Breast MRI: Image Quality, Artifacts and Quality Control

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Educational Objectives

- Describe common artifacts and image quality issues encountered in clinical breast MR images.
- Discuss methods for addressing breast MR image quality problems.
- Describe quality control procedures accreditation programs specific to breast MRI.

Breast MR Image Quality

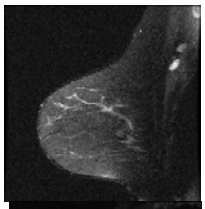
Challenges:

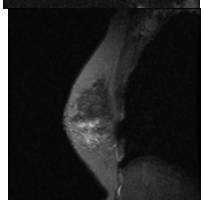
- Adequate SNR *ACR: "not too grainy"*
- Good spatial resolution
  - 1mm x 1mm in-plane resolution
  - ≤ 3mm slice thickness
- Temporal resolution dynamic series (60-90 sec/phase)
- Absence of (or minimal) artifacts
- Effective, uniform fat suppression

SNR

Potential causes of low SNR:

- Low field strength
- Poor Coil connection
- Coil element failure
- Incorrect center frequency selection
- Protocol parameters:
  - Small voxels (large matrix, small FOV, thin slices)
  - trade-offs: speed, SNR, resolution





$$SNR \propto \rho_{1H} \frac{FOV_{\upsilon} \quad FOV_{\phi}}{\sqrt{N_{\upsilon} \quad N_{\phi} \quad \Delta\upsilon_{samp}}} \quad \delta_s \quad \sqrt{N_{ave}} \quad B_0 \quad f$$

Spatial resolution

High contrast spatial resolution requires small voxels:

- Large matrix
- Small FOV
- Thin slices

$\delta_\upsilon = FOV_\upsilon / N_\upsilon$	Resolution (frequency-encoding direction
$\delta_\phi = FOV_\phi / N_\phi$	Resolution (phase encoding direction)
δ_{slice}	Resolution (slice direction)

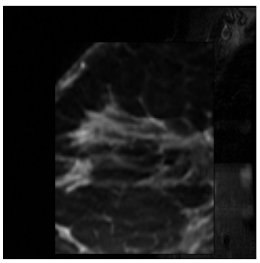
Trade-offs:

- Longer scan time if phase matrix is increased

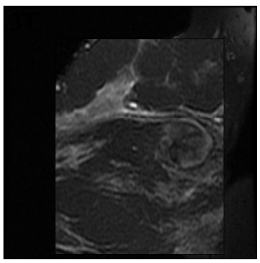
$T_{scan} = TR \quad N_{ave} \quad N_\phi$	Acquisition time

- Reduced SNR → improve with 3T imaging

3T– trade additional SNR for increased spatial resolution or faster scan time



FSE T2W w/ fat sat,
FOV 220mm, 256x192, 4mm



FSE T2W w/ fat sat,
FOV 200mm, 320x192, 3mm

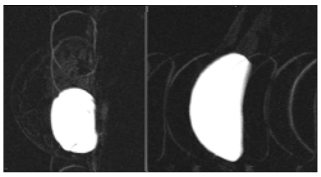
Breast MRI Artifacts

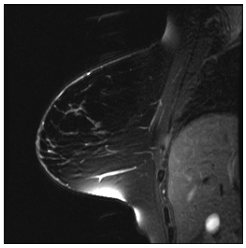
Common artifacts in breast MRI

- Motion
- Truncation artifacts
- Out of volume wrap
- Susceptibility artifacts
- Signal non-uniformity
- Poor or non-uniform fat saturation

Motion artifacts

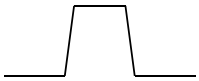
Occur in the phase encoding direction. Caused by cardiac motion, respiration, patient movement. Results in phase mis-mapping in k-space due the time delay between phase-encoding and signal readout.



