Physicists’ Quality Control for MR Equipment

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Overview

- ABR and the role of the Qualified Medical Physicist/MR Scientist
- Phantom selection and the degree of latitude given the QMP/MRS
- Annual survey tests:
  - Magnetic field homogeneity
  - RF Coil SNR, image uniformity & ghosting
- Roles of physics assistants & technologists

ACR MRI Accreditation Program Overview

- Evaluates effectiveness of quality control measures
- Collects findings to further the development of quality control information
- Promotes the Qualified Medical Physicist/MR Scientist as individual responsible for overseeing the equipment quality control program

ACR Position on QMP/MRS

- 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.
- The medical physicist/MR Scientist will follow the ACR MRI Quality Control Manual in order to perform a complete annual system performance evaluation.
ACR Position on QMP/MRS

- This evaluation includes an evaluation of the weekly QC performed by a technologist.
- A technologist may still perform the ACR phantom portion of the accreditation submission.
- The ACR strongly recommends the services of a medical physicist or MR scientist for this also.

Qualified Medical Physicist or MR Scientist?

Qualified Medical Physicist: ACR recommends that the individual be certified in the appropriate subfields* by:
- the American Board of Radiology
- the Canadian College of Physics in Medicine, or
- for MRI, by the American Board of Medical Physics in MRI physics.

*The appropriate subfields of medical physics for this standard are Diagnostic Radiological Physics and Radiological Physics.

Qualified MRI Scientist:
- obtained graduate degree in a physical science involving nuclear MR or MRI
- Should have 3 yrs. of documented experience in a clinical MRI environment.
- Physicist/MR scientist shall be knowledgeable in:
  - principles of MR safety, FDA & other regulations
  - Nuclear physics & MRI technology
  - clinical imaging protocols and their methods of optimization

Initial MRAP Applications


 Estimate of initial applications based on numbers of units submitting MRAP phantom studies for review.

MRI Accreditation Standard Phantom Design Goals
- Easy to Use
  - Multiple inserts
  - Not too bulky
  - Applicable to all MRI systems
- Moderately Priced
  - $1050

ACR Standard MRI Phantoms

MRAP Standard Phantom Models
S/N 2256
S/N 2857
ACR MRAP Small Phantom

Small version of standard ACR MRAP phantom – designed for use in clinics that have dedicated extremity imagers that allow application for ACR Accreditation of knee module only.

MRAP Small Phantom Specs

- inside length 100 mm
- inside diam. 100 mm
- filled with a solution of NiCl & NaCl
  - 10 mM NiCl₂ and 0.45% by weight aqueous NaCl.
  - A separate vial is filled with 20 mM NiCl₂ but no aqueous NaCl.

Sagittal image show positions for seven slices acquired with small ACR MRAP phantom.

MRI Phantoms: General Features

- Nonsignal-producing container
- Proton density similar to water
- Shorten T1: NiCl & CuSO₄
- Mimic Conductivity of tissues: NaCl
Phantoms Developed by Users

- Uniform Spherical Phantoms
- Agarose Gel Phantom with Inserts

Responsibilities of the Medical Physicist / MRI Scientist

- Write Purchase Specifications
- Perform Acceptance Testing
  - Baseline Measurements
- Determine Action Limits
- Set up Daily/Weekly QC Tests
- MRI equipment performance review

MRI Annual Performance Review

- Should be performed by a qualified medical physicist or MRI scientist
- Should be done at least once a year
- Also after major hardware repair and/or upgrades

Annual Survey Tests

- Magnetic Field Homogeneity
- Slice Position Accuracy
- Slice Thickness Accuracy
- Radio Frequency Coil Checks
  - Inter-Slice RF Interference
  - Soft Copy Displays (monitors)

See ACR MRI QC Manual
Magnetic Field Homogeneity

<table>
<thead>
<tr>
<th>Ideal Homogeneity</th>
<th>Good Homogeneity</th>
<th>Poor Homogeneity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denotes a totally uniform magnetic field. All signal is at resonant frequency, $\omega_0$.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fourier transform of signal produces a Lorentzian peak in well-shimmed magnet</td>
<td></td>
<td></td>
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<tr>
<td>Magnet field homogeneity can be characterized using FWHM of resonance peak</td>
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</table>

Is it required to perform the homogeneity test for the annual system performance evaluation?

- Yes, a homogeneity test of some kind is required as part of the annual system performance evaluation for all accredited magnets, and those applying for accreditation.
- The ACR QC Manual describes this in the Medical Physicist’s/MR Scientist’s section.

If the methods in the QC Manual can’t be performed, a field map or equivalent field homogeneity assessment that has been performed within the last 12 months from the service engineer may be submitted.

The QMP/MRS may use alternate method of accurately assessing homogeneity but must include a description of the methodology.
Overall, the phase mapping technique provides the best mechanism for evaluating field homogeneity.

