Breast MR Imaging and Quality Control

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THE UNIVERSITY OF TEXAS
MD Anderson Cancer Center
Making Cancer History®

Educational Objectives

1. Provide an overview of breast MR imaging and MR-guided biopsy procedures.
2. Describe breast MR image quality criteria and protocol optimization.
3. Discuss the components of a breast MRI quality control program.

Breast MR Imaging

- Screening for patients at higher risk for breast cancer due to family history or the presence of genetic markers.
- Detect malignancies not visible on mammography, ultrasound
- Determine the extent of disease
- Monitor response to treatment
- Detect implant rupture

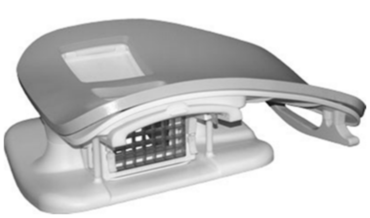
Breast MR Imaging Systems

Dedicated breast MRI systems:

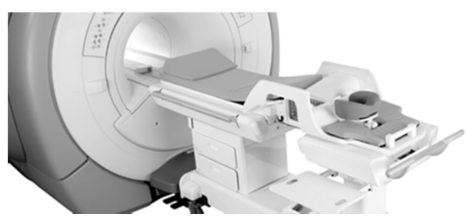
www.auroramri.com

Whole body MRI systems:

~ dedicated tables with integrated breast coils
~ detachable table-top breast coils



www.invivocorp.com/coils/



www.sentinellemedical.com/products.html

Breast MR Image Quality

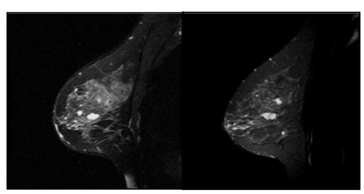
Challenges:

- 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
- Uniform signal
- Uniform fat suppression
- Good contrast

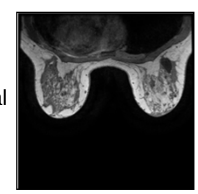
Example of Diagnostic Breast MRI Protocol

3-plane localizer

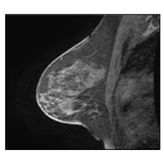
2D Sag Unilateral T2W fat sat bright fluid series

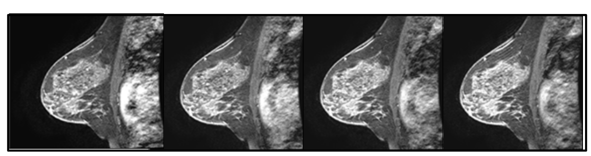


Axial Bilateral T1W series



3D T1W bilateral multi-phase series, Gd contrast, fat sat





Axial Post-Gd high resolution (512x350), fat sat, T1W series

May include spectroscopy, diffusion-weighted imaging (DWI).
Protocols vary between facilities.

Image contrast

T2, bright fluid series:

- T2-weighted FSE, 4mm slice thickness, no gap
- FOV, matrix to achieve pixels <1mm
- Bright fluid contrast distinguishable from background
- Good SNR
- Uniform signal
- Uniform fat saturation

Clinical example

T2W bright fluid series:

- Bright fluid contrast
- Fat saturation fairly uniform

GE 1.5T HDXt
2D T2W, sagittal
FSE, ETL 17, fat sat
TR/TE 4950/89 ms
256x192, NEX 2
FOV 220mm,
4.0mm/0 gap

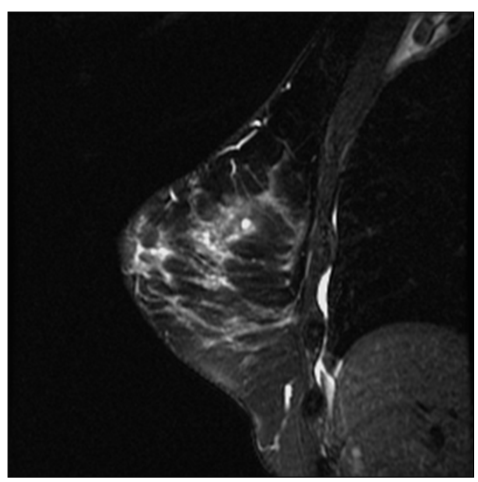
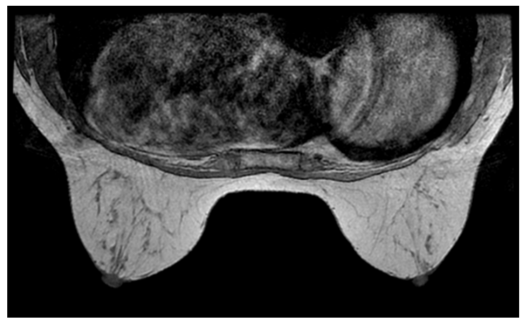


Image contrast

Pre-contrast T1-weighted images:
- Bright fat
- Uniform signal
- Vessels: dark on spin-echo, bright on gradient echo sequences
- Fibrous, glandular tissue, cysts appear dark

GE 1.5T HDXt
Axial 3D FSPGR, fat sat
TR/TE 7.5/4.2 ms
384x384, NEX 1
FOV 280mm
1.8 mm / 0.9 spacing
ASSET acceleration



Fat Saturation Methods

- Frequency-selective fat saturation (fat sat, chem sat) dependent on good magnetic field homogeneity
- Subtraction of T1W co-registered pre- and post-contrast images
- Dixon methods
- Inversion-recovery based sequences (STIR)

Frequency-selective Fat Saturation

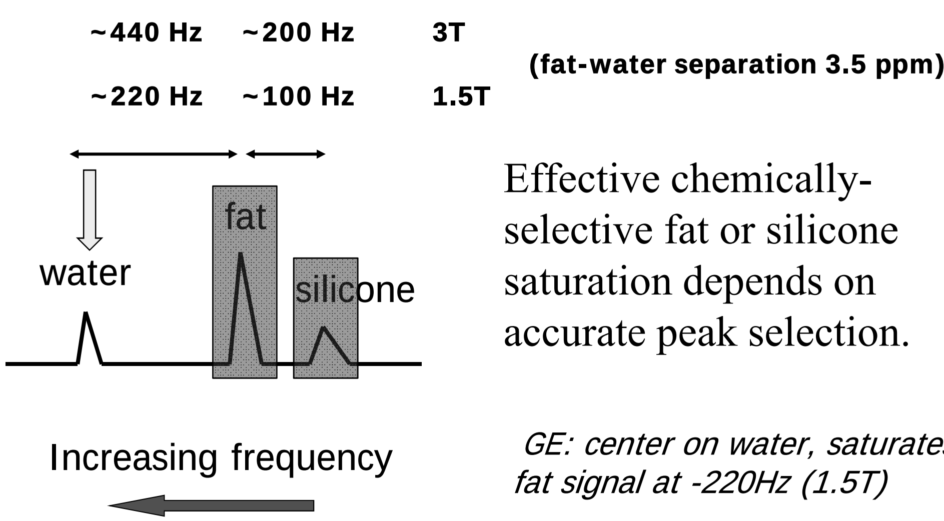
• Frequency-selective fat or silicone saturation is routinely used in breast imaging. Frequency of saturation pulse must match resonant frequency of fat/silicone.

