MRI QC
The role of QC and protocolling for better clinical MRI

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Which of the following two conversations happen in your hospital?

* QC Tech to MR Tech:
  “Have you noticed low signal strength in the right side of the anterior portion of the Body RF coil array?”

* MR Tech to QC Tech:
  “Did this piece of {amazing technology} pass QC this week? It seems like I’ve been looking at PE ghosts in the cardiac coil scans for weeks now.”
Why should I do quality control (QC)?

Because you have to!

* The American College of Radiology (ACR) requires a series of measurements on weekly/annual basis for a site to be accredited.

* In the US, accreditation of sites has force of law (Medicare Improvement for Patients and Providers Act of 2008 (MIPPA)) and is required for sites to bill Medicare [1].

* In Canada, the Canadian Association of Radiologists (CAR) “highly recommends” sites follow the ACR guidelines [2].

* Most Canadian hospitals must satisfy Standard 16 from Accreditation Canada, requiring documented QC protocols for all DI equipment. Hospitals are audited regularly to enforce compliance.

[1]: http://www.acraccreditation.org/modalities/mri#s1
Preventative Maintenance (PM) is not Quality Control (QC)!

* Vendors have responsibility for quality assurance (designing robust equipment). This includes preventative maintenance to service vulnerable parts (water filters, table adjustments, system calibrations).

* Preventative maintenance involves some measurements that control quality (magnet field homogeneity, SNR tests for standard coil/sphere) but is not comprehensive (testing all RF coils).

* Quarterly PM is also not frequent enough for QC.
Where does quality come from?

Every stage from equipment purchase to radiologist performance!

* 1) Request for Proposal (RFP) design - what RF coils, what software.
* 2) MRI Acceptance – Was this MRI delivered meeting specifications?
* 3) MRI QC – Is this MRI just as good as it was last week/year (trends)?
* 4) MRI Protocolling – Do I have the correct scan parameters/sequences?
* 5) Radiologist Performance – ACR requires double reads with mutual agreement. Summary statistics specific to individual radiologists (Dr. X) and groups (eg. Halifax MSK radiologists relative to other MSK groups).

• All are important and frequently poor quality is ascribed to the wrong category!
• Focus on MRI QC and Protocolling today.
MRI Acceptance and QC
Now Performed Throughout Nova Scotia (10 MRIs)
The ACR requires 15 tests in total (8 weekly, 7 annually).

More tests can be added depending on the sites specialized applications (spectroscopy, fMRI) to fully evaluate systems (gradient, RF, static field).

Daily QC is not required, but a simple 5 minute SNR protocol (head coil, spherical phantom) is recommended if feasible. Vendors often supply a daily QC test with trending capability that can combat daily startup issues.
What is in the ACR phantom?
ACR recommends one person perform weekly QC per MRI if workflow permits. Use clear instructions and phantom positioners to encourage consistency otherwise (or also).

Example Label on Face of ACR Phantom

<table>
<thead>
<tr>
<th>PHANTOM AND COIL SETUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Use 32 Channel Head Coil with BOTH velcro pads IN PLACE.</td>
</tr>
<tr>
<td>2) Insert ACR phantom until contact with back pad.</td>
</tr>
<tr>
<td>3) Level phantom L/R with non-magnetic level provided.</td>
</tr>
<tr>
<td>4) Do NOT remove gauss pads under ACR (levels S/I direction).</td>
</tr>
<tr>
<td>5) Use thin blue foam wedges left/right of phantom for stability.</td>
</tr>
<tr>
<td>6) Landmark to ACR crosshair (not coil landmark). Laser half on/off grid edge.</td>
</tr>
</tbody>
</table>
How do I perform the ACR scan?

- Basic acquisition consists of 3 series (one sagittal slice, 11 axial slices using T1 and T2 weight sequence with precise parameters.
- For US accreditation, both T1 and T2 standard parameters (below), and site neuro T1 and T2 protocol required. Clinical images for various modules also needed.
- Receive BW of 16 kHz or higher OK at 1.5T or 3T.

