CE-Imaging: The Physics and Technology of Magnetic Resonance Imaging – II, July 24, 2007

ACR MR Accreditation: Changes and the Expanding Role of the Medical Physicist

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THE UNIVERSITY OF TEXAS
MD ANDERSON
CANCER CENTER
Making Cancer History™

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Outline

- MRAP Requirements in 2001 (Release of initial QC manual)
- MRAP Requirements in 2004 (Release of first revision of QC manual)
- Changes of July 2005
  - 3.0T systems
  - Required submission of annual system evaluation test results and ongoing QC data
- Changes of July 2007
  - CME requirements
  - Fee structure changes
- New modules
  - Active: Cardiac
  - Pending: Breast, orthopedic, modular whole body
- Expected QC manual revisions

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ACR MR Standard as of 2001

The ACR *Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging Equipment* (1999) called for annual checks of:

Physical / mechanical inspections
Phase stability
Field homogeneity
Gradient calibration
RF calibration for all coils
SNR and uniformity for all coils
Slice thickness and location accuracy
Interslice RF interference

Artifact evaluation
Film processor QC
Hard-copy fidelity
Plus
- Documented acceptance testing
- Involvement of a qualified Medical Physicist OR MR Scientist.

Original Definition of QMP/MR Scientist

- Originally, involvement of a QMP/MR Scientist was strongly recommended, but not required.
- Definitions from original documentation (2001):
  - QMP – "ABR certified in Diagnostic Radiological Physics or Radiological Physics"
  - MR Scientist – "graduate degree in physical science involving nuclear MR (NMR) or MRI and should have three years of documented experience in a clinical MRI environment"

Medical Physicist / MR Scientist Responsibilities

- Performs acceptance tests
  - New systems before first patient scan
  - Following any major hardware or software upgrade
- Acquires baseline QC data acquisition and establishes action limits
  - Central frequency
  - Transmitter gain / attenuation
  - Geometric accuracy
  - High contrast resolution
  - Low contrast object detectability
- Artifact analysis

Medical Physicist / MR Scientist Responsibilities

- Laser camera QC
  - Establish operating levels (in consultation with laser film system service engineer)
- Acquire baseline data (using SMPTE test pattern)
- Corrective actions
  - Determination of whether problem lies in the camera, processor, and/or MR system

Medical Physicist / MR Scientist Responsibilities

Annual Physics Tests

- Magnetic field homogeneity
- Slice position accuracy
- Slice thickness accuracy
- RF coil checks
  - Signal-to-noise ratio (all coils)
  - Image uniformity (volume coils)
- Interslice RF interference
- Phase stability (ghosting)
- Soft copy displays (monitors)

ACR Accreditation Process Overview

Clinical Images

- Brain (for headache)
- Cervical Spine (for radiculopathy)
- Lumbar Spine (for back pain)
- Knee (for internal derangement)

Evaluated for 1) appropriate pulse sequence and contrast, 2) filming technique, 3) anatomic coverage and imaging planes, 4) spatial resolution, 5) artifacts, and 6) appropriate labeling, *etc.*

Must be acquired within ±1 week of phantom images.

Clinical Images

Routine brain examination (for headache)

- Sagittal short TR/short TE with dark CSF
- Axial or coronal long TR/short TE and long TR/long TE (*e.g.*, long TR double echo) (Note: FLAIR can be used in place of long TR/short TE scan.)

Routine cervical spine (for radiculopathy)

- Sagittal short TR/short TE with dark CSF
- Sagittal long TR/long TE or T2*W with bright CSF
- Axial long TR/long TE or T2*W with bright CSF

Clinical Images

Routine lumbar spine (for back pain)

- Sagittal short TR/short TE with dark CSF
- Sagittal long TR/long TE or T2*W with bright CSF
- Axial short TR/short TE with dark and/or long TR/long TE with bright CSF

Routine knee examination (for internal derangement)

- Sagittal and coronal with at least one sequence of bright fluid

Clinical Image Recommendations

Sequence	Slice thickness	Gap	Maximum Pixel Dimensions
Brain – Sagittal & Axial and/or Coronal	≤ 5 mm	≤ 2 mm	≤ 1.2 mm
Cervical Spine – Sagittal	≤ 3 mm	≤ 1 mm	≤ 1 mm
Cervical Spine – Axial	≤ 3 mm	≤ 1 mm	≤ 1 mm
Lumbar Spine – Sagittal	≤ 5 mm	≤ 1.5 mm	≤ 1.5 mm
Lumbar Spine – Axial	≤ 4 mm	≤ 1 mm	≤ 1.5 mm
Knee – Sagittal & Coronal	≤ 4 mm	≤ 1 mm	≤ .75 mm

ACR Accreditation Process Overview

Phantom Images

- Acquired on ACR MR Accreditation Phantom using specified T_1- and T_2-weighted protocols *plus* the site's T_1- and T_2-weighted protocols (for brain imaging).
- Must be submitted in DICOM format on CD-ROM
- Evaluated for 1) geometric accuracy, 2) high contrast spatial resolution, 3) slice thickness accuracy, 4) slice position accuracy, 5) signal uniformity, 6) ghosting, 7) low contrast detectability.

ACR MR Accreditation Phantom

ACR MR Accreditation Phantom

J.M. Specialty Parts
11689-Q Sorrento Valley Road
San Diego, CA 92121
619 794 -7200

$730

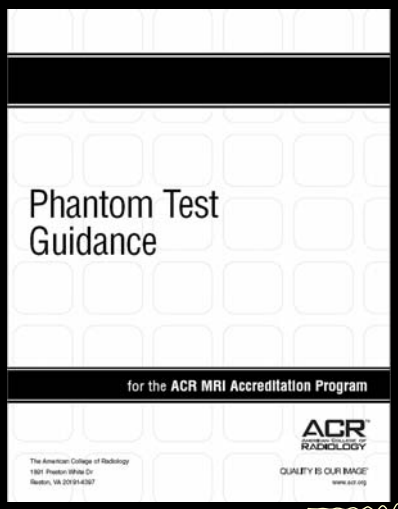
ACR Phantom Scan Documentation

Contains information on:
- Phantom position
- Pulse sequences to be used
- Filming and data preparation instructions

Sent to site with Full Application

Available from www.acr.org

ACR Phantom Scan Documentation



Contains information on:

- Test analysis
- Performance criteria
- Common reasons for failure

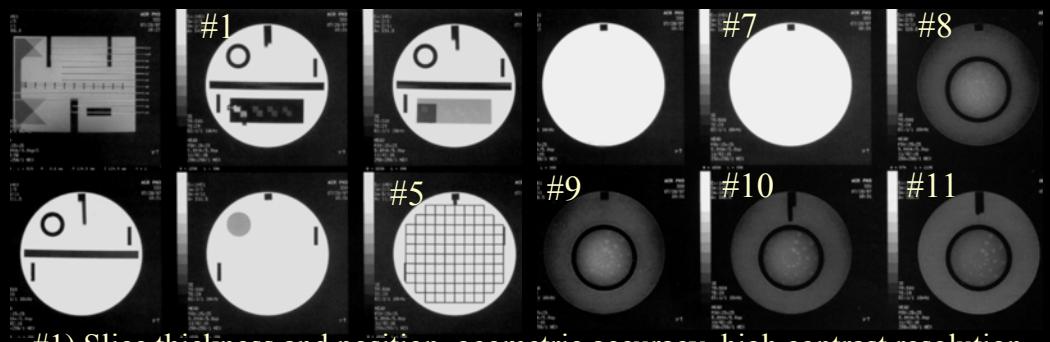
Sent to site with Full Application

Available from www.acr.org

ACR Phantom Scans

- Sagittal Localizer
  - TE/TR=20/200ms, 25 cm FOV, 256x256, 1 20-mm, 1 NEX, 0:56
- ACR T_1 Axial Series
  - TE/TR=20/500ms, 25 cm FOV, 256x256, 11 5-mm slices (graphically prescribed), 1 NEX, 2:16
- ACR T_2 Axial Series
  - TE1/TE2/TR=20/80/2000ms, 25 cm FOV, 256x256, 11 5-mm slices (same locations as for ACR T1 series), 1 NEX, 8:56
- + Site T_1 and T_2 Axial Brain Series

ACR Accreditation Process Overview



#1) Slice thickness and position, geometric accuracy, high contrast resolution
#5) Geometric accuracy
#7) Percent image uniformity, ghosting
#8-11) Low contrast object detectability, and slice position (in #11)