• 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

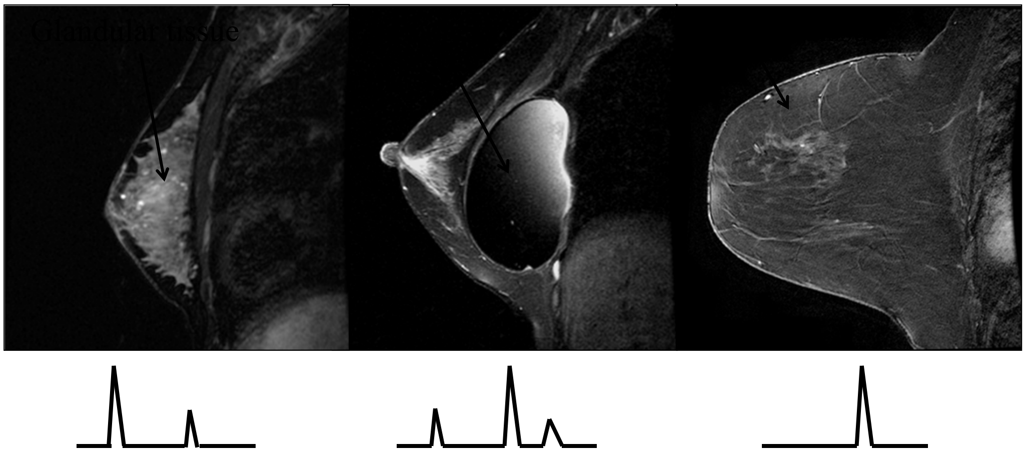
Fat/silicone saturation - peak selection



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

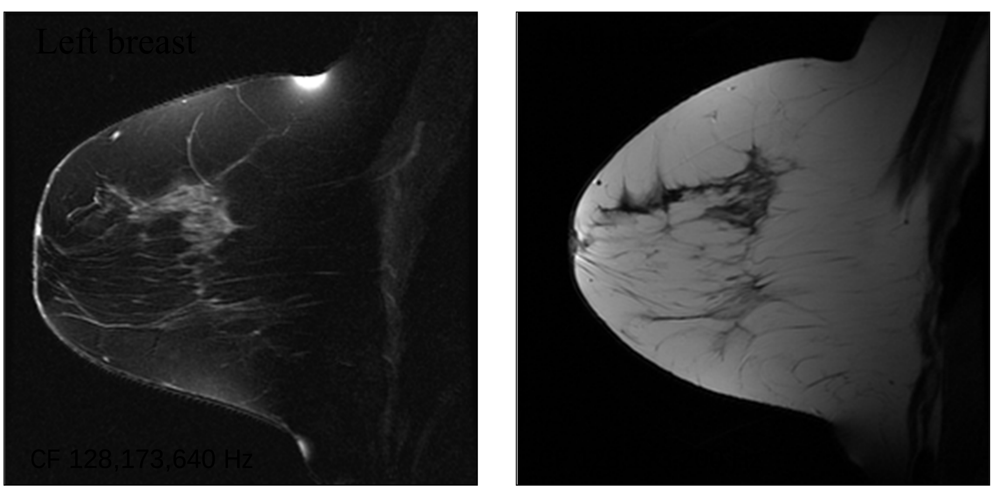
GE: center on water, saturates fat signal at -220Hz (1.5T)

Composition of breast tissue



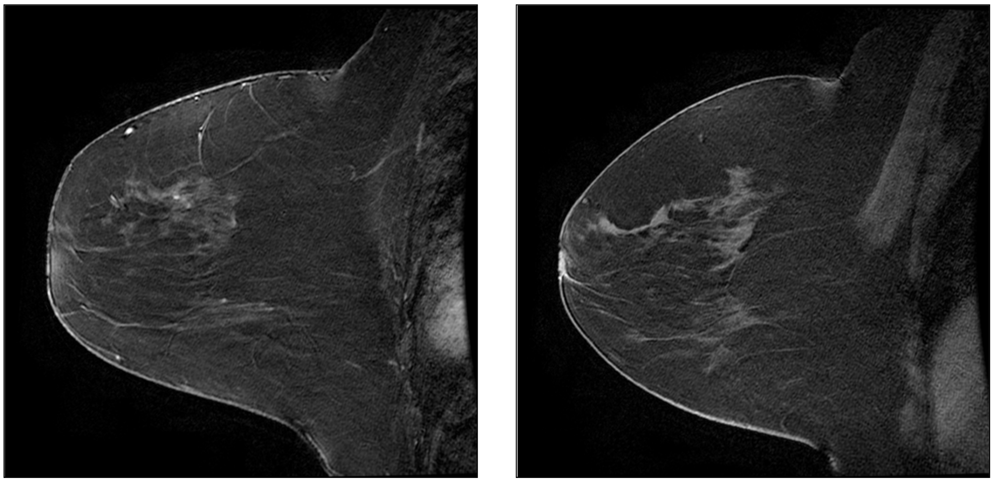
Composition of breast tissue (adipose/glandular/silicone) determines appearance of spectrum. Peaks may not be distinct. Selecting the correct peak to achieve fat or silicone saturation can be challenging.

T2-weighted FSE, fat sat failure



Difference in center frequency 440 Hz (3.5 ppm) equal to 3T difference in resonant frequency between fat-water. Centered on fat peak → fat sat failed to suppress fat signal.

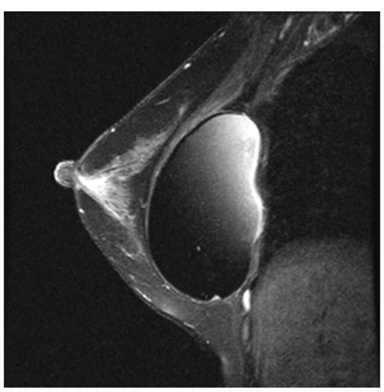
3D T1 post-contrast dynamic, fat sat



Center frequency = 128,173,593 Hz

Good fat saturation achieved on both sides

Saturation failure

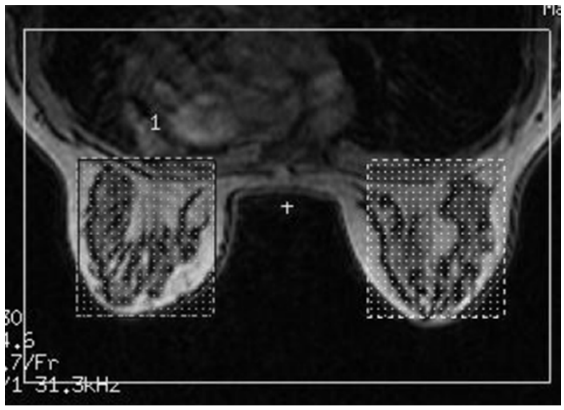


T2W fast spin-echo
TR =3500ms / TE =86 ms
echo train length = 8
122 Hz/pixel bandwidth
256x256 matrix, 200 mm FOV
1 average
fat sat

- 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

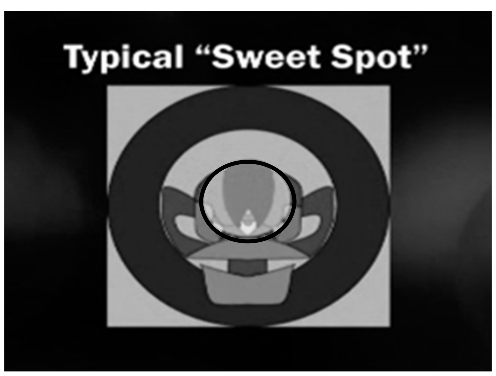
- Shim volume – user may prescribe graphically
- Current in shim coils adjusted to optimize B_0 field uniformity within the volume. Improves uniformity of fat saturation.