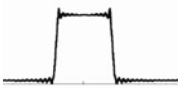


Truncation Artifacts

- Occur at high contrast edges.
- Also known as Gibbs or "ringing" artifact.
- Can occur in either phase or frequency direction.
- Minimized by increasing matrix size
  - High contrast spatial resolution improves
  - Scan time also increases if phase matrix is increased
  - SNR reduced

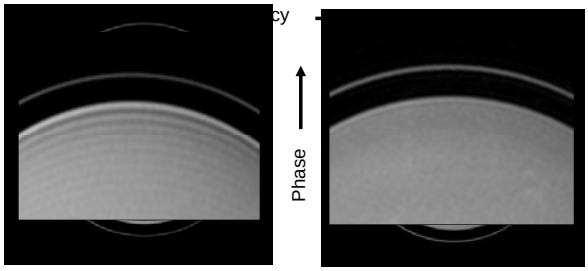


Object profile



Measured intensity profile

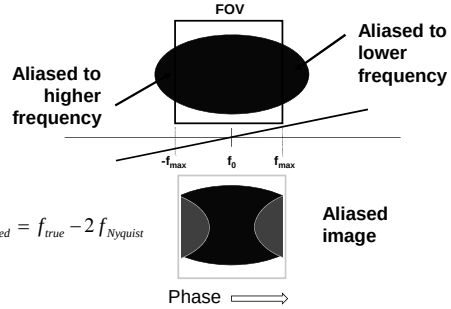
Truncation Artifacts



Small ACR phantom in 3T GE HD Breast array

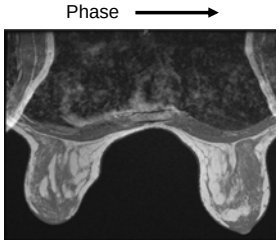
320x192 matrix 320x320 matrix

Aliasing or "Wrap-Around" Artifacts



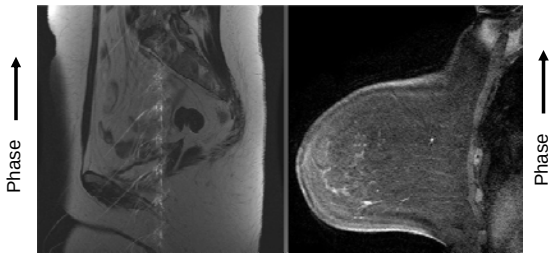
$$f_{aliased} = f_{true} - 2 f_{Nyquist}$$

Aliasing or "Wrap-Around" Artifacts



- Increase FOV to include entire object - increase phase-encode steps to maintain resolution (trade-off: impacts scan time)
- Swap phase and frequency-encoding directions : shorter dimension in phase-encoding direction. (trade-off: motion artifacts)
- Use "No phase wrap" or "anti-aliasing" techniques.

Peripheral signal artifact (annefact, star artifact)



FSE: Spine exam using phased array surface coil .

FSE: Star artifact – bright signal close to center of images.

Signal originates in region where gradients are nonlinear. FID from 180 pulses not crushed – aliases back into image.

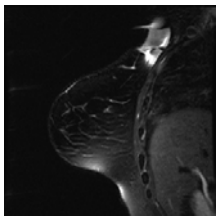
Magnetic Susceptibility Artifacts

Metallic objects can cause distortions of the static and gradient fields, RF fields, or both

- Ferromagnetic objects - distort B_o and B_1 fields
- Non-ferromagnetic metal objects - distort B_1 fields

Typical effects are signal voids and geometric distortions.

Most noticeable on GRE (rather than SE or FSE). Appearance reduced with wider receive BW, shorter TE.



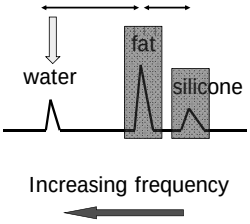
Frequency selective fat sat

- Frequency-selective fat or silicone saturation is routinely used in breast imaging. Frequency of saturation pulse must match resonant frequency of fat/silicone.
- Selection of resonant peak usually automated, but may require manual adjustment → Technologist training essential.
- Uniform saturation dependent on homogeneity of B_0 field within the imaged volume:
  - challenge (breasts off isocenter)
  - shimming is important

Fat/silicone saturation - peak selection

~440 Hz	~200 Hz	3T
~220 Hz	~100 Hz	1.5T

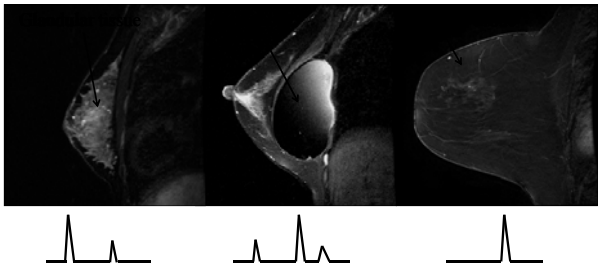
(fat-water separation 3.5 ppm)



Effective chemically-selective fat or silicone saturation depends on accurate peak selection.

