Discussion paper on MRI Quality Control and Assurance across VBIC Nodes

Victorian Biomedical Imaging Capability (VBIC)

www.vbic.org.au

Table of Contents

Version: 1
Approved by: VBIC CC
Date of approval: Mar 2015

Discussion paper on MRI Quality Control and Assurance across VBIC Nodes

Disclaimer

The information contained in this document is a guide only and no VBIC or non-VBIC site is compelled to implement this guide. The VBIC Coordination Committee takes no responsibility for the success, failure, competence or capability resulting from the implementation of suggestions made in this document. All imaging facilities and imaging researchers should review this information in the context of their own ethics applications (and approvals), quality control, quality assurance, training and risk management strategies. Those seeking to implement this guide are advised to check it against their specific ethics approval(s) and their organisation's legal and insurance regulations.

What is QA/QC?

Quality assurance (QA) refers to the planned and systematic activities implemented in a quality system so that quality requirements for a product or service will be fulfilled. It is the systematic measurement, comparison with a standard, monitoring of processes and an associated feedback loop that confers error prevention.

Quality control (QC) is a process by which entities review the quality of all factors involved in production. QC focuses on the process outputs.

Why is QA/QC being considered for MRI data?

QA/QC is important to ensure production of high quality images:

- Minimally affected by non-biological variability
- Consistent with study protocols
- Consistent with previously obtained data during a study

Other benefits of routine QC include:

- Verification of operational integrity of imaging systems
- Early identification of technical issues
- Consistent quantitative accuracy

What does QC/QA involve?

Developing QC/QA for MRI data:

1. Determining factors that impact image quality
   E.g. this varies between anatomical imaging, fMRI or diffusion MRI
2. Determining important QC tests
3. Determining the image marker that will be used for QC tests
4. Determining the MRI image quality
5. Creating control limits to assess (pass or fail) MRIs; i.e. action limits
6. Determining a course of action to take

How will it impact my daily MRI schedule?

A properly designed and implemented on-site QC program should not require more than about 7 minutes per day for a daily program or 10 minutes per week.

If the technologist on the last shift places the phantom for the QC tests in the head coil before leaving, QC can be run overnight or can be the first scan of the next day and little effort is wasted in setup.

How is this document structured?

This document has the following components:

1. Guidelines on QC programs for MRI data – general guidelines to develop a QC program
2. Possible approaches – information on available phantoms for QC
3. Addendum – further information for your interest

Guidelines on QC programs for MRI data

Factors that impact image quality

It may seem obvious that if an MRI scan is adequate for qualitative interpretation by a radiologist, then it should be of sufficient quality to be used to extract quantitative metrics of brain pathology, however, this is not necessarily true.

The success of image-processing techniques can be significantly affected by spatial and/or temporal variability in MRI intensities resulting from methodological sources:

- Scanner and hardware/software upgrades
- Scanner hardware deterioration: scanner variability arising from variations in hardware performance (day-to-day variation)
- Human error (e.g. incorrect parameters within MRI sequence)

The resulting intensity variability can obscure pathological changes. This highlights the importance of assessing **image quality** of each MRI data set that enters an image-processing pipeline. To detect and control all factors that impact image quality, appropriate tests should be performed.

Important QC tests

QC procedures should have the flexibility to detect and report image quality issues that prevent the reliable calculation of a specific metric, without rejecting the entire scanning session as a whole. The QC procedure should objectively quantify the quality of an image and subsequently objectively reject images with quality metrics that do not meet software-specific *a priori* defined control limits.

QC tests can be determined using a semi-automated dynamic error identification procedure as outlined in figure 1.

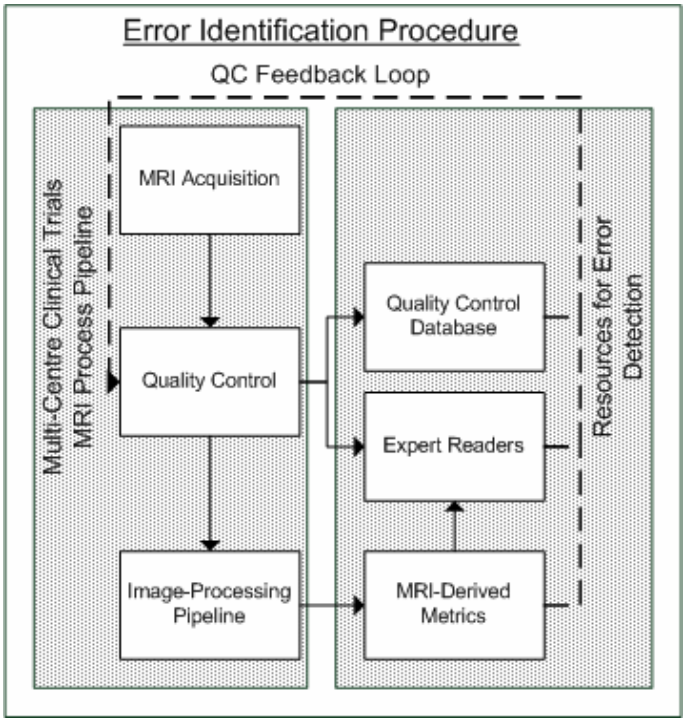


Fig 1. An error identification procedure that is used to detect poor quality MRIs. Here, expert readers experienced with MRIs, information within the QC database, and MRI-derived metrics are the primary resources to detect errors. Using a QC feedback loop, those errors are used to ensure that the tests in the QC procedure are current and effective.[3]

Expert MRI readers are trained professionals that have experience working on MR images. They are able to distinguish between visual artefacts and expected MRI variations. QC databases provide access to historical QC measurements that are especially important for identifying longitudinal inconsistencies.

Table 1 provides an example of a standardized QC tests and their frequency as set by the American College of Radiology Imaging Network (ACRIN) within the Centres for Quantitative Imaging Excellence (CQIE) MRI procedures.

Table 1. Example standardised QC – MRI[1]

Test	Minimum Frequency
Center Frequency	Weekly
Table Positioning	Weekly
Signal to Noise	Weekly
Artifact Analysis	Weekly
Geometric Accuracy	Weekly
High-Contrast Resolution	Weekly
Low-Contrast Resolution	Weekly
Magnetic Field Homogeneity	Quarterly
Slice Position Accuracy	Quarterly
Slice Thickness Accuracy	Quarterly
Radiofrequency Coil Checks	Annually

In deciding between daily and weekly QC, it is important to note that the latter will decrease the likelihood of spotting