Shimming

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

AuroraSUPERSHIM™



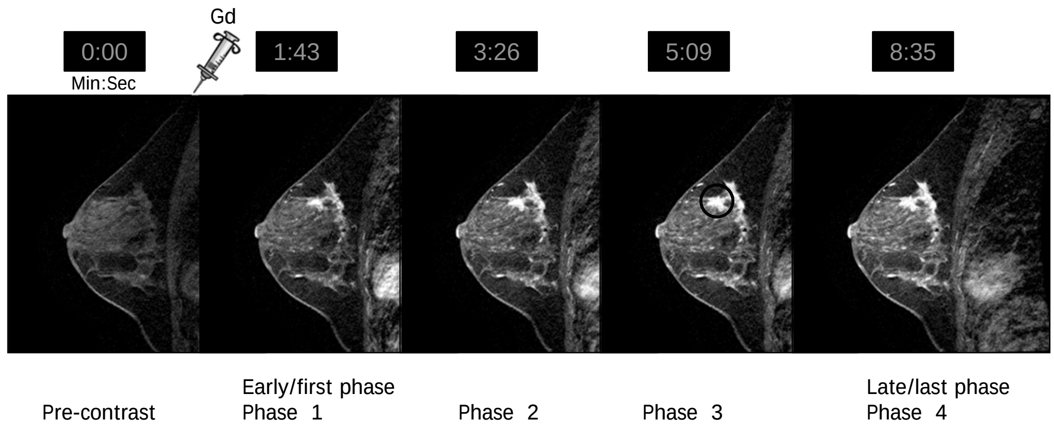
typical MRI

Aurora MRI

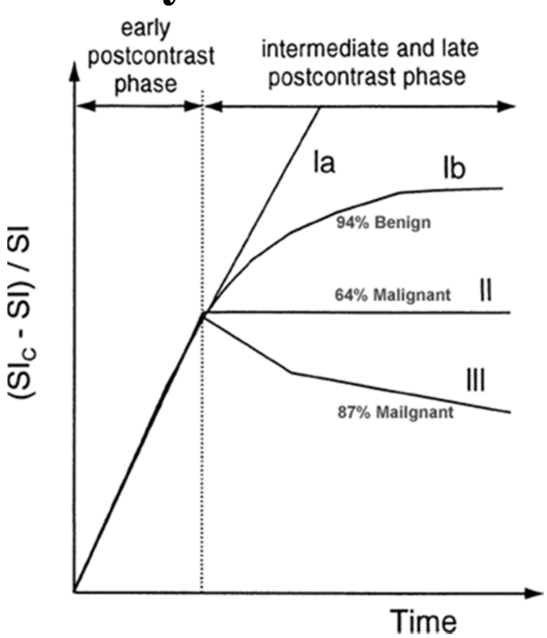
Oval shape and positioned more anterior so that bilateral breast tissue is centered within shim volume.

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

T1W DCE Multi-phase series



Dynamic Contrast Enhancement (DCE)



Types I, II, III:

- Persistence of enhancement
- Timing of peak enhancement,
- Rate of washout

Kuhl CK, et al. Dynamic breast MR imaging: are signal intensity time course data useful for differential diagnosis of enhancing lesions?

Radiology. 1999 ;211(1):101-110.

Dynamic Contrast Enhancement (DCE)

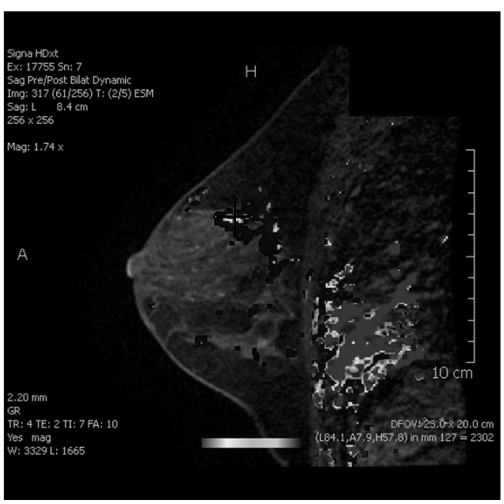
Uptake rate depends on:

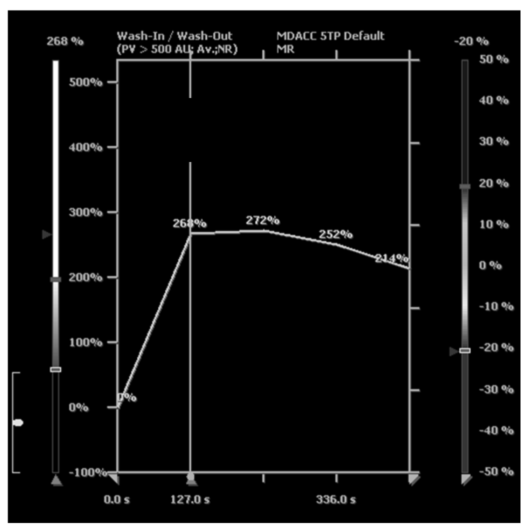
- vascular density: tends to be higher in tumors
- Wash out rate:
  - Faster rate in malignancies
  - Slower in benign lesions

Also affected by

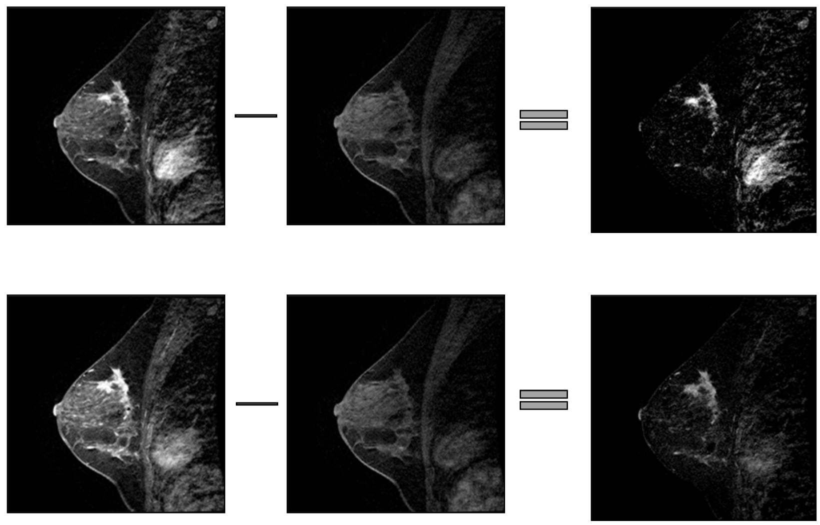
- Hormone replacement
- Timing within menstrual cycle

T1W Multi-phase series





Multiphase T1 series w/o fat sat: subtractions



ACR: Submit pre- and post-contrast series and both subtracted series

Image Contrast

Post-Gd contrast T1-weighted images

- Gadolinium contrast agent shortens the T1 relative to adjacent tissues.
- Lesions that uptake contrast agent appear bright on T1-W images
- Non-malignant pathologies may also appear bright
- Fat suppression necessary to differentiate between bright fat and enhancing tissues.