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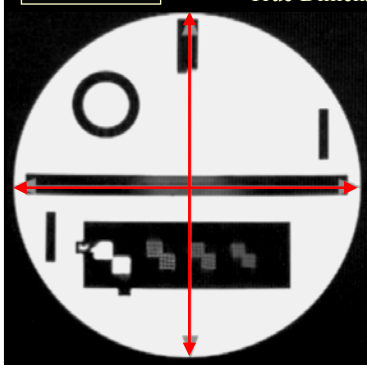
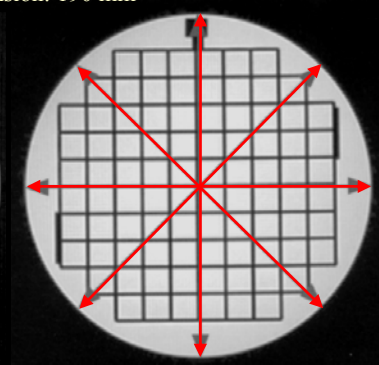
Geometric Accuracy

ACR T1

True Dimension: 190 mm

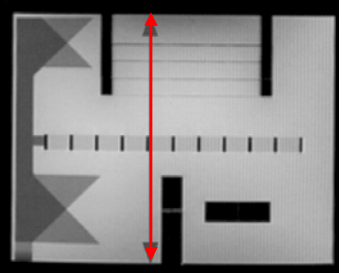


Slice 1



Slice 5

True Dimension: 148 mm



Sag Loc

Set WW & WL to min, then raise WL until 1/2 water is dark (*mean*)
Set WW to *mean* and WL to 1/2(*mean*)

Criterion: ± 2 mm

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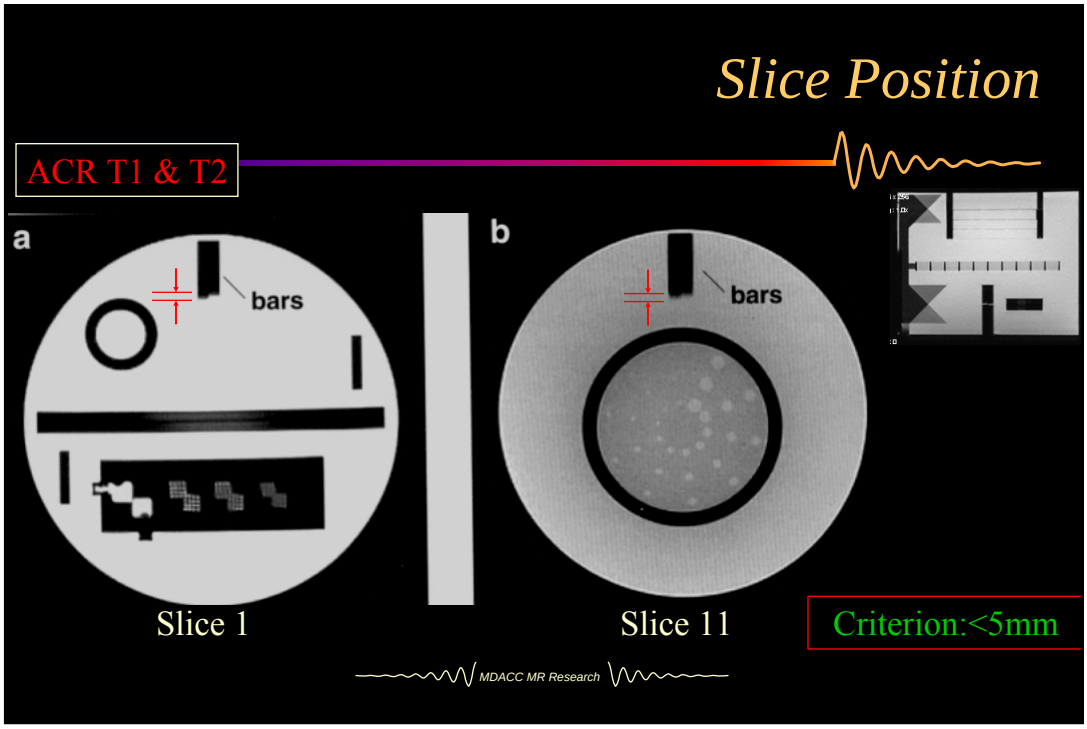
Slice Position
ACR T1 & T2
a
bars
b
bars
Slice 1
Slice 11
Criterion:<5mm
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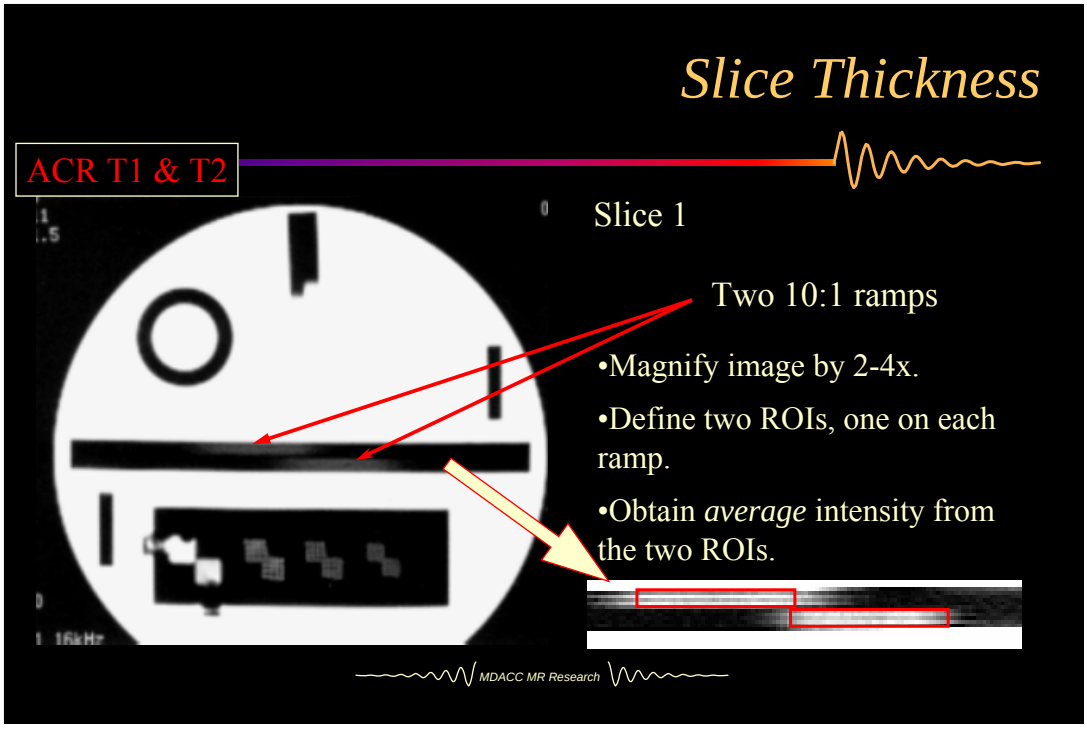
Slice Thickness
ACR T1 & T2
Slice 1
Two 10:1 ramps
•Magnify image by 2-4x.
•Define two ROIs, one on each ramp.
•Obtain average intensity from the two ROIs.
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Slice Thickness

Measurements:

- lower level to ½ *average*
- set window width to minimum
- measure lengths of top and bottom ramps
- calculate slice thickness

$$slice\ thickness = 0.2 \times \frac{(top \times bottom)}{(top + bottom)}$$

Criterion: 5.0±0.7 mm

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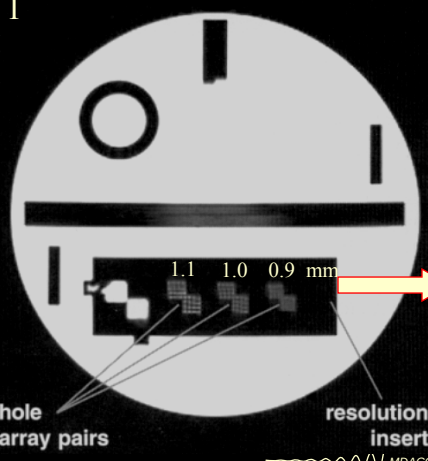
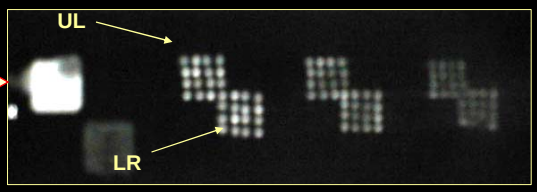
High Contrast Spatial Resolution

ACR T1 & T2

Slice 1



- Magnify by 2-4x.
- Use UL for horizontal resolution and LR for vertical resolution.
- Must be able to resolve 1.0 mm holes vertically and horizontally.