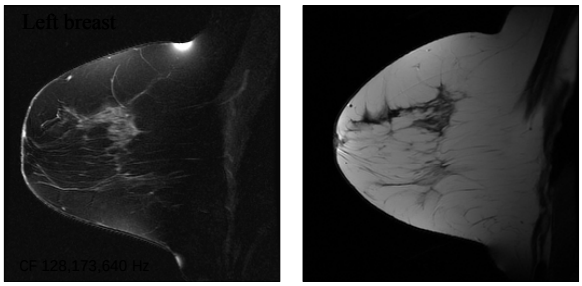
GE: center on water, saturates fat signal at -220Hz

Composition of breast tissue



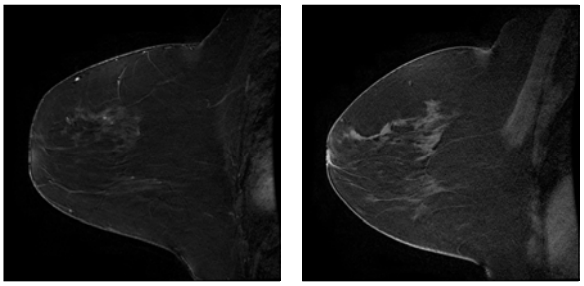
Composition of breast tissue (adipose/glandular/silicone) determines appearance of spectrum. Selecting the correct peak to achieve fat or silicone saturation can be challenging.

T2 FSE, fat sat



Difference in center frequency 440 Hz (3.5 ppm) = 3T difference in resonant frequency between fat-water. Centered on fat peak → fat sat failure.

3D T1 post-contrast dynamic, fat sat

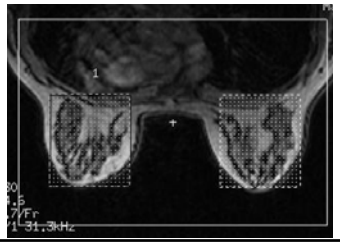


Center frequency = 128,173,593

Good fat saturation achieved on both sides

Shimming

- Shim volume – user prescribes graphically
- Current in shim coils adjusted to optimize B_0 field uniformity within the volume. Improves uniformity of fat saturation.



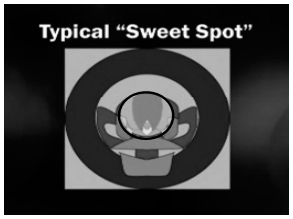
Saturation failure

T2W fast spin-echo
TR =3500ms / TE =86 ms
echo train length = 8
122 Hz/pixel bandwidth
256x256 matrix, 200 mm FOV
1 average
fat sat

- Bandwidth of the sat pulse centered on fat sufficient to saturate both fat and silicone signal – both appear dark.
- Incomplete saturation of fat and/or silicone can occur in regions with large static magnetic field inhomogeneties.

Shimming

One vendor's shim coil system is designed to improve fat suppression in breast MR imaging AuroraSUPERSHIM™



typical MRI

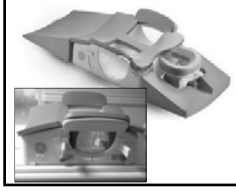
Aurora MRI

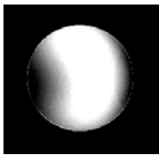
Oval shape and positioned more anterior so that bilateral breast tissue is centered within shim volume.

http://www.auroramri.com/mri/index.shtml

Signal uniformity and breast coil design

1.5T Sentinelle coil - axial image of small ACR phantom





3T GE HD array - axial image of small ACR phantom

Breast MRI Quality Control

Quality control of MRI systems used for diagnostic breast MR imaging and biopsy guidance

- Is important to ensure production of high quality images by evaluating whether MRI scanner and coils used for breast imaging are performing consistently over time.
- Should be part of a comprehensive MRI quality control program.
- May be required to satisfy accreditation program requirements

ACR Breast MRI Accreditation Program

ACR Breast Magnetic Resonance Imaging Accreditation Program (BMRAP) launched in May 2010 under breast imaging accreditation programs (mammography, stereotactic breast biopsy, and breast ultrasound).