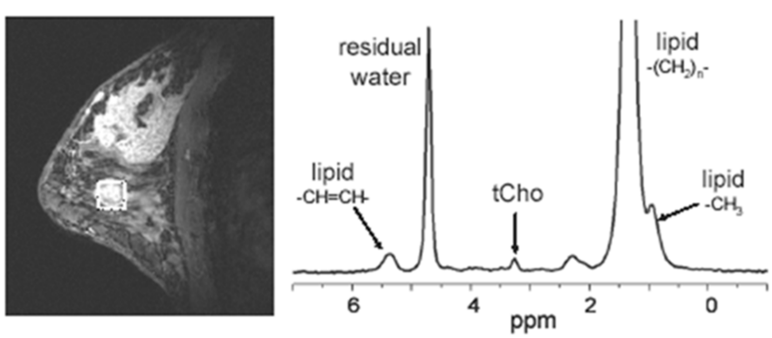
Breast MRI Artifacts

Common artifacts in breast MRI

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

Breast MR Spectroscopy

- Potential to improve specificity
- Choline (tCho) indicator of cell proliferation
- If present, likely malignant



Bolan, P.J. ISMRM, 2004.

Spatial Resolution

Spatial Resolution: ACR Criteria only apply to pre- and post-contrast T1-weighted multi-phase series:

- Acquired (not interpolated) thickness must be ≤ 3mm, >4.0mm will fail.
- 3-4mm: may fail if there are deficiencies in other categories.
- In-plane resolution must be ≤ 1mm (phase and freq), >1.2mm will fail, 1.0-1.2mm may fail if deficiencies in other categories.
- Interslice gap must be ≤ 0mm (i.e. slices either overlap or are contiguous with no gap), >0mm will fail

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

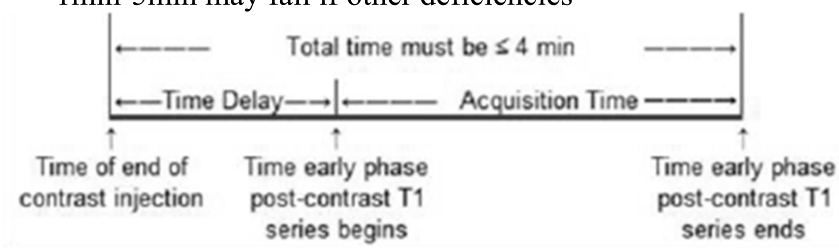
$T_{scan} = TR \; N_{ave} \; N_\phi$	Acquisition time

- Reduced SNR → improve with 3T imaging

Temporal Resolution

Temporal Resolution: ACR criteria apply to T1-weighted multi-phase series:

- Total time between contrast injection completion and end of early phase:
  - ≤4min
  - >5min will fail
  - 1min-5min may fail if other deficiencies



Speed

Parameters that improve speed (DCE temporal resolution):

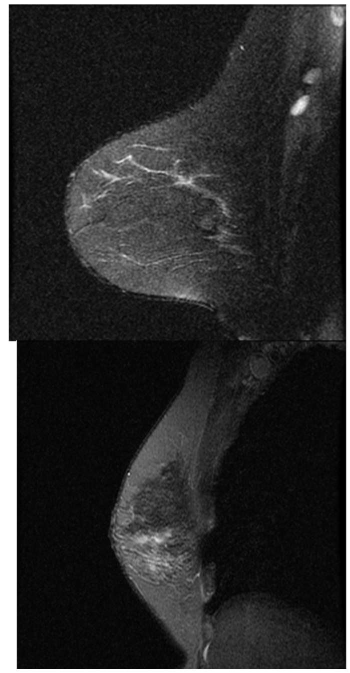
Parameter	Trade-off
↓ Repetition time (TR)	↓SNR
↓ Number of scan averages (NSA, NEX)	↓SNR
↓ Phase encode matrix	↓Resolution (in-plane)
↓ Number of 3D slice encodes (thicker slices)	↓Resolution (slice direction)
Hardware: gradient performance (↑dB/dt)	↑ Cost
Coil: ↑ # of independent phased array elements	↑ Coil cost, ↓ Uniformity
Parallel imaging: ↑Acceleration factor	↓ SNR, potential artifacts

SNR

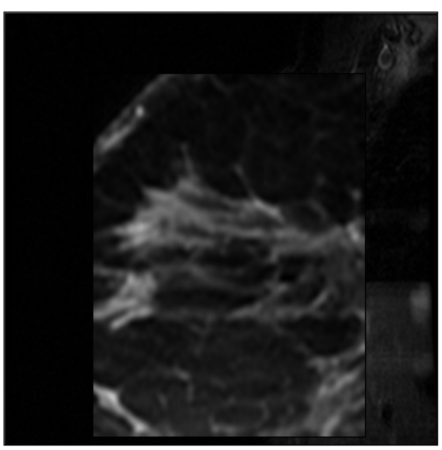
Potential causes of low SNR:

- 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

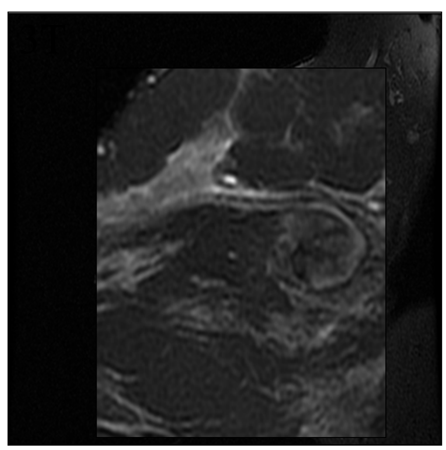
$$SNR \propto \rho_{1_H} \frac{FOV_\upsilon \quad FOV_\phi}{\sqrt{N_\upsilon \quad N_\phi \quad \Delta\upsilon_{samp}}} \quad \delta_s \quad \sqrt{N_{ave}} \quad B_0 \quad f$$



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



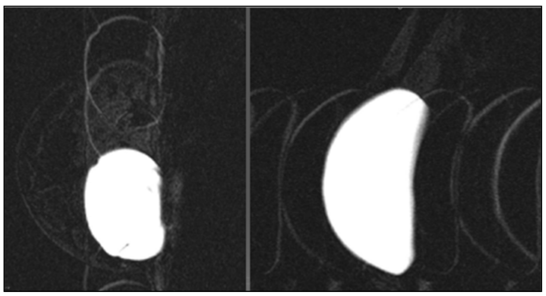
FSE T2W w/ fat sat,
FOV 220mm, 256x192, 4mm

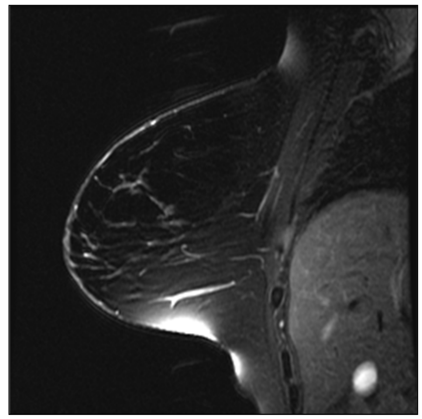


FSE T2W w/ fat sat,
FOV 200mm, 320x192, 3mm

Motion artifacts

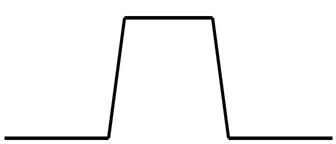
Occur in the phase encoding direction. Caused by cardiac motion, respiration, patient movement. Results in phase mis-mapping in k-space due the time delay between phase-encoding and signal readout.