<table>
<thead>
<tr>
<th>Study</th>
<th>Pulse Sequence</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>FOV (cm)</th>
<th>Number of Slices</th>
<th>Slice Thickness (mm)</th>
<th>Slice Gap (mm)</th>
<th>NEX</th>
<th>Matrix</th>
<th>Routine Receive Band-Width (kHz)</th>
<th>Scan Time (min:sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACR Sagittal locator</td>
<td>Spin Echo</td>
<td>200</td>
<td>20</td>
<td>25</td>
<td>1</td>
<td>20</td>
<td>N/A</td>
<td>1</td>
<td>256</td>
<td>256</td>
<td>0:56</td>
</tr>
<tr>
<td>ACR Axial T1</td>
<td>Spin Echo</td>
<td>500</td>
<td>20</td>
<td>25</td>
<td>11</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>256</td>
<td>256</td>
<td>2:16</td>
</tr>
<tr>
<td>ACR Axial T2 Double-echo</td>
<td>Spin Echo</td>
<td>2000</td>
<td>20/80</td>
<td>25</td>
<td>11</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>256</td>
<td>256</td>
<td>8:56</td>
</tr>
</tbody>
</table>
How do I perform the ACR scan?

- Position 11 slices with 1st and last slice intersecting the 45 degree crossed plastic wedges.
- If ACR phantom is not level (S/I direction), slices will not intersect wedges AND thin low contrast disks (slices 8-11).
- Use non-magnetic level to reposition if un-level.
- Consider building/purchasing a positioning system if challenging for your head coil.
How do I analyze the ACR data?

- There are 7 tests to perform from these measurements using the 1 sagittal and 11 axial slices from the T1 and T2 series.
- The measurements are very tedious and take approximately 20+ minutes to perform per dataset.
- Commercial packages for automated analysis exist to allow faster and more accurate analysis.
- Our site has adapted an open source Matlab package freely downloadable as a starting point to build a customized data analysis/archiving system. [http://jidisun.wix.com/osaqa-project](http://jidisun.wix.com/osaqa-project)
- 3 minutes to analyze each dataset and all data recording/trending within excel is automatic, requires no manual data entry, and is an archive satisfying regulatory needs. Data is pulled from dicom header (Transmit Gain, Analogue/Digital Gain, Center Frequency, Date scanned, System name).
ACR Test #1: Geometric Accuracy

- **Action Criteria**
  - 2 mm accuracy in lengths for all measurements.
  - Lasers within 5mm accuracy.
  - 1mm reposition accuracy.

- **Reasons for failure**
  - Gradient gain calibration.
  - Low receive bandwidth.
  - Strong Bo inhomogeneity.
ACR Test #2: High Contrast Spatial Resolution (HCSR)

- **Action Criteria**
  - Resolve 1mm or 0.9mm holes UL and LR

- **Reasons for Failure**
  - Poor eddy current compensation (gradient fidelity)
  - Excessive image filtering
  - Phantom motion (stabilize with pads or tighten positioner)
  - Excessive phase encode ghosting (RF or gradient stability)
ACR Test #3: Slice Thickness Accuracy

**Action Criteria**
- Slice thickness must be $5.0 \pm 0.7$ mm

**Reasons for Failure**
- Poor RF linearity distorts RF pulse shapes affecting slice thickness
  - RF amp droop
  - RF cable/switch failures at high power
  - Body Transmit RF coil failure
- Very poor gradient calibration

**What to do?**
- Threshold to 50% signal intensity
- Measure each length and divide by 10 (ramp has 10:1 slope)
ACR Test #4: Slice Position Accuracy

What to do:
- Threshold to 50% signal intensity
- Measure each length and calculate difference. Slice position error is half the difference (45 degree wedges).

Action Criteria
- 2 mm slice position accuracy is required for performing Test 7 (low contrast object detection).
- 1 mm reposition accuracy (Home->Advance to Scan repeat).