- Separate from the ACR MR Accreditation Program (MRAP)
- Provides accreditation for MR systems used for breast imaging:
  - Dedicated breast MRI systems or
  - Whole body MRI systems with
    - detachable table-top breast coil
    - dedicated tables with integrated breast coils

ACR Breast MRI Accreditation Program

- Currently no phantom image submission.
- Clinical cases (bilateral) for each scanner acquired within 2 months* of date on testing memorandum. Cases reviewed by two radiologists.
  - BI-RADS category 1: negative, or 2: benign findings
  - BI-RADS category 6: known, enhancing, biopsy-proven malignancy
- CD/DVD must open in less than 2 minutes.

- Quality control program and medical physicist involvement essentially the same as MRI Accreditation Program (MRAP)
- Breast MRI-specific experience/training requirements for technologists and radiologists.

ICAMRL Accreditation Program

Intersocietal Accreditation Commission Magnetic Resonance Lab (ICAMRL) offers a breast MRI accreditation option.

- No phantom image review.
- Clinical images acquired within the last year submitted for review.
- Breast MRI-specific experience/training requirements for radiologists.
- Cost similar to ACR BMRAP program.

ICAMRL Accreditation Program

- Quality control program established by Quality Assurance Committee and/or the Medical Director. Tests performed according to manufacturer's performance standards.
- Acceptance testing required after installation and major upgrades.
- Periodic maintenance (PM) required
- QC performed by MR technologist, service engineer, medical physicist or "qualified expert".
- Daily and periodic QC required
  - Equipment function and safety
  - Center frequency
  - SNR
  - Uniformity
  - Artifact assessment

Breast MRI QC

Physicist:

- MRI system performance evaluation after scanner installation, annually and following major repair or hardware/software upgrade
- Annual QC of all RF coils (including breast MRI coils)

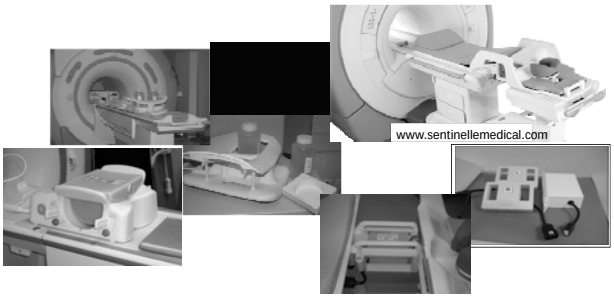
Service engineer:

- Periodic/preventative maintenance (PM). Frequency defined in service contract

MRI technologist:

- Daily/weekly phantom scans

Breast RF Coil Quality Control



Breast RF Coil Quality Control

Establish baseline coil performance in order to monitor coil performance over time.

- Coil inspection
- Signal-to-noise ratio (SNR)
- Signal uniformity
- Phased array coils: compare SNR for individual channels
- Artifact evaluation (including ghosting)
  - Using QC protocol
  - Using clinical protocol

Breast RF Coil Quality Control

Coil inspection

- Inspect coil, cables, cable insulation, ports and connectors for damage
- Could present a safety issue or result in low SNR or image artifacts.

Breast RF Coil Quality Control

Coil testing:

- Important to test coils:
  - after installation of new scanner or new coils
  - at least annually
  - whenever artifacts or coil problems occur
- Manufacturers provide a coil manual for each coil
  - includes description of clinical use of the coil
  - may include detailed description of coil test procedure
  - may include pass/fail limits
  - may only say "establish baseline and monitor over time"

Breast RF Coil Quality Control

Coil testing:

- Test all available coil configurations.
- Note any error messages.
- In our experience the vendor is more likely to respond to coil QC failure when manufacturer's QC procedure is followed.

Uniformity:

- Follow procedure in 2004 ACR MRI QC Manual (min, max signal intensity within small ROI)

Breast RF Coil Quality Control

Artifact evaluation

- Evaluate images acquired using QC protocol
- To troubleshoot artifacts observed on patient images may acquire images of homogeneous QC phantom using clinical protocol.