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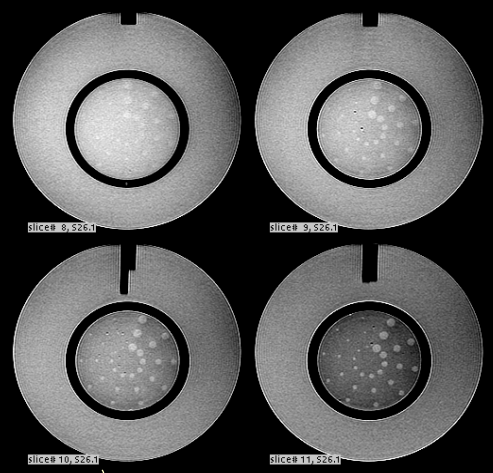
Low Contrast Detectability

ACR T1 & T2

Slices 8-11

Slice 8:	1.4%
Slice 9:	2.5%
Slice 10:	3.6%
Slice 11:	5.1%

Criterion ≥ 9 spokes



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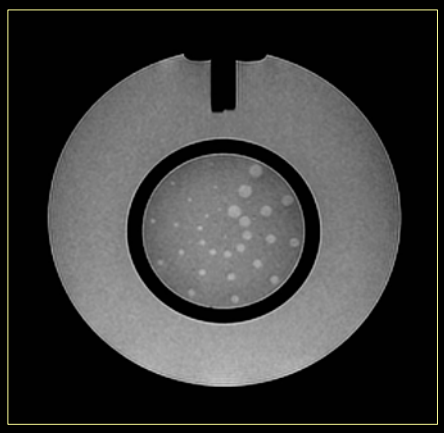
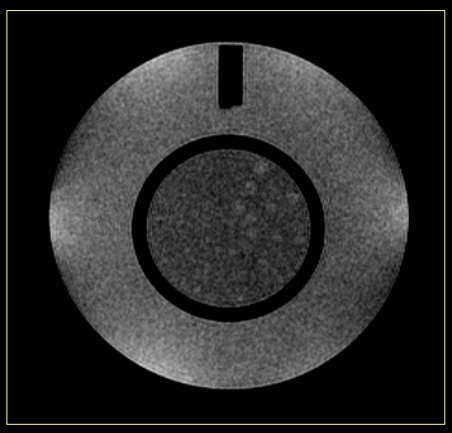
Low Contrast: High vs. Low Field

1.5 T



0.3 T



Slice 11 - ACR T1 series

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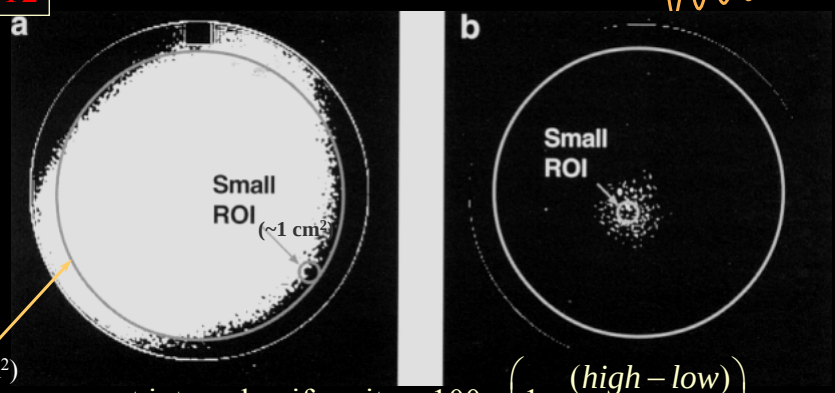
Percent Image Uniformity

ACR T1 & T2

Slice 7



Large ROI
(195-205 cm²)

$$\text{percent integral uniformity} = 100 \times \left(1 - \frac{(high - low)}{(high + low)}\right)$$

Criterion: PIU ≥ 87.5%

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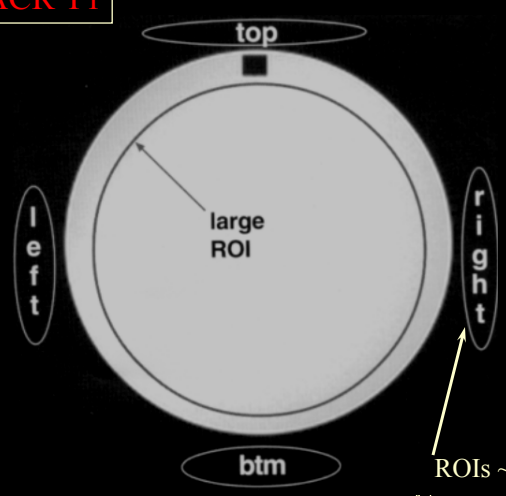
Ghosting

ACR T1

Slice 7



Ghost ratio =

$$\frac{|(\text{top}+\text{bottom}) - (\text{left}+\text{right})|}{(2 \bullet \text{large ROI})}$$

Criterion: ≤ 0.025

ROIs ~ 10 cm² with ~4:1 length:width

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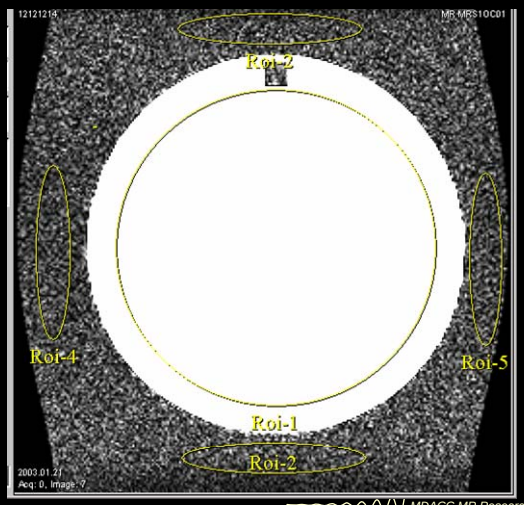
Ghosting



Window and level to make sure ROIs are in background noise! (Warping of image space due to gradient nonlinearity corrections.)

Outcomes

- As of November 2006:
  - 5094 applications received / 4384 facilities accredited
  - 7363 units / 5950 accredited (currently active: 4747 / accredited: 3915)
- Initial application pass rate FY2006 (FY1997):
  - Initial: 69% (44%)
  - Confidential report sent with suggestions to correct any deficiencies
  - 2nd attempt: 100% (76%)
  - 3rd attempt: ---- (72%)
- Renewal application:
  - Initial: 72% (53% in FY2000)
  - 2nd attempt: 88% (91% in FY2000)
- Field strengths that have been accredited: 0.2 – 3.0 T

MRI QC Manual 2001 Overview

- Radiologist's Section
  Describes requirements and the role in a QA program
- Technologist's Section
  Outlines the recommended daily (weekly) QC tests
- Physicist's / MR Scientist's Section
  Suggestions for setting up a QC program
  Outlines recommended annual equipment performance tests

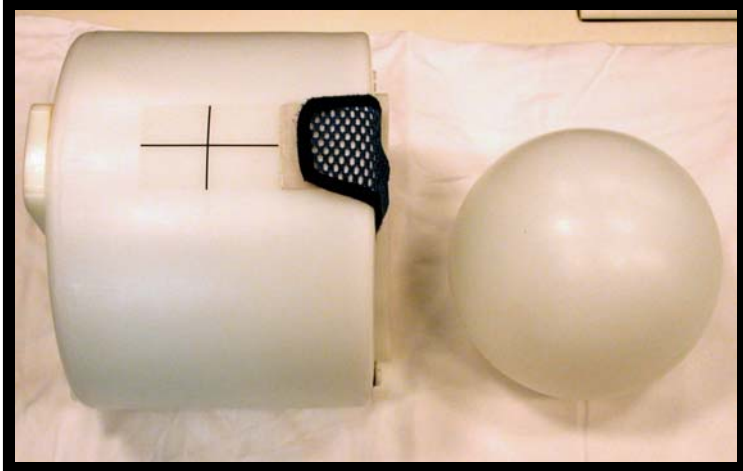
Medical Physicist / MR Scientist Responsibilities

Annual Physics Tests

- Magnetic field homogeneity
- Slice position accuracy
- Slice thickness accuracy
- RF coil checks
  - Signal-to-noise ratio (all coils)
  - Image uniformity (volume coils)
- Interslice RF interference
- Phase stability (ghosting)
- Soft copy displays (monitors)

QC Manual 2001

Magnetic Field Homogeneity



One vendor's "head equivalent" phantom.

Insert sphere can be used for homogeneity test.

(Remove sphere from cylindrical "loader" first. Place at isocenter in head coil.)