Reasons for failure
- Poor slice prescription.
- Failure in table positioning mechanism.
- Strong Bo inhomogeneity or terrible gradient calibration.
ACR Test #5: Image Intensity Uniformity

PIU = 88.013708%. Close Figure to Continue

What to do?
• Draw small ROI in hottest (red circle) and coldest (blue circle) part of slice 7.
• Compute percent image uniformity (PIU) as percent difference from mean of two ROIs.

Action Criteria
– PIU should be greater than 87.5% (1.5T) or 82% (3T).

Reasons for failure
– For array head coils, use surface coil intensity correction (SCIC) algorithms or similar.
– Phantom is not centered in coil (usually A/P). Remove/add pads.
– Severe phase encode ghosting (RF or gradient stability, phantom movement)
– Failure of RF coil elements or Transmit/Receive coil decoupling.
ACR Test #6: Percent Signal Ghosting

What to do?
• Draw pair of elliptical ROIs top/bottom (TB) and left/right (LR).
• Compute percent signal ghosting (PSG) as percent difference from TB and LR ROIs, divided by the mean of signal within the phantom.

Action Criteria
• PSG should be less than 2.5% for T1 and T2 series (slice 7).

Reasons for failure
• Phantom movement (stabilize with pads).
• Gradient or RF stability problems.
ACR Test #7: Low Contrast Object Detection (LCOD)

What to do?
- Threshold to best see 10 rungs of 3 circles
- Count number of rungs seeing all 3 circles (stopping when first failing).
- Add result from slices 8-11 (max score 40).

Action Criteria
- Score must be ≥ 37 for 3T, and ≥ 9 for 1.5T (typically 30 for 1.5T).

Reasons for Failure
- Poor slice prescription (more than 2mm error in test #4) or phantom tilt
- Low SNR (receive chain or RF coil problems).
- Phase encode ghosting from RF/gradient stability problems.
MRI systems essentially have 4 systems that must be well calibrated AND stable.

* **Gradients**
  * Eddy current compensation, amplifier gain drift, amplifier stability
* **RF Transmit**
  * RF amp linearity, cable/switch or RF transmit coil integrity
* **RF Receive**
  * RF coil or receive chain failure
* **Main Field**
  * Field homogeneity (shim)
  * Field drift (center frequency)
The ACR phantom/tests have been around for decades and modern scanners frequently pass several tests easily even with poor clinical image quality.

Modern applications (fMRI, DTI) have a particular premium on stability (fMRI) and gradient fidelity (DTI), so we have added two tests to capture issues with greater sensitivity.

* **EPI Stability**
  * 2 minute dynamic EPI timecourse with 1s frame rate to assess stability (RF, gradient). No acceleration and no coil intensity correction please (they spatially alter noise)!

* **DTI Calibration**
  * 6 direction b=1000 diffusion tensor image acquisition to observe slice stretch or shift from poor eddy current compensation.
EPI Stability Test (ACR phantom)

- **Action Criteria**
  - Greater than 10% change in SNR temporal stability
  - Greater than 50% outlier probability (abnormal image in time course)
  - Greater than 10% change in EPI Nyquist N/2 Ghost level.

- **Reasons for Failure**
  - Non-specific gradient/RF stability problems (very sensitive version of ACR test #6).
  - Phantom movement (stabilize with pads).
DTI Calibration Test

- **Action Criteria**
  - Root mean square (RMS) displacement and shift should be less than 1mm for DTI tracking.

- **Reasons for failure**
  - Poor eddy current compensation calibration (gradient fidelity).

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**What software does?**
- Measures L/R, Up/Down and diagonal distances and shifts.
- Reports RMS changes for 6 B=1000 diffusion direction scans.
Weekly ACR QC protocol

- Total protocol 16m 40s (under 20min including setup).
- Axial slices automatically copied from EPI multi-phase time-course to other series.
- Auto-scan allows no interaction after 1 min Sagittal localizer until pausing for final series (contrast flag pauses scanner).
- Final series requires a bed “Home” and “Advance to Scan” to test bed repositioning accuracy.
- Use a multi-channel head coil not a single channel transmit/receive coil so multiple receive channels and the main body RF transmit coil can be assessed weekly (not one channel only and ignoring Body RF coil).
### Data Archiving and Action Triggers

- Measurements are irrelevant unless they are acted upon.
  - Red highlight automatically for deviation from ACR or site physicist limits (Action required).
  - Yellow highlight automatically for deviations from mean beyond 1 SD (~33% of measurements for normal distributions). Watch trending.
- Measurements beyond ACR mandated ones (that provide regulatory support) must be evaluated for failure prediction as part of an MRI QC **Program**.