Truncation Artifacts

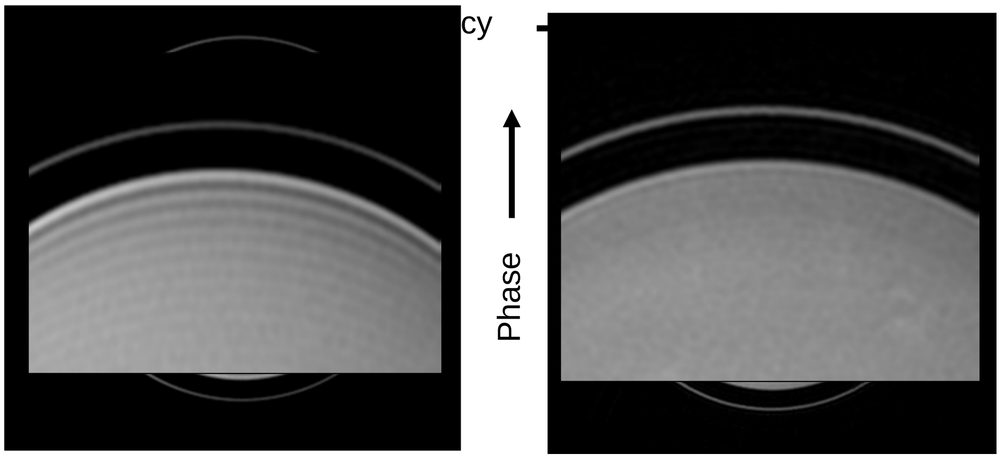
- Occur at high contrast edges.
- Also known as Gibbs or “ringing” artifact.
- Can occur in either phase or frequency direction.
- Minimized by increasing matrix size
  - High contrast spatial resolution improves
  - Scan time also increases if phase matrix is increased
  - SNR reduced



Object profile

Measured intensity profile

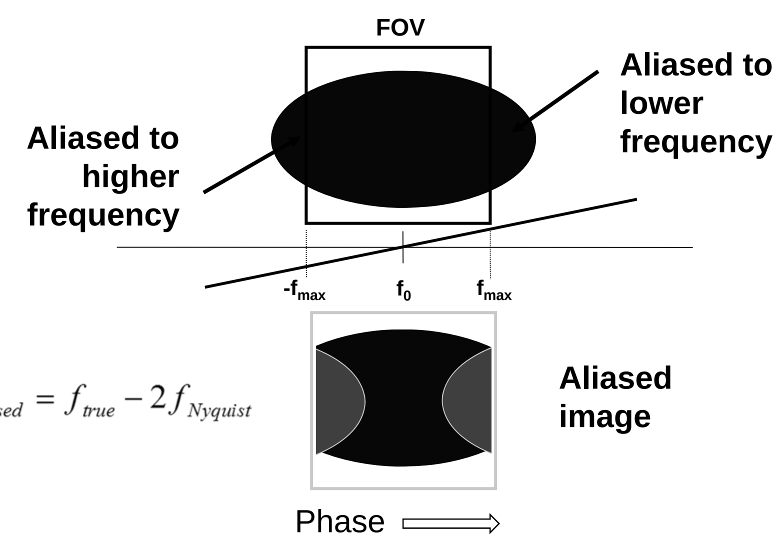
Truncation Artifacts



Small ACR phantom in 3T GE 8 channel HD breast array

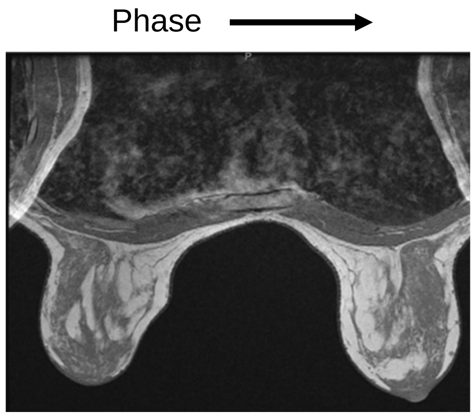
320x192 matrix 320x320 matrix

Aliasing or “Wrap-Around” Artifacts



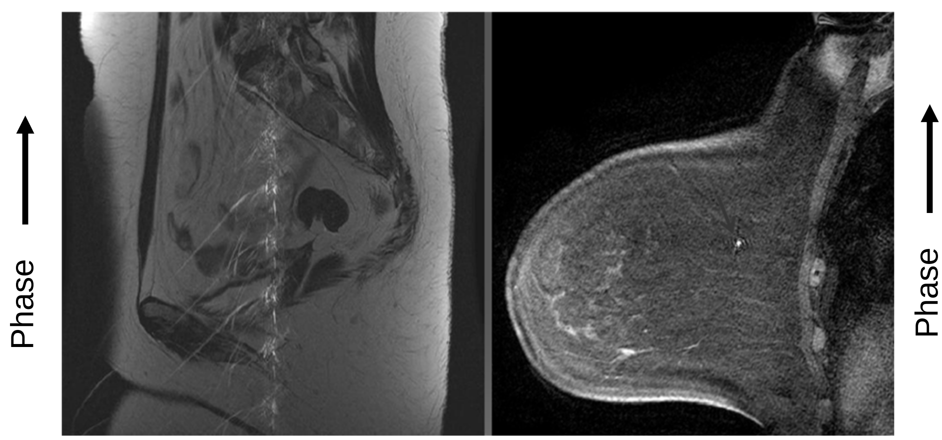
$$f_{aliased} = f_{true} - 2f_{Nyquist}$$

Aliasing or "Wrap-Around" Artifacts



- Increase FOV to include anatomy & 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: cardiac/ respiratory motion artifacts)
- Use "No phase wrap" or "anti-aliasing" techniques.

Peripheral Signal Artifact (annefact, star artifact)



FSE: Spine exam using spine phased array coil .

FSE: Star artifact – bright signal close to center of 3D images.

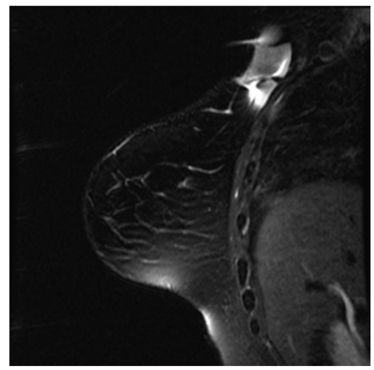
Signal originates in region outside FOV where gradients are nonlinear. FID from 180 pulses not crushed – aliases back into image.

Magnetic Susceptibility Artifacts

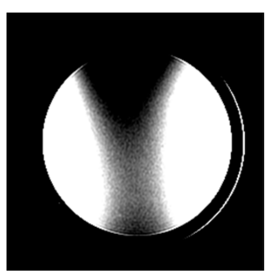
Metallic objects can cause distortions of the static and gradient fields, RF fields, or both

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

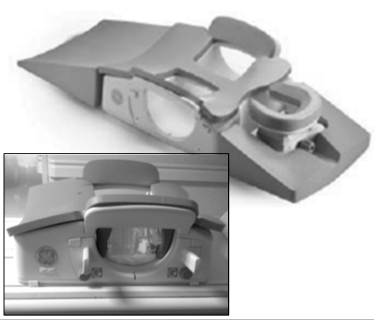
Typical effects are signal voids and geometric distortions. Most noticeable on GRE (rather than SE or FSE). Reduce appearance with wider receive BW, shorter TE.