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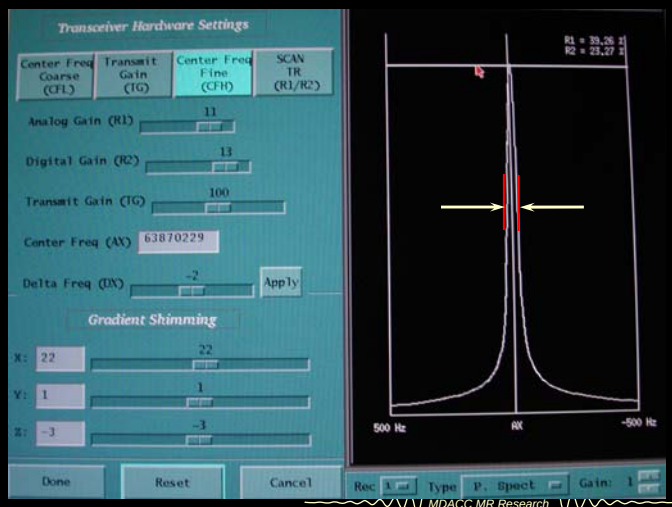
QC Manual 2001

Magnetic Field Homogeneity



With sphere in head coil, use manual prescan.

Adjust center frequency twice to determine the "full width at half maximum" of the spectrum.

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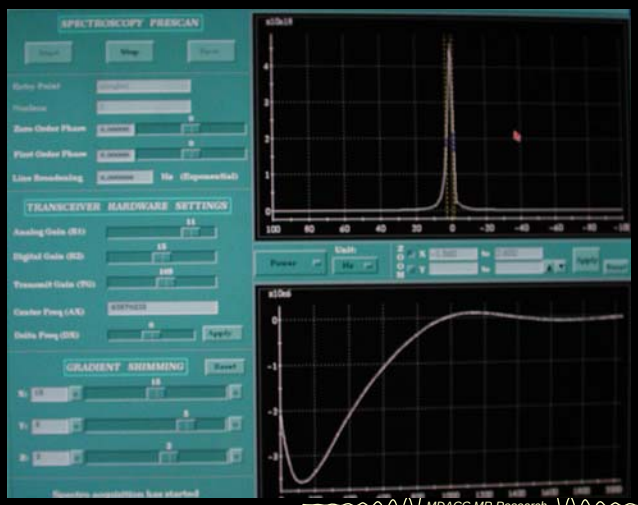
QC Manual 2001

Magnetic Field Homogeneity



If scanner has spectroscopy capabilities, then the spectroscopy prescan page can be used to easily measure "frequency spread".

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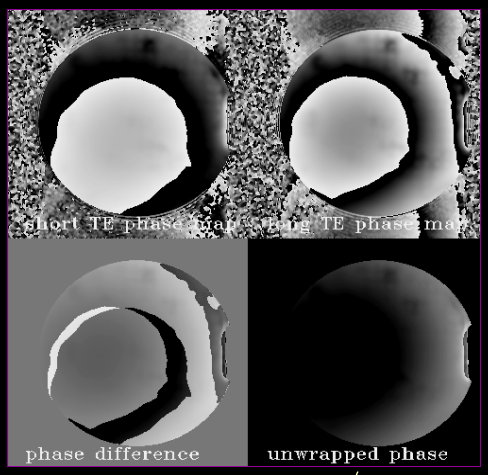
QC Manual 2001

Magnetic Field Homogeneity



Phase images from GRE sequences with 10ms difference in TE's

Phase and Unwrapped Phase Images

The change in phase across the phantom is proportional to the inhomogeneity of the magnetic field.

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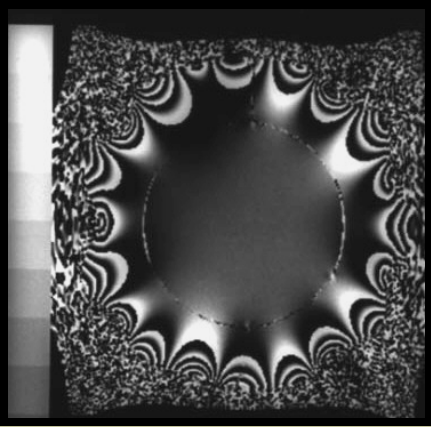
QC Manual 2001

Magnetic Field Homogeneity



LVshim Report

Exam 50196, Series 2, Image 1

(Fri Jan 24 20:35:23 1997)

Scan Bandwidth = 200 Hz

Field of View = 50 cm

Sampling Diameter = 22 cm

Inhomogeneity

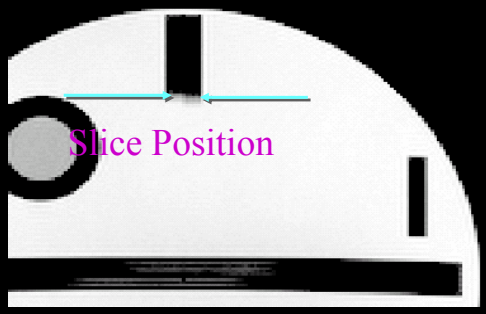
3.19 Hz (0.050 ppm)

Harmonic Coefficients given for Z1, Z2, Z3, Z4, Z5, Z6, X, Y, ZX, ZY, X2-Y2, XY, Z2X, Z2Y, ZXY, *etc.*

Magnetic Field Homogeneity

- Either the FWHM technique (on a given spherical phantom) or the phase difference technique can be used to assess homogeneity *if possible at a given site.*
- Alternative: Use the service engineer's report on homogeneity for your site records of homogeneity.

Slice Position Accuracy



SLICE #1

SLICE #11

Crossed wedges should be of equal length
if position and spacing are accurate (and phantom is not tilted!)

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QC Manual 2001

Slice Thickness

Measurements:

- lower level to ½ average
- set window at <u>minimum</u>
- measure lengths of top and bottom ramps
- calculate slice thickness

$$slice\ thickness = 0.2 \times \frac{(top \times bottom)}{(top + bottom)}$$

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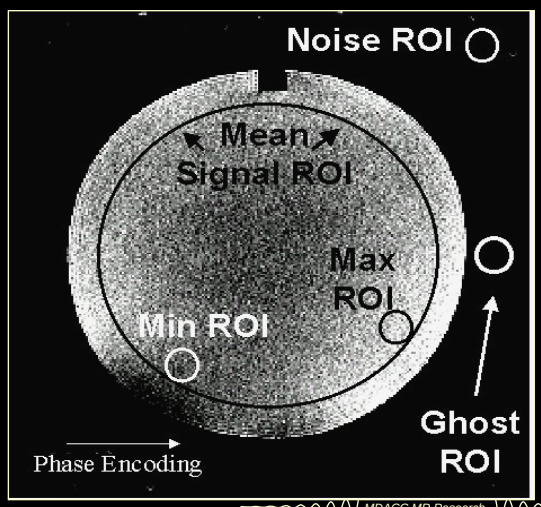
QC Manual 2001

Volume RF Coil Measurements



Must assess SNR, uniformity, and ghosting ratio for <u>every</u> volume coil.

ACR Phantom Slice #7

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QC Manual 2001

Volume Coils - SNR, Uniformity, and Ghosting

- Uniformity performance criteria: PIU ≥ 90%

$$100 * \left(1 - \frac{\overline{S}_{\max} - \overline{S}_{\min}}{\overline{S}_{\max} + \overline{S}_{\min}} \right)$$

- SNR (no fixed criteria)

$$\overline{S}_{ROI} \Big/ \sigma_{noise}$$

- Percent Signal Ghosting

$$\left| \frac{\overline{S}_{Ghost} - \overline{S}_{Noise}}{2 * \overline{S}_{ROI}} \right| * 100$$

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QC Manual 2001

Phased-Array Coils

Abdomen-Pelvis
Phased Array

Torso
Phased Array

Cervical-Cranial Phased Array

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QC Manual 2001

Phased-Array Coils

Example of a particular vendor's C-T-L spine phased array coil QC phantom

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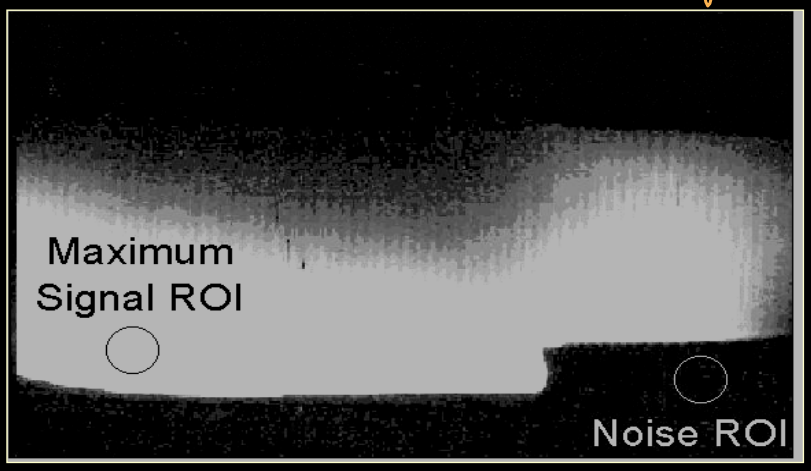
QC Manual 2001

