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

\[
\text{SNR} = \frac{\text{FOV}_{\text{freq}} \cdot \text{FOV}_{\text{phase}}}{\sqrt{N_{\text{freq}} \cdot N_{\text{phase}}}} \cdot \delta \cdot \sqrt{N_{\text{acq}}} \cdot B_0 \cdot T
\]

Spatial resolution

High contrast spatial resolution requires small voxels:
• Large matrix
• Small FOV
• Thin slices

\[
\text{Resolution} = \frac{\text{FOV}}{N}
\]

Trade-offs:
• Longer scan time if phase matrix is increased
• Reduced SNR \( \rightarrow \) 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 to 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

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: Star artifact – bright signal close to center of images.
FSE: Spine exam using phased array surface coil.

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 B₀ and B₁ fields
- Non-ferromagnetic metal objects - distort B₁ 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 B₀ field within the imaged volume:
  - challenge (breasts off isocenter)
  - shimming is important

Fat/silicone saturation - peak selection
- Effective chemically-selective fat or silicone saturation depends on accurate peak selection.
- GE: center on water, saturates fat signal at ~220 Hz

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

Signal uniformity and breast coil design
1.5T Sentinel 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

**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.

**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**

- 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.

- No phantom image review.
- 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.
- Acceptance testing required after installation and major upgrades.
- Daily and periodic QC required
  - Equipment function and safety
  - Center frequency
  - SNR
  - Uniformity
  - Artifact assessment

*Same as MRI Accreditation Program (MRAP)
Breast RF Coil Quality Control

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

- Coils 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

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”

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.

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

Unilateral biopsy mode  Bilateral imaging mode

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

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