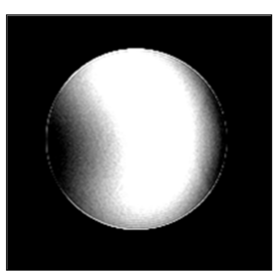


Signal uniformity and breast coil design



1.5T Sentinelle coil - axial image of small ACR phantom





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

Signal Uniformity

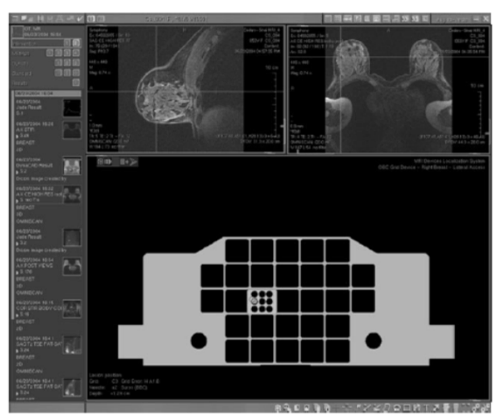
- Patient position and fit within the coil
- Shape and position of coil elements, how well coil conforms to breast shape

Figure 28: Optimal Height of Lateral Coil Arrays

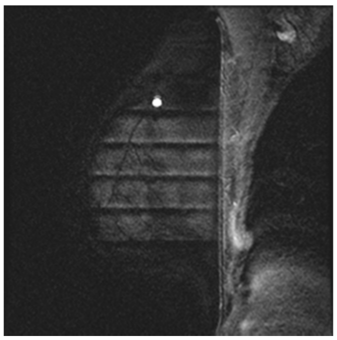
MR-guided Breast Biopsy

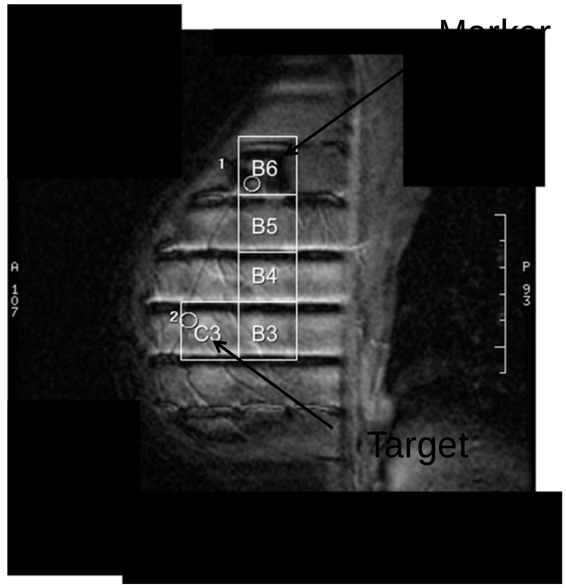
- Equipment needed:
  - Breast biopsy coil
  - Grids/compression devices
  - Core needles
  - Biopsy unit
  - Localization software

Suros ATEC MR
Compatible
Vacuum Biopsy System

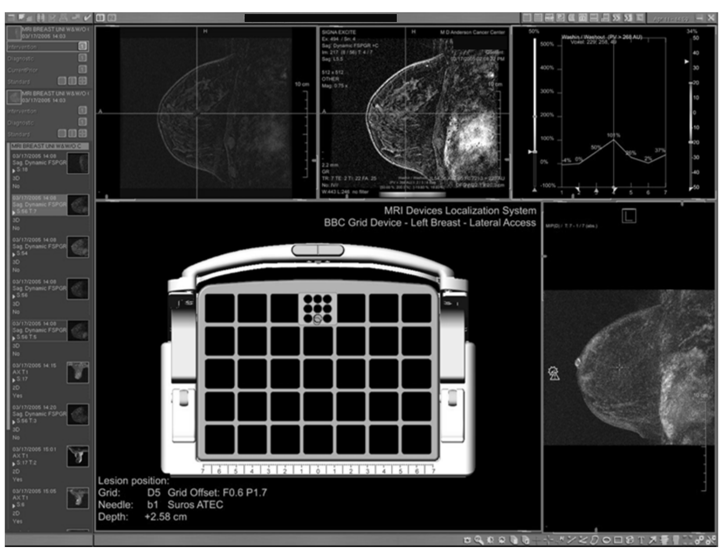


MR-guided Breast Biopsy

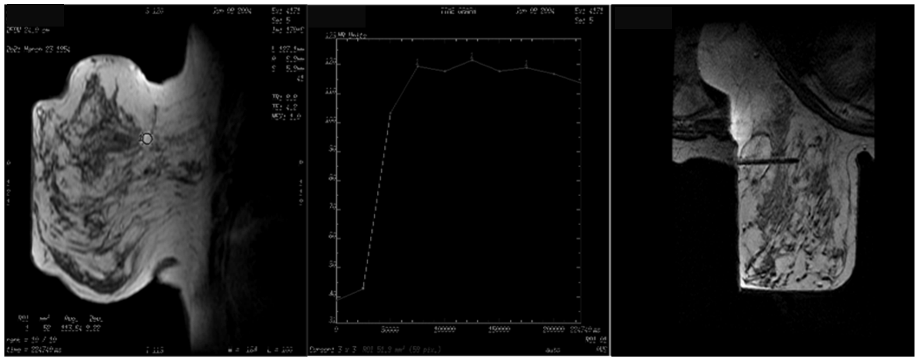




DynaCad Biopsy Guidance



MR-guided Breast Biopsy



(1) Dynamic MRI to locate target
(2) Axial Post to verify skin-target distance
(3) Fast, high BW sequence to localize
(4) Post-Bx images to verify

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

www.acr.org

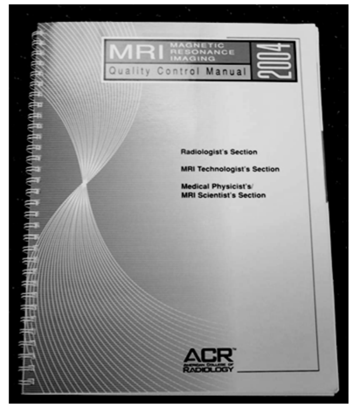
Breast Magnetic Resonance Imaging (MRI) Accreditation Program Requirements

ACR AMERICAN COLLEGE OF RADIOLOGY

Breast MRI Accreditation Program

Clinical Image Quality Guide

ACR AMERICAN COLLEGE OF RADIOLOGY



ACR MRI QC Manual (under revision)

ACR Breast MRI Accreditation Program

- Any field strength
- Coils capable of simultaneous bilateral imaging
- Must accredit all MR systems at the facility that are used to perform *diagnostic breast MR imaging*. Does not include:
  - Dedicated systems used for radiation therapy treatment planning
  - Dedicated interventional MRI systems
  - Systems used for MR-guided breast biopsy but not breast MR imaging

ACR Breast MRI Accreditation Program

- Currently no phantom image submission.
- Clinical case (bilateral) for each scanner
  - BI-RADS category 6: known, enhancing, biopsy-proven malignancy
- 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)
- Review of technologist QC

Service engineer:

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

MRI technologist:

- Daily/weekly phantom scans
- Image quality assessment during acquisition

Breast MRI QC

Radiologist:

- Review of clinical images for quality, diagnostic value
- Provide feedback to technologist
  - Positioning
  - Quality of fat saturation
  - Use of appropriate sequences/scan parameters
- Optimization of breast MR protocols
- Incorporation of new sequences, coils, or scan options

In collaboration with the MR Physicist for technical guidance

ACR BMRAP Quality Control Program

QC program identical to ACR MRI Program

- Acceptance, annual, post-upgrade/repair testing
- Annual testing of all RF coils

Daily/weekly QC:

Choice of phantom and action criteria determined by "qualified medical physicist/MR scientist in cooperation with the system vendor".