Surface RF Coil Measurements



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QC Manual 2001

Volume Coil Data

% Image Uniformity	Max Signal Min Signal
Signal-to-Noise	Mean Signal SD of Background Signal
Percent Signal Ghosting	Ghost Signal Mean Signal Background Signal

Surface Coil Data

Maximum Signal-to-Noise	Maximum signal SD of Background Signal

QC Manual 2001

Slice Cross-Talk Measurements

1. Position 5mm slices on the uniform volume (slice 7)
2. Repeat measurements decreasing the slice gap :

Series #	1	2	3	4
No. Slices	11	11	11	11
Slice Gap (mm)	min	0.5	1.0	5.0

- Measure the signal-to-noise ratio (SNR) for each of the image sets.
- Plot the SNR *vs.* percentage slice gap

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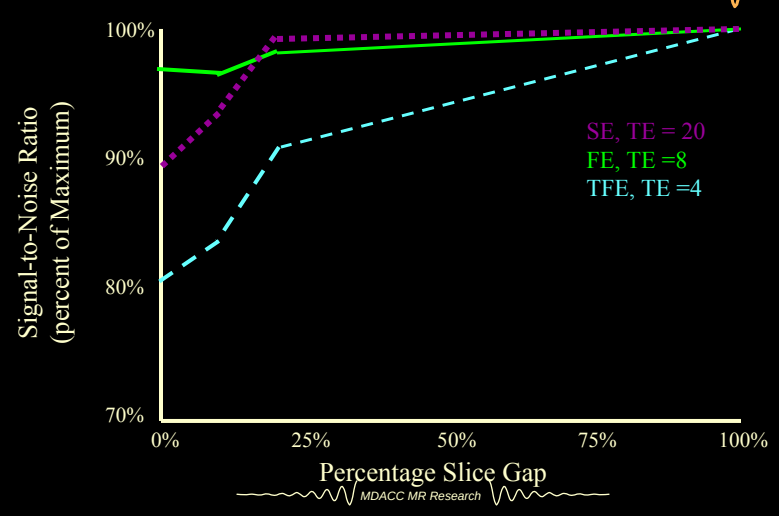
QC Manual 2001

Signal-to-Noise vs Inter-slice Gap



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QC Manual 2001

Soft Copy Displays

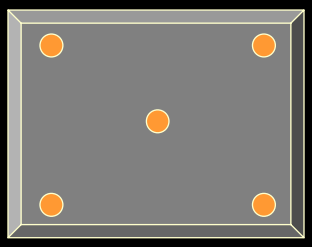
Four tests:

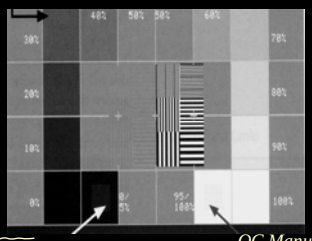
- Maximum and minimum luminance
- Luminance uniformity
- Resolution (SMPTE)
- Spatial accuracy (SMPTE)

QC Manual 2001

Soft Copy Displays

- Max luminance (WL/WW min): ≥90 Cd/m^2
- Min luminance: <1.2 Cd/m^2
- Luminance uniformity: Each of the luminance values obtained at the four corners of the screen should be within 30% of the maximum value measured at the center (WL/WW min).
- Resolution: Use SMPTE 100% contrast patterns (see QC manual, p. 117).
- Spatial accuracy: Use SMPTE grid pattern (see QC manual, p. 117).





QC Manual 2001

QC Manual 2004 Revisions

Minor revisions were made to the QC manual in 2004:

- Daily frequency of technologist tests changed to weekly.
- Correction of minimum OD control limit typo (±0.08 instead of ±0.80).
- Correction of equation for calculating magnetic field inhomogeneity from phase map data.
- Luminance uniformity measurement changed to be consistent with recommendations of AAPM TG18.
- Correction of minor typographical errors.

Significant Changes in July 2005

- First requirement for submission of annual MRI System Performance Evaluation test report and ongoing QC records as part of the initial accreditation or reaccreditation review process.
- 3.0T scanners could become accredited
  - First incorporation of field strength specific pass criteria!
- First statement (on www.acr.org) that a QMP/MR Scientist is required.

Submission of QC Documentation

3. Does the ACR require that a physicist or MR scientist perform testing services for a facility to apply for accreditation?
Starting July 1, 2005, sites applying for MRI accreditation must submit an annual MRI system performance evaluation performed by a medical physicist or MR scientist. A technologist may still perform the ACR phantom portion of the accreditation submission, although the ACR strongly recommends the services of a medical physicist or MR scientist for this also.

Sites must submit annual test report and most recent quarter of daily / weekly QC records. Data is reviewed by ACR staff based on checklist developed by the MRAP MR Physics Subcommittee.

www.acr.org – MR FAQs

Submission of QC Documentation

A qualified medical physicist/MR scientist ***should*** have the responsibility for overseeing the equipment quality control program and for monitoring performance upon installation and routinely thereafter. All facilities applying for accreditation or renewal must demonstrate compliance with the ACR requirements for quality control (QC) by including a copy of the facility's most recent **Annual MRI System Performance Evaluation** (must be dated within 1 year of the date of ACR MRI submission for accreditation) and copies of the facility's weekly on-site QC data (forms on pages 64, 65, and 66 of the *2004 ACR MRI Quality Control Manual*) for the most recent quarter. If the facility has been conducting QC for less than one quarter, the facility will submit whatever they have on these forms. Additionally, if the **Annual MRI System Performance Evaluation** and/or QC files show performance deficits (e.g. problems with the system and/or data outside of the action limits), the facility must state what steps it has taken to correct the problems. All QC testing must be carried out in accordance with the written procedures and methods outlined in the ACR *2004 MRI Quality Control Manual*.

www.acr.org

MR Accreditation Program Requirements

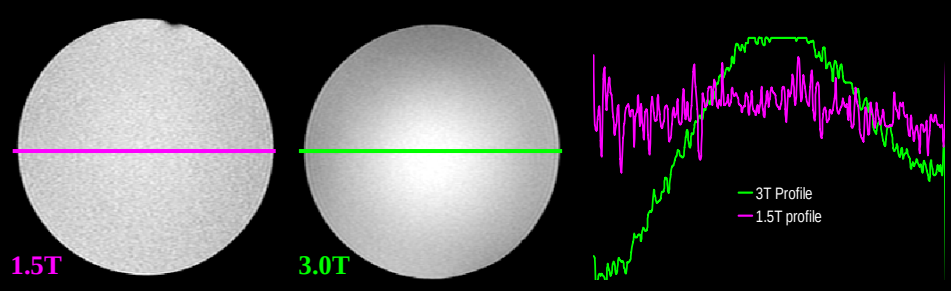
3.0T Systems

13. Does the ACR accredit 3.0-T magnets?
Yes. Starting July 1, 2005 the ACR will be accepting MRI accreditation applications for 3.0-T magnets. In order to accurately measure the performance of these units, 2 of the physics tests performed for ACR accreditation will have different pass/fail criteria for 3.0-T units. For the low-contrast object detectability (LCOD), the required number of total spokes for a 3.0-T magnet is equal to or greater than 37. For the image intensity uniformity, the required percent integral uniformity (PIU) for a 3.0-T magnet is equal to or greater than 82%.