Phase-maps in several planes can be obtained to determine the spherical harmonic coefficients and allows a means of “shimming” the magnet.
Bandwidth-Difference Method

\[ MFH(x, y) = \frac{BW_1 \cdot BW_2 (d_1 - d_2)}{\gamma \cdot FOV \cdot (BW_2 - BW_1)} \]

- The MFH is measured from the change in distance between landmarks in the phantoms between the two bandwidths.
- FOV = field of view in m
- \( \gamma = \gamma/2\pi = 42,567 \text{ Hz/mT} \)

Optimization of Parameters

![Graph showing optimization of parameters]

- FOV = 330 mm
- \( d_1 - d_2 = 1 \text{ mm} \)

Magnetic Field Homogeneity

- For some systems, service personnel may provide use of phase-mapping acquisition and analysis tools.
- Filmed copy of vendor’s final homogeneity map and shim coefficients is useful for documenting initial conditions and establishing a baseline.

Radio Frequency Coil Checks

- Volume coils
- Signal-to-noise ratio
- Percent integral uniformity
- Percent signal ghosting
- Surface Coils Maximum SNR Tests
Bird-Cage Head Coil

RF coils produce uniformity patterns characteristic of their design.

Volume RF Coil Measurements

ACR Phantom Slice #7

Image Intensity Uniformity

- Performance criteria: PIU ≥ 87.5% except 3T (82%)
- Percent integral uniformity = $100 \times \left(1 - \frac{\text{high} - \text{low}}{\text{high} + \text{low}}\right)$
- Measurement Considerations:
  - Display may not show signal values
  - Display may not allow user to set signal display level
  - There may not be a well-defined high/low intensity level

Percent Integral Uniformity - T1-Weighted

Date of Measurement
**Percent Integral Uniformity - T2-Weighted**

Date of Measurement

<table>
<thead>
<tr>
<th>System #1</th>
<th>System #2</th>
<th>System #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>30%</td>
<td>40%</td>
<td>50%</td>
</tr>
<tr>
<td>60%</td>
<td>70%</td>
<td>80%</td>
</tr>
<tr>
<td>90%</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

**Uniformity Patterns**

Birdcage Coil
- High Field
- Solenoid Coil
- Low Field

**Uniformity at 3 Tesla**

- B1 field maps in a conductive saline phantom (18 cm diameter)

**Phased-Array Coils**

- The signal is viewed from more “angles”
- Using four channels does not produce $\sqrt{4} \cdot S/N$

**Abdomen-pelvis phased-array**

**Cervical-Cranial Phased Array**

**RL Greenman et al. JMRI 2003, 17(6): 648-655**
Surface RF Coil Measurements

Volume Coil Data

<table>
<thead>
<tr>
<th>% Image Uniformity</th>
<th>Max Signal</th>
<th>Min Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal-to-Noise</td>
<td>Mean Signal</td>
<td>SD of Background Signal</td>
</tr>
<tr>
<td>Percent Signal</td>
<td>Ghost Signal</td>
<td>Mean Signal</td>
</tr>
<tr>
<td>Ghosting</td>
<td>Background Signal</td>
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Surface Coil Data

<table>
<thead>
<tr>
<th>Maximum Signal-to-Noise</th>
<th>Maximum Signal</th>
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<tbody>
<tr>
<td>Noise</td>
<td>SD of Background Signal</td>
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MRI Physics Assistants

- QMP/MRS may be assisted in obtaining QC test data by properly trained individuals.
- These individuals must be trained and approved by the QMP/MRS in the:
  - techniques of performing the tests
  - function and limitations of the imaging equipment and test instruments
  - reasons for the tests
  - importance of the test results.
- The QMP/MRS must review and approve all measurements.

MRI QC Program Roles

- MRI Physicist
  - runs baseline tests of system performance
  - sets action criteria for routine ACR phantom tests
  - performs annual calibration checks with appropriate phantoms
  - reviews QC program
MRI QC Program Roles

- Technologist
  - Performs daily tests to assess image quality using ACR phantom
  - Weekly checks of hard copy output
- All measurements made, problems discovered, and actions required to resolve the problems are recorded for review

Summary

- As of June 2009, ACR’s MRAP has about 7000 participating sites
- The qualified medical physicist/MRI scientist plays an important role in the QC aspects of the MRAP
- The ACR phantom is not adequate for all QC test – the QMP/MRS must use other phantoms & methods
- MRI magnet homogeneity is an important but problematic test

Summary

- All radiofrequency coils must be tested in every mode of operation used clinically
- This may pose a challenge for newer, many-channel systems
- It is advisable to use coil manufacturer’s phantoms and tests where available
- ACR has posted all Testing & QC Forms for download at:
  http://www.acr.org/accreditation/mri/mri_qc_forms.aspx