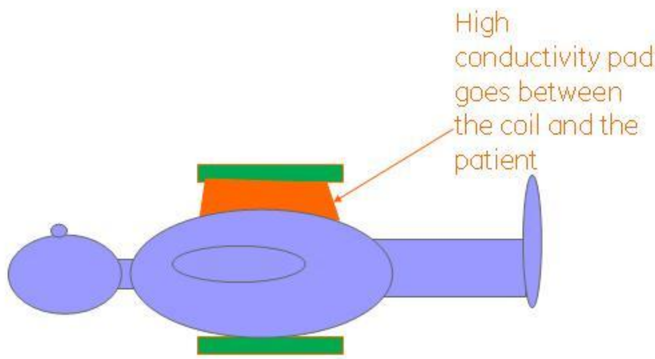
- Larmor frequency increases for stronger magnets
- RF wavelength decreases and approaches body dimensions and FOV dimensions
- λ_{air} = 4.7m at 1.5T
- λ_{air} = 2.35m at 3T
- λ_{tissue} = 0.3m at 3T !!!!!!!! (high dielectric constant)

- Dielectric resonances reduce RF penetration
  - Produces Image shading
  - Worse in body imaging than head
  - Worse in large patients (obese)

Correction of Dielectric Artifact

1. Choosing an imaging protocol that is relatively insensitive to flip angle.
2. Using a multi-channel phased-array receive coil which have a stronger B1-sensitivity near the surface of the patient
3. Using an image post-processing method *that remove low spatial frequency intensity variation in the image* domain.
4. Advanced methods, such as crafted RF pulses.
5. Use Dielectric Pads

Dielectric Pads Can Minimize the Effect That Is Seen...

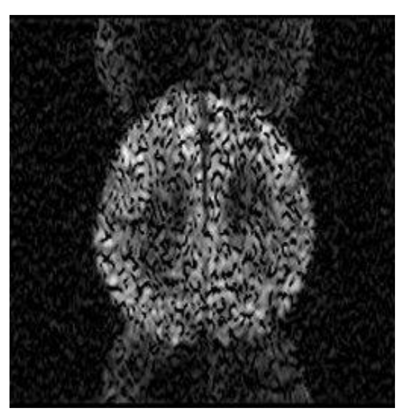


Dilute Manganese Chloride solution

Eddy Current Artifacts

- Induce electrical currents in conductors such as cryostat due to varying magnetic field from gradients
- This causes distortion of the gradient waveforms.

- Particularly a problem with EPI that uses strong, rapidly changing gradients.



Correction of Eddy Current Artifacts

- Precompensation- A "distorted" gradient waveform is used which corrects to normal.

- Shielded gradients – Active shielding coils between gradient coils and main gradients.