MDACC MR Research

www.acr.org – MR FAQs

3.0T System Issues - Uniformity



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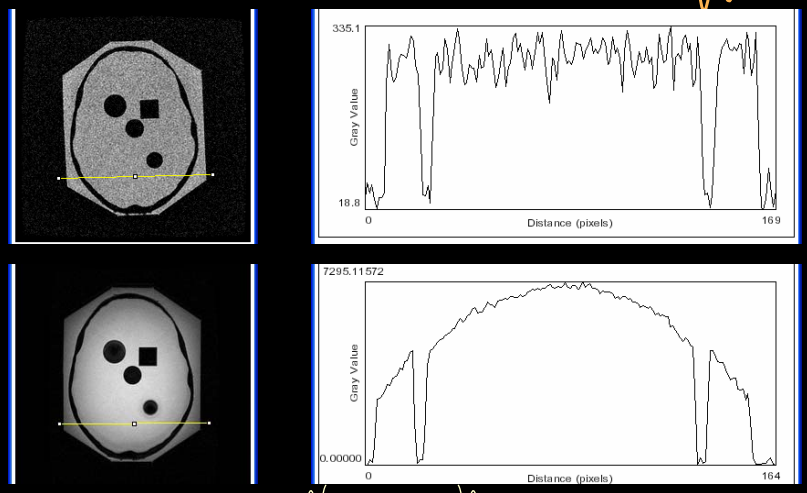
Images from R. Jason Stafford, PhD

3.0T System Issues - Uniformity



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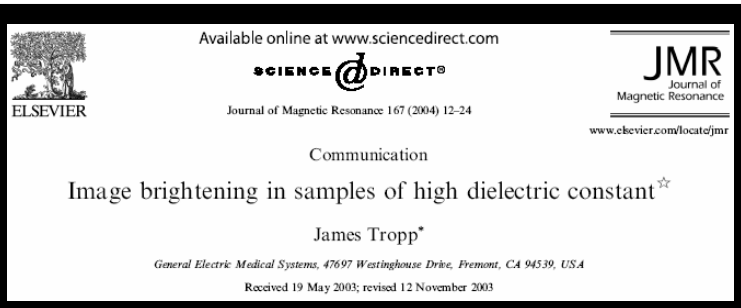

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Communication

Image brightening in samples of high dielectric constant☆

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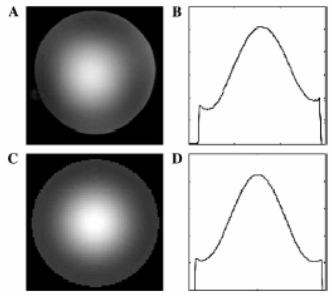

Fig. 2. Above, experimental gradient recalled proton image (20° flip angle) at 3.0 T, (A) and profile, (B) of cylindrical phantom, radius 9.25 cm, filled with 0.05 aqueous NaCl; below (C) and (D), computer simulations of same, at 128 MHz, with $\varepsilon = 80$ and $\sigma = 0.5$.

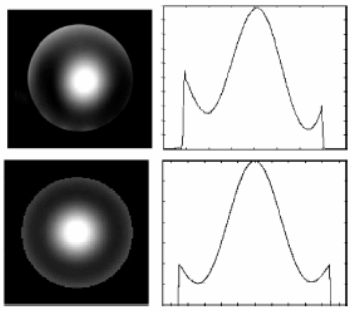

Fig. 3. As in Fig. 2 above, except images taken at 4.0 T, and simulations done at 170 MHz. The asymmetry of the experimental image and profile is due apparently to distortion of the RF homogeneity, probably due to reactive loading of resonator by the phantom, as noted in

Changes in July 2007

- Introduction of MR specific CME requirements for QMP / MR Scientists
- Increase in fee structure
  - First magnet - $ 2,400
  - Second and subsequent magnets - $ 2,300
  - Initial magnet added mid-cycle - $ 1,400
  - Repeat fee - $ 800

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Sites renewing in:	Continuing Education Requirement
July 2007	Physicians and medical physicists/MR scientists must have earned at least 5 CME (category 1) hours in the prior 12-month period. The 5 CME hours must be earned for each modality in which they are renewing (CT, MRI, nuclear medicine, PET and ultrasound).
July 2008	Physicians and medical physicists/MR scientists must have earned at least 10 CME (half of which must be category 1) hours in the prior 24-month period. The 10 CME hours must be earned for each modality in which they are renewing (CT, MRI, nuclear medicine, PET and ultrasound).
July 2009	Physicians and medical physicists/MR scientists must have earned at least 15 CME (half of which must be category 1) hours in the prior 36-month period. The 15 CME hours must be earned for each modality in which they are renewing (CT, MRI, nuclear medicine, PET and ultrasound).

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MR Accreditation Program Requirements

New Module in 2006

Cardiac Magnetic Resonance Imaging Program

- Same phantom and phantom acquisitions as for whole body program
- Same requirements for annual testing and ongoing QC record requirements
- Same costs as for whole-body program ($2,400 first magnet / $2,300 subsequent magnets at the same radiology group at the same facility address)
- Medical Physicist / MR Scientist requirements – same as for whole-body program

Cardiac MRI Module

Cardiac Magnetic Resonance Imaging Program

- Clinical exams required:
  - Black blood exam (e.g., SE, FSE/TSE) – one exam
    - T1W or PDW
    - Axial or short-axis plane
    - Cardiac gated
    - Must cover entire heart
  - Delayed enhanced exam - two exams
    - Short axis cines
    - Long axis cines (2-chamber and 4-chamber views)
    - Delayed enhanced Gd (IR-prepped)

Cardiac MRI Module

Cardiac Magnetic Resonance Imaging Program (cont)

- Clinical exams required (cont):
  - Basic cardiac exam – one exam
    - Short axis cines (SSFP preferred)
      - Entire left ventricle from base to apex
    - Long axis cines
      - Two-chamber view
      - Four-chamber view
      - Left ventricular aortic outflow tract view

Other (Probable) Upcoming Changes

- Changes to the Whole Body MR Program
  - Introduction of modular design as opposed to "one size fits all" current design requiring brain, C-spine, L-spine, and knee scans.
  - Six modules: Brain, Spine, Body, MSK, MRA, Cardiac
- Breast MR Module
- Orthopedic MR Module (will require dedicated phantom)
- Revised Quality Control Manual (probably fall 2007)

Anticipated Changes

Anticipated Revisions to QC Manual 2004

- Will take into account the current recommendations of the *ACR Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment* (2006).
  - Eliminates the RF slice interference component.
  - Qualifications of a QMP are modified to include either ABR certification (diagnostic radiological physics or radiological physics) <u>or ABMP</u> (magnetic resonance imaging physics). (Need to continue to push for certification of "MR Scientists", e.g., require ABMP MR physics certification.)
- Will revisit magnetic field homogeneity assessment.
- Will revisit percent uniformity evaluations
- Will revisit soft copy display evaluations

Expanding Roles of QMP

How can QMPs/MR Scientists contribute to the expanding MRAP efforts:

- Education
  - Common pitfalls, consults with radiologists re: protocols, etc.
- Involvement during:
  - Initial accreditation phase
    - Acquisition and data review of phantom scans
    - Advice on clinical scan protocols
    - Establishment of QC program procedures and action limits
  - Ongoing QC processes and reaccreditation
    - Annual MRI System Performance Evaluations and reports
    - Review of ongoing weekly/daily QC data / records.

Expanding Roles of QMP

How can QMPs/MR Scientists contribute to the expanding MRAP efforts:

- Education
  - Common pitfalls, consults with radiologists re: protocols, etc.
  - Some examples:
    - Phantom data acquired using multielement array head coils can/should be processed using "surface coil intensity correction" algorithms as long as such algorithms are used for clinical scans.
    - Clinical protocols with insufficient spatial resolution, contrast, etc.
    - Phantom data CD-ROM submitted without being reviewed by a QMP/MR Scientist and/or missing data sets, typically the sagittal loc.
    - Phantom data CD-ROM submitted with embedded viewer (which is directly counter to the instructions) and/or compressed DICOM format.