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<table>
<thead>
<tr>
<th>Date</th>
<th>Transmit Gain</th>
<th>Analogue Rec Gain</th>
<th>Digital Rec Gain</th>
<th>Center Freq</th>
<th>Table Reset Accuracy</th>
<th>Laser Slice Offset (mm+/-)</th>
<th>Patient Weight</th>
<th>EPI SNR</th>
<th>EPI Temporal SNR</th>
<th>EPI Signal to Ghost Ratio</th>
<th>EPI Outlier Probability</th>
<th>EPI PIU</th>
<th>EPI Low X</th>
<th>EPI Low Y</th>
<th>DTI Stretch</th>
<th>DTI Shift</th>
<th>Center Freq Offset</th>
<th>Center Freq Offset Detrend</th>
<th>Main Field drift</th>
</tr>
</thead>
</table>
Weekly QC purpose is to flag outliers for timely response.

Value also in comparing magnet baseline values.

- Valley lasers outside 5mm range.
- Yarmouth has highest EPI Outlier (white pixel artifact potentially).
- Sydney and HI 3T have non-zero Bo field drift (3T pure field offset, Sydney caused by linear supercon gradient term).
- IWK and Sydney have lowest EPI Signal to Ghost ratio (eddy current calibration?).
Annual Physicist Checks

* The ACR requires that all multi-channel RF coils be checked at least annually.
  * This is not always/often a part of vendor quarterly PM.
  * When first adopting this policy at a 1.5T site after 5+ years in service, 4 of 14 coils failed multi-channel coil checks (≥25%).
  * Intensity correction algorithms can hide this failure (elevated noise in failure regions)
  * Each coil takes approximately 15mins to setup/run the coil check.
* The ACR also requires magnetic field homogeneity (shim) be checked annually
  * This is typically part of vendor PM and tests can be reviewed for trends or accuracy.
What is an RF coil check?

* Precise arrangement of each multi-channel RF coil with phantoms, custom designed by vendor for this purpose, is required to accurately test performance of all channels.

* Data acquisition is usually in the service desktop, is available to the customer, and runs automatically with simple “Start” button-press.
What is an RF coil check?

- Signal Images made individually for each of 14 channels in Head-Neck Unit (HNU) coil
- Clinical scans combine these to a single image.
- SNR failure thresholds (red) for each channel are typically exceeded by factor of two (black) for healthy coils.
- Some elements have no failure threshold (zero SNR) but are tested by other slice positions (other setup configurations).
- SNR can fail due to loss of signal in an element, or dramatic increase in noise.
Province Wide RF Coil Check Results

* **Overall (10 MRIs)**
  * 89 coils
  * 121 configurations
  * 11 failures (12% failure rate)
  * 5 of 10 sites with failed coils (50%)

* **City (4 MRIs)**
  * 37 coils
  * 55 configurations
  * 9 failures (24% failure rate)
  * 3 of 4 sites with failed coils (75%)

* **Rural (6 MRIs)**
  * 52 coils
  * 66 configurations
  * 2 failures (4% failure rate)
  * 2 of 6 sites with failed coils (33%)

* **City Year 2 (2 MRIs – VG and HI 1.5T)**
  * 22 coils
  * 33 configurations
  * 2 failures (9% failure rate)
  * 1 of 2 sites with failed coils (50%)

* City failure rate much higher than rural (24% city vs 4% rural).
* Failure rate in city reduced from 24% to 9% from year 1 to 2.
Protocolling

“If you want 6 opinions just ask 5 neuroradiologists”
Dr. Matthias Schmidt
Protocolling has two important aspects.