Breast RF Coil Quality Control

Consistent scan/measurement methods:

Identical phantom and positioning within coil

- Homogeneous phantom (sphere, cylinder, custom)
- ACR or other phantom

Identical scan parameters:

- Pulse sequence, timing parameters, slice thickness and position, matrix, FOV, receive bandwidth, etc
- Record center frequency, transmit gain/attenuation, receiver gains

Identical measurement methods, ROI positions

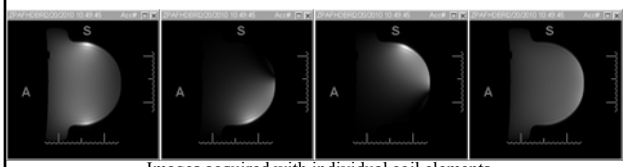
- SNR, signal uniformity, ghosting, stability tests
- Evaluation of channel performance

SNR methods

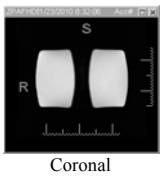
Signal
- Signal measured in ROI within magnitude image

Noise
- Noise measured in background of signal image
- NEMA approach: Noise measured in subtraction image:
  - 2 images acquired with identical protocols and prescan parameters (center frequency, transmit gain/attenuation, receiver gains)
- Noise measured in "pure noise" image acquired with no RF excitation

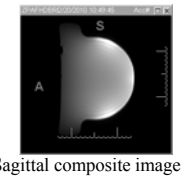
Breast RF Coil Quality Control



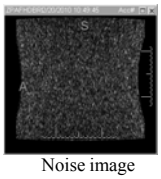
Images acquired with individual coil elements



Coronal

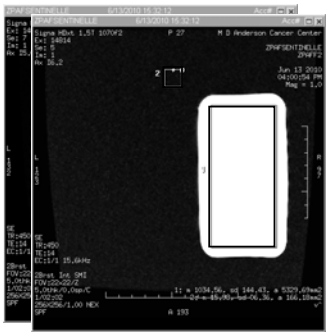


Sagittal composite image

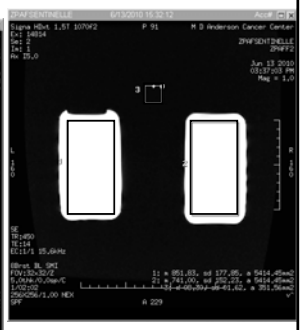


Noise image

Breast RF Coil Quality Control



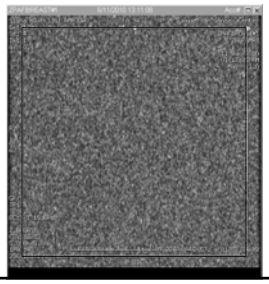
Unilateral biopsy mode



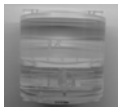
Bilateral imaging mode

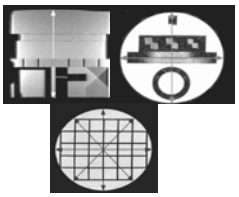
Breast RF Coil Quality Control

- Signal ROI: SE T1, unilateral and bilateral imaging modes
- Noise image (no RF excitation)



Breast RF Coil Quality Control





The small ACR phantom may be utilized for breast coil quality control. Phantom contains objects that enable evaluation of:

- geometric accuracy
- high contrast spatial resolution
- slice thickness accuracy
- slice position accuracy
- image intensity uniformity
- ghosting
- low contrast detectability

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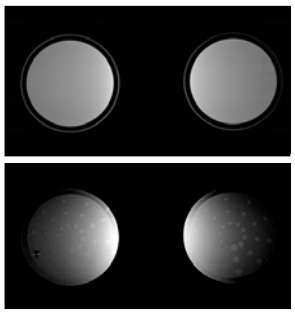
Breast RF Coil Quality Control

Small ACR phantoms
Bilateral mode

Images courtesy of R. Price, PhD



SE, Philips Achieva 1.5T, 16 channel breast array

Summary

- High quality breast MR images exhibit adequate SNR and contrast, high resolution, absence of artifacts, and uniform fat/silicone saturation. Compromises are often necessary to achieve this in addition to good temporal resolution of the DCE series.
- Effective and uniform fat saturation can be challenging to achieve and can be more consistent with technologist education and use of proper shim techniques.
- Two breast MRI accreditation programs are currently available (ACR, ICAMRL)
- A comprehensive quality control program, including testing of breast RF coils, is important to ensure optimal performance and image quality of breast MRI systems.

References

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2. ACR Technical Standards for Diagnostic Medical Physics Performance Monitoring of MRI Equipment, revision 2009. www.acr.org
3. Breast MRI Accreditation Program Requirements, 7/27/2011. www.acr.org
4. ICAMRL 2010 Standards for Accreditation in Magnetic Resonance Imaging Parts I and II, 9/10. www.icamrl.org
5. Determination of Signal-to-Noise Radio (SNR) in Diagnostic Magnetic Resonance Imaging, NEMA Standards MS 1-2008. www.nema.org