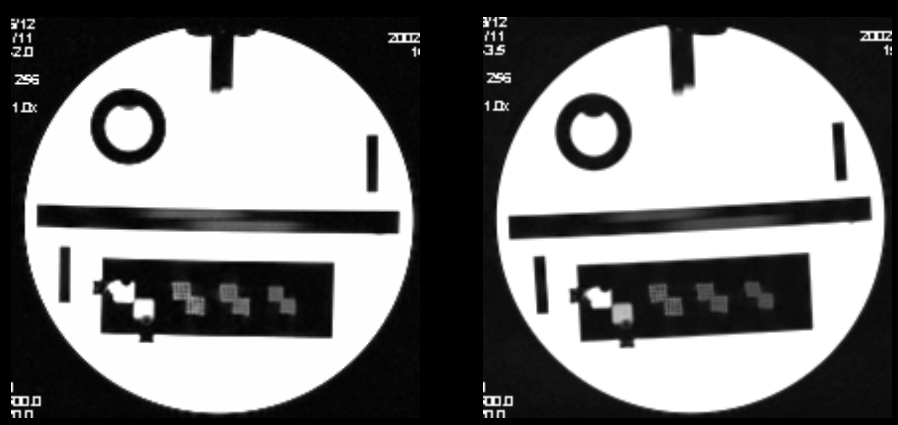
Common Problems and Artifacts

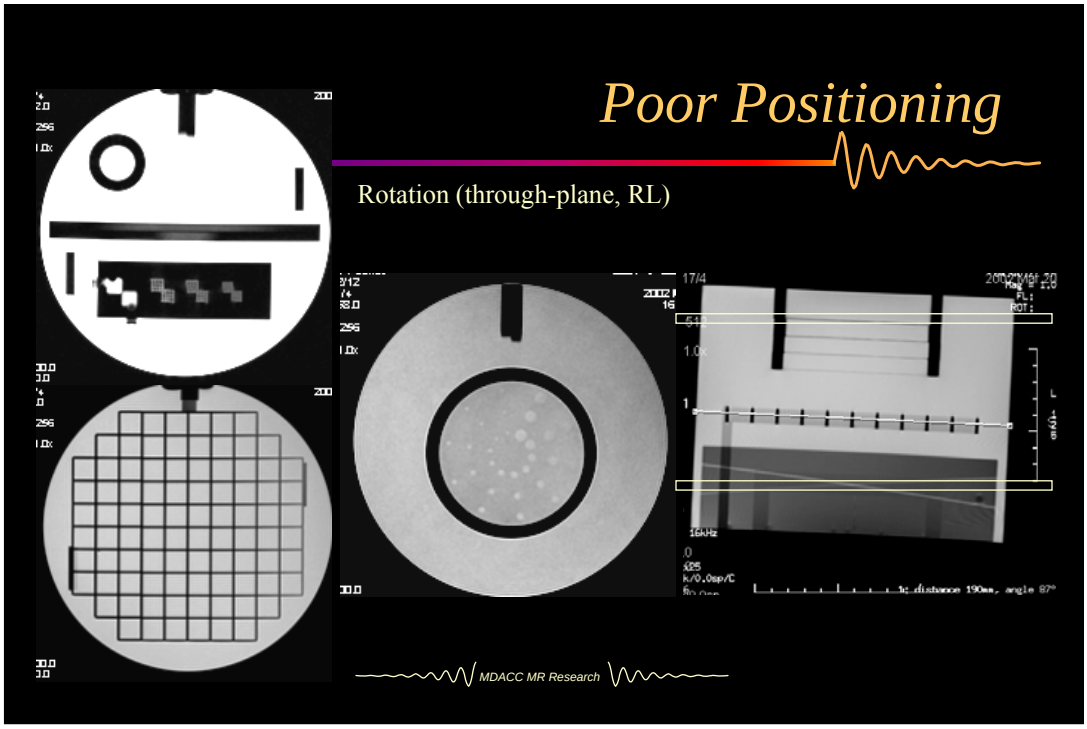
Potential Causes of Geometric Accuracy Failures

- Poor phantom positioning - relatively common problem
- Poor gradient calibration
- B_o inhomogeneity
  - Ferromagnetic objects in magnet
  - Poor magnet shimming
- Gradient non-linearity (not appropriately corrected)
- Inappropriate receiver bandwidth
- Poor eddy current compensation
- Combination of two or more of above

Poor Positioning

Rotation (in-plane)




Poor Positioning
Rotation (through-plane, RL)
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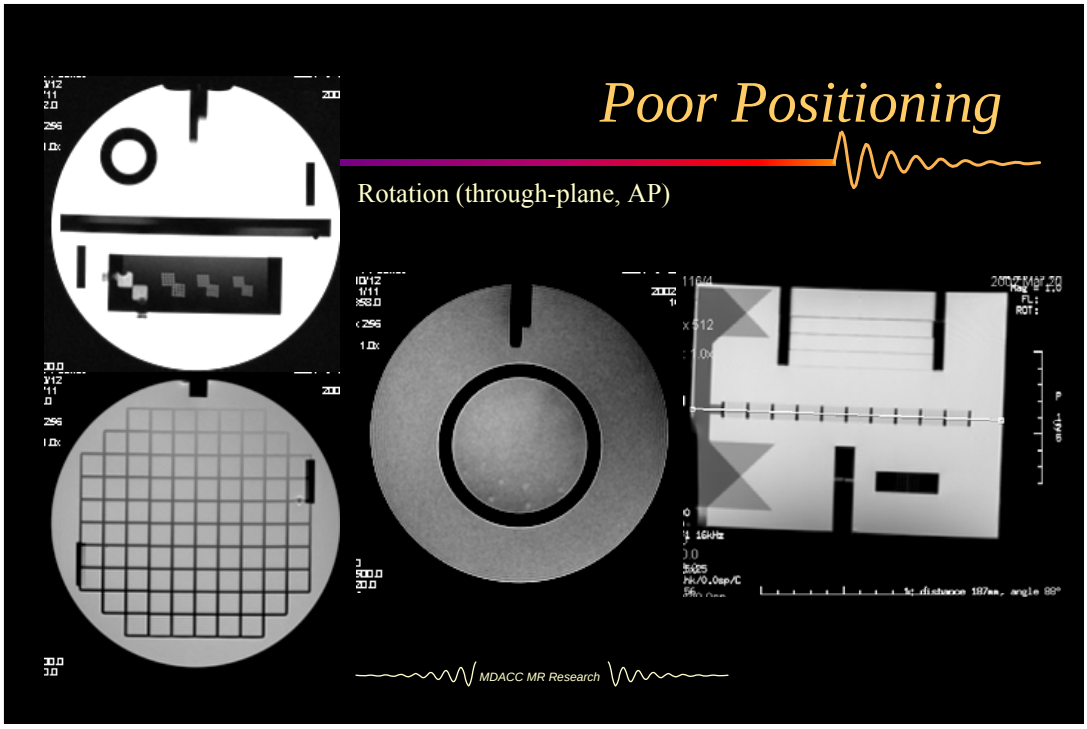
Poor Positioning
Rotation (through-plane, AP)
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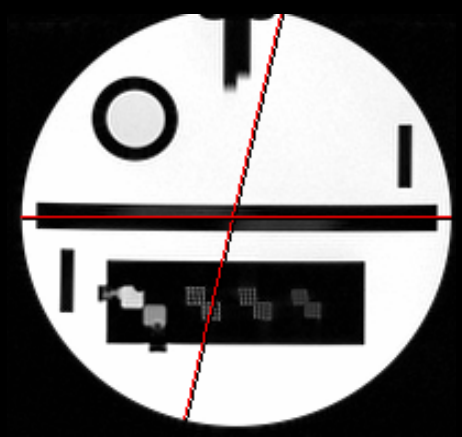
Sources of Geometric Distortion

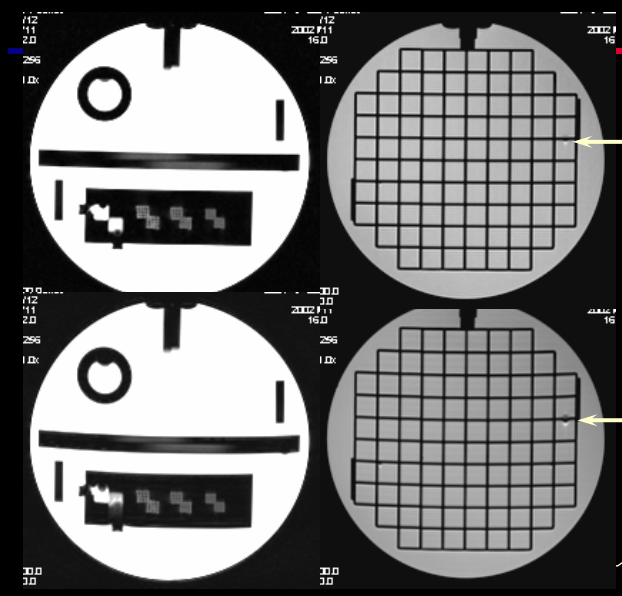
- System Limitations
  - Poor B_o homogeneity
  - Linear scale factor errors in the gradient fields
  - Field distortion due to induced eddy currents
  - Nonlinearities of the gradient fields
- Object-Induced
  - Chemical shift effects
  - Magnetic susceptibility variations (object induced)

Air Bubbles



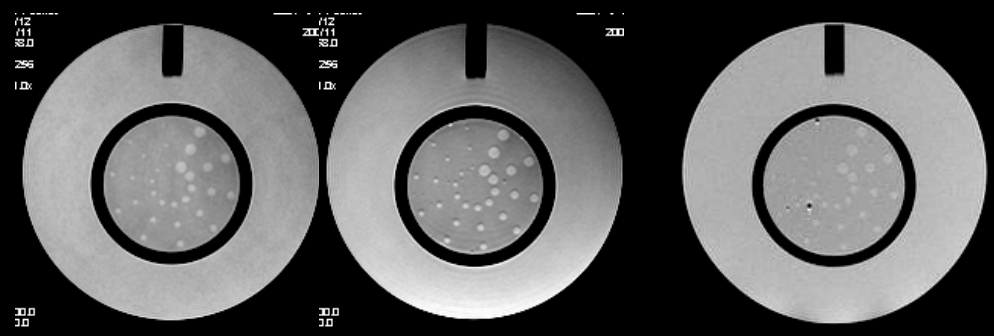
When a large air bubble is present in the phantom, geometric distortion measurement may have to be taken along diagonal instead of vertical.

Low Acquisition Bandwidth



Note distortion as well as increased susceptibility artifacts.