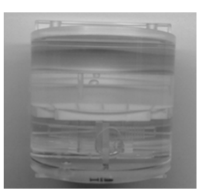
- Large ACR phantom in head coil
- Dedicated breast MR systems may choose to use small ACR phantom in breast coil.
- Other vendor-supplied phantom

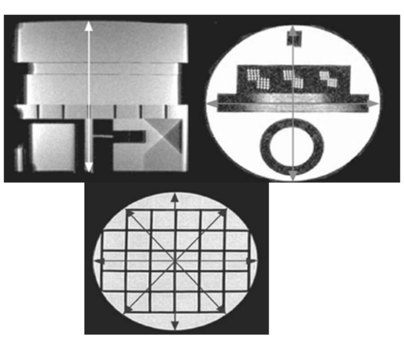
Quality Control - Technologist

Technologist QC test	Minimum frequency*
Center frequency	Weekly
Table positioning	Weekly
Set up & scanning	Weekly
Geometric accuracy	Weekly
High contrast resolution	Weekly
Low contrast resolution	Weekly
Artifact analysis	Weekly
Film QC	Weekly
Visual Checklist	Weekly

*daily recommended

Breast MRI Quality Control



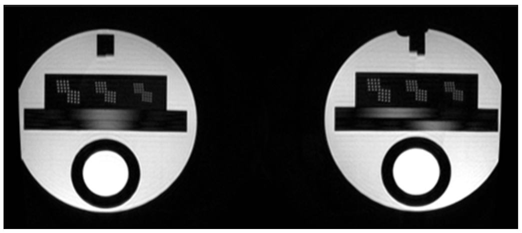


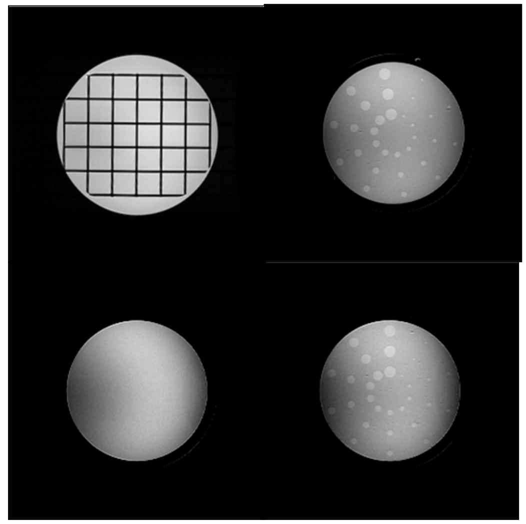
The small ACR phantom may be utilized for breast MR system QC. Phantom contains objects that allow evaluation of:

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

Breast MRI Quality Control

Small ACR phantoms
Bilateral mode



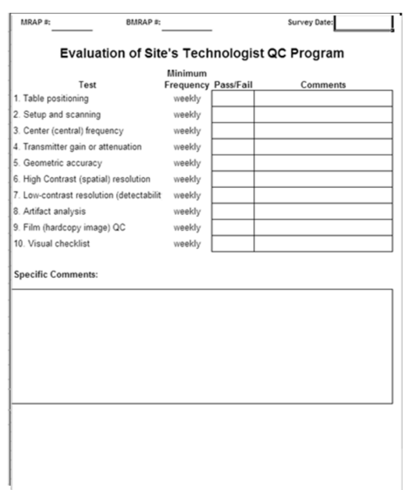


GE Excite HD, 1.5T, 8 channel breast array

Annual System Performance Evaluation report

Must include:

- MRI Equipment Evaluation Summary form
- Include all data pages (entire report), not just summary page
- Indicate corrective action taken
- Evaluation of the Technologist QC program form. (physicist must repeat Tech QC)



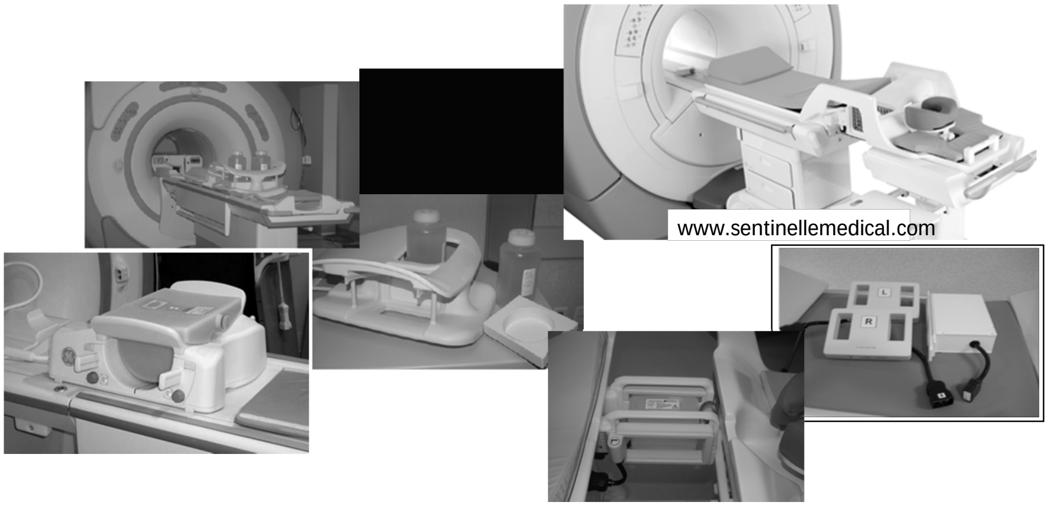
MRAP #: ______ BMRAP #: ______ Survey Date:

Evaluation of Site's Technologist QC Program

Test	Minimum Frequency	Pass/Fail	Comments
1. Table positioning	weekly		
2. Setup and scanning	weekly		
3. Center (central) frequency	weekly		
4. Transmitter gain or attenuation	weekly		
5. Geometric accuracy	weekly		
6. High Contrast (spatial) resolution	weekly		
7. Low-contrast resolution (detectabilit	weekly		
8. Artifact analysis	weekly		
9. Film (hardcopy image) QC	weekly		
10. Visual checklist	weekly		

Specific Comments:

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 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

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

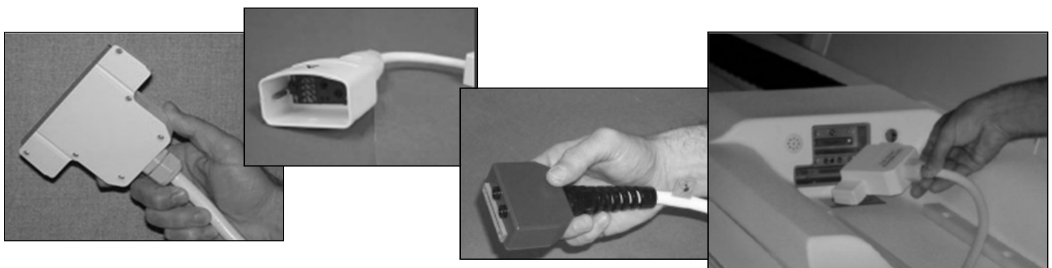
Identical measurement methods, ROI positions

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

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.