* **Radiologists:** For each clinical indication, specify which series and contrasts will be performed (3D axial T2, pre and post contrast DCE etc).

* **Technologists:** For each series, what scan parameters will optimize image quality (acceleration factor, TE/TR, matrix size, FSE or Propeller, patient positioning in RF coil, breath-hold instructions).

Protocolling is a process that is ongoing **not** a one and done.

* New acquisition software, RF coils, changes in practice drive change in protocols.

* Convergence on optimized consistent protocols would benefit image quality and reduce repeat exams from various sites for local preference.
For each clinical section (body, MSK, neuro, etc) identify a lead technologist and radiologist.

- Technologist coordinates with radiologist to prioritize problematic protocols.
- Each magnet has 1 day/month unbooked until ~3 weeks prior for booking of appropriate patients for protocol refinement.
- Initially standard clinical series, plus a competitive alternate series (an alpha) are run. The alpha can differ for each patient until something looks promising.
- If a potential improvement is seen, an alternative day with this single protocol is repeated over at least 6 patients (beta test).
- Successful beta tests become the new clinical protocol (product).
- MRI physicist is a resource to technologist to identify potential alpha protocol parameters.
# Neuro protocols

Rebecca Jessome and Dr. Bob Vandorpe

## Protocol Table

<table>
<thead>
<tr>
<th>Protocol Number</th>
<th>Protocol Name</th>
<th># of series (exclude loc)</th>
<th>Recommended booking time (min)</th>
<th>Current booking time (min)</th>
<th>Current Status (ok, alpha test, beta test)</th>
<th>Issue Description (if status not “ok”)</th>
<th>Protocol Testing Date</th>
<th>Protocol Testing Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Brain-Aneurysm</td>
<td>5</td>
<td>30</td>
<td>30</td>
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<tr>
<td>2</td>
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<td>3</td>
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<tr>
<td>3</td>
<td>Brain-cerebrospinal</td>
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<tr>
<td>4</td>
<td>Brain-CSF Flow</td>
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<td>5</td>
<td>Brain-Epilepsy</td>
<td>8 (plus 5 optional)</td>
<td>453:607</td>
<td>60</td>
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<td>6</td>
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<td>7</td>
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<td>8</td>
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<td>9</td>
<td>Brain-Orbits</td>
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<td>ALPHA</td>
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<td>11</td>
<td>Brain-Routine</td>
<td>4 (plus 2 optional)</td>
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<td>12</td>
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</table>

## Issue Table

<table>
<thead>
<tr>
<th>Issue Number</th>
<th>Protocol Number</th>
<th>Protocol Name</th>
<th>Issue Open/Close Date</th>
<th>Issue Description</th>
<th>Attempted Solution</th>
<th>Results of Testing</th>
<th>Date of Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19, 21</td>
<td>Spine-C Spine, Spine-T Spine</td>
<td>Jan-17</td>
<td>Rads complaining of high signal folding artifact interfering with cord on C&amp;T Spines</td>
<td>Altering parameters to attempt to decrease artifact</td>
<td>Balanced all of the TE's on the spines</td>
<td>29-May-17</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rads satisfied with image quality, will keep flow comp on, do PD for MS, make sure techs know not to change ETLs (unbalanced TE's)</td>
<td>26-Jun-17</td>
</tr>
</tbody>
</table>
The ACR requires weekly and annual measurements be performed for accreditation.

Documentation (electronically ideally) is best accomplished with automated programs with clearly visible action triggers for measurements that exceed acceptable limits.

Quality comes from many stages including procurement, protocolling, QC and reporting.

Vendors speak in the language of systems (gradients, RF, main field homogeneity) while hospital QC tests involve measuring image artifacts. Translation to systems terminology can pinpoint issues for vendors facilitating timely service.

Using vendors tests when possible (RF coil checks, LV Shim field homogeneity) produces best vendor response when identifying failures.