Air Bubbles



16 kHz 8 kHz

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High Contrast Spatial Resolution

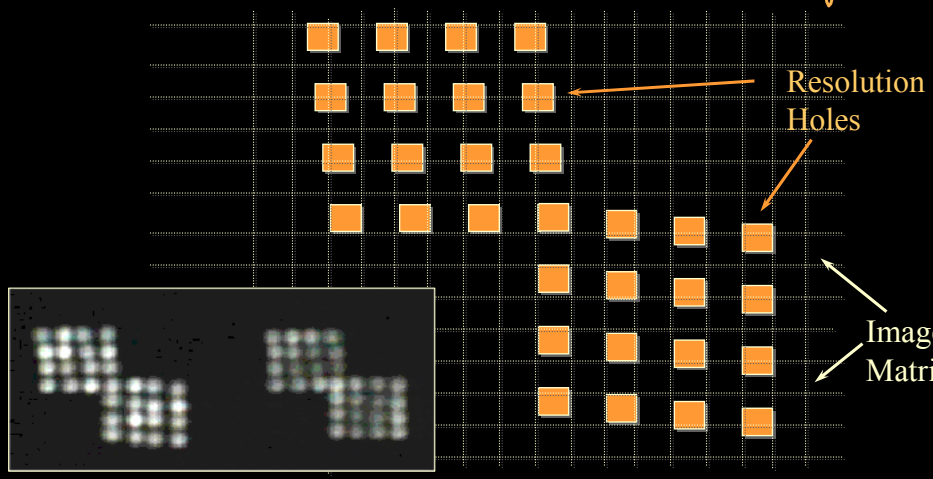

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Image compliments of Geoff Clarke, PhD

High Contrast Spatial Resolution

Common causes of failure;

- Incorrect FOV or matrix size
- Poor gradient calibrations
- Excessive filtering (smoothing)
- Poor eddy current compensation
- Gradient amplifier instability

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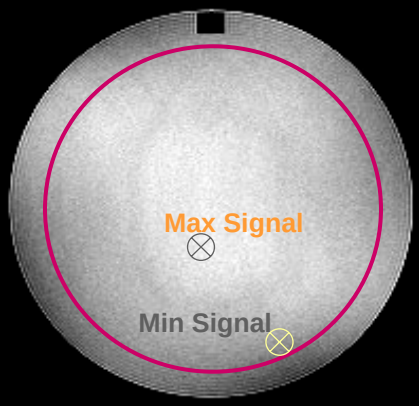
Image Intensity Uniformity

Big ROI ~ 195 cm^2
(19,500 mm^2)

Small ROI's ~ 1 cm^2
(100 mm^2)



ACR phantom - Slice #7

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Image Intensity Uniformity

Common causes of failure:

- Poor phantom centering in coil (usually in AP direction)
- Ghosting
- Motion or vibration
- Mechanical failure in head coil

Note: Uniformity becomes poorer with increasing B_o (especially above 2 T) because of dielectric field focusing phenomenon (aqueous phantom).

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Percent Signal Ghosting

- Must pass on slice #7 of ACR T1-weighted axial series.
- Ghost signal is measured and reported as percentage of the signal in the true image
- Excessive ghosting in other images may be counted as "Unacceptable Artifact"

Phase Ghosting

Phase

Readout

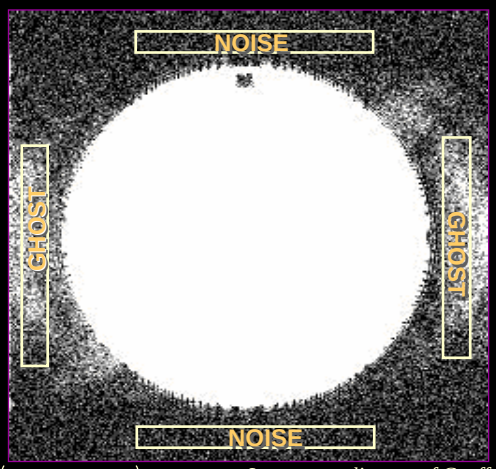
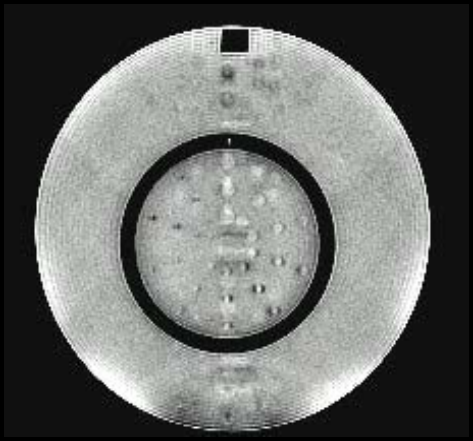


Image compliments of Geoff Clarke, PhD

Ghosting is Nonspecific

- Instability in MRI signal from pulse to pulse
- Phantom motion
- Loose connections or bad cable
- Partial failure of radiofrequency coils or gradient subsystem
- Pulse sequence calibration error
  - Eddy currents in Fast Spin Echo series

Ghosting



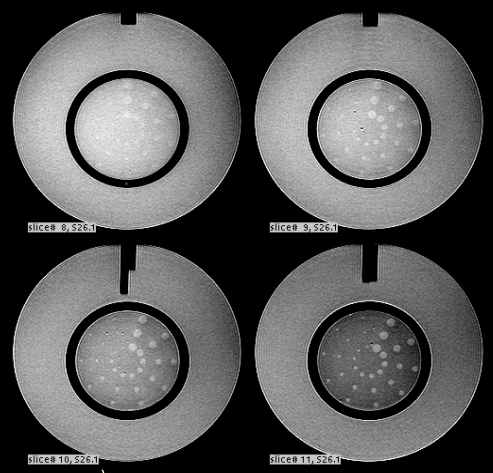
Ghosting may obscure otherwise visible LCD spokes

Image compliments of Geoff Clarke, PhD

Low Contrast Detectability

ACR T1 & T2

Slice 8:	1.4%
Slice 9:	2.5%
Slice 10:	3.6%
Slice 11:	5.1%



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Low Contrast Detectability

Some common causes of failure:

- Incorrectly positioned slices
  - Contrast based on partial volume averaging
- Tilted phantom
- Incorrect slice thickness
- Ghosting
- Inadequate SNR

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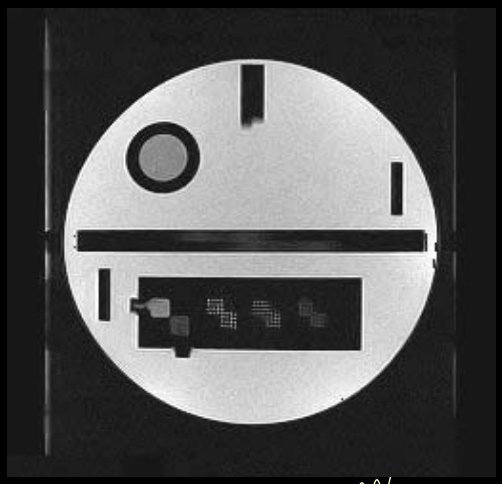
DC Offset Artifacts



- Zero frequency artifacts
- Not important if off to the side

DC Offset Artifacts

Large artifact off to side.
NEX=1; frequency shifted

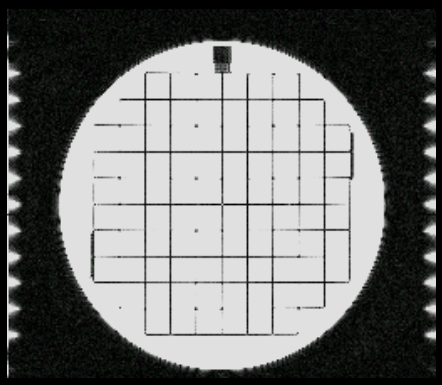
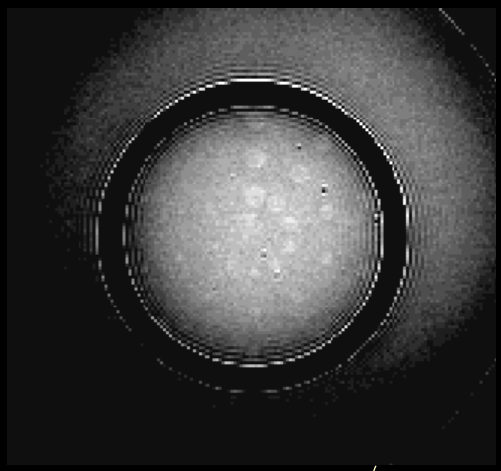


Image compliments of Geoff Clarke, PhD

Susceptibility Artifacts



Small inclusions in LCD insert can make analysis difficult.