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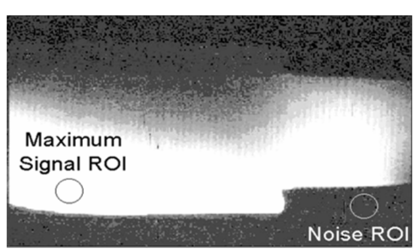
Measuring coil SNR

- Method 1:
  - SNR = mean signal within ROI divided by the noise (std dev of the same ROI or in background)

$$SNR = \bar{S} / \sigma$$

  - This method can be used for surface coils:

Maximum signal ROI / noise std dev

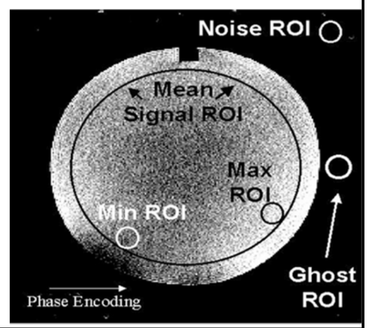


Measuring coil SNR

- Method 2:
  - SNR = 0.655 x mean Signal divided by the std deviation (of an ROI in air)

$$SNR = \sim 0.655\ \bar{S} / \sigma_{air}$$

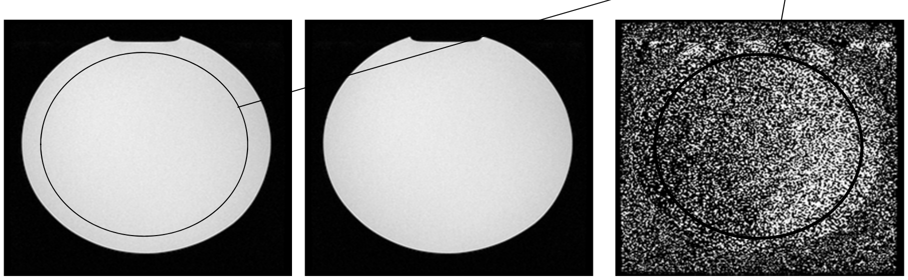
  - 0.655 factor corrects for the background signal in magnitude images having Rician distribution, rather than Gaussian
  - Noise ROI should be placed to avoid artifacts



Measuring coil SNR

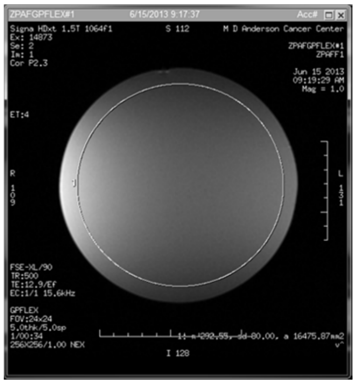
- Method 3: (NEMA subtraction)
  - Acquire 2 images with exactly same parameters
  - Subtract one image from the other
  - SNR = √2 x mean signal of ROI in one image / std dev of ROI in subtracted images.

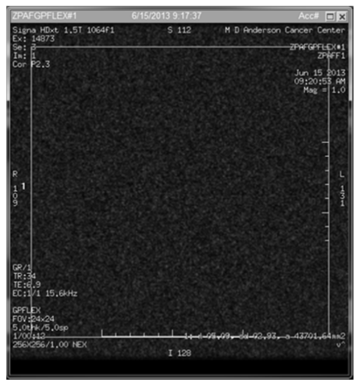
$$SNR = \sqrt{2}\ \bar{S} / \sigma$$



Measuring coil SNR

- Method 4:
  - Acquire signal image
  - Turn off RF excitation (service mode) – acquire noise image
  - Noise value is the standard deviation of ROI in noise image





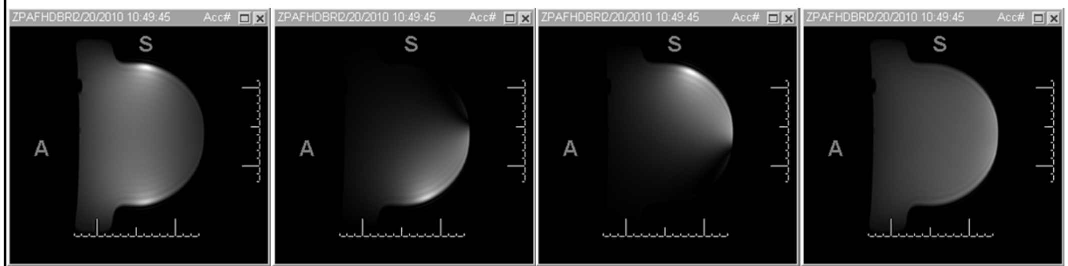
$$SNR = \bar{S} / \sigma$$

Breast RF Coil Quality Control

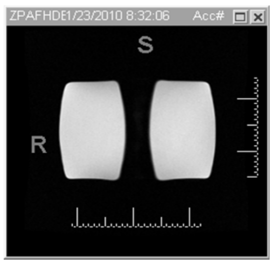
Coil
- GE 3.0T 8-channel HD Breast Array

QC Method
- Phantom: manufacturer-supplied breast phantom
- Automated image acquisition, signal, noise measurements, report generation (text file)
- Images generated using each channel, plus composite image
- Noise from pure noise image

Breast RF Coil Quality Control



Images acquired with individual coil elements



Coronal image

Sagittal composite image

Noise image

Breast RF Coil Quality Control

Coil

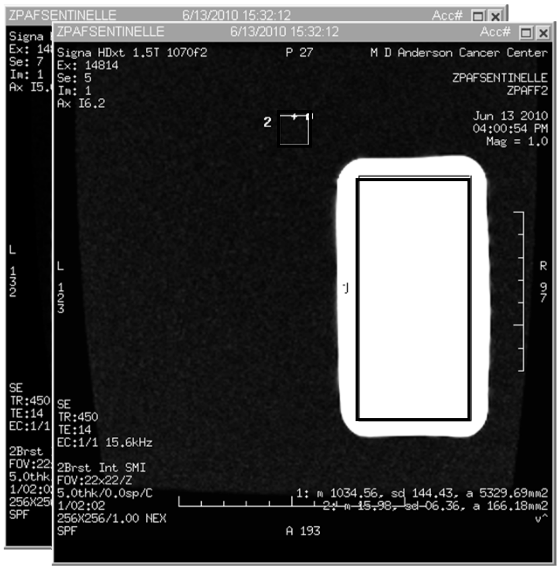
- Invivo 1.5T 7-channel Breast Array

QC Method

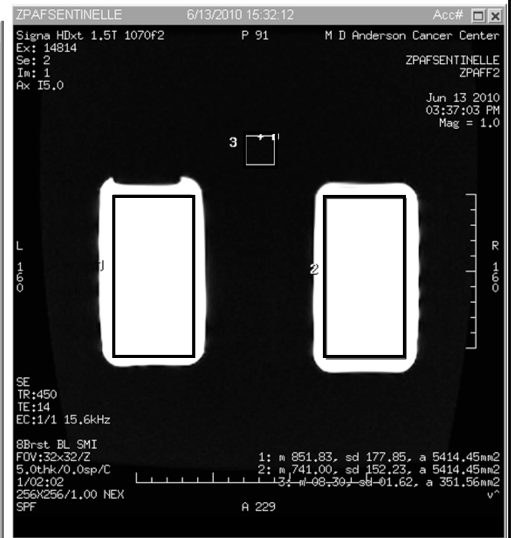
- Described in coil manual
- Phantom: manufacturer-supplied phantoms (bottle phantoms)
- Manual image acquisition, user-drawn ROIs to measure signal, noise
- Manufacturer SNR protocol: noise measured in air

http://www.invivocorp.com/coils

Breast RF Coil Quality Control



Unilateral biopsy mode



Bilateral imaging mode

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 suppression can be challenging to achieve and can be more consistent with technologist education and use of proper shim techniques.
- A comprehensive quality control program, including testing of breast RF coils, is important to ensure optimal performance and image quality of breast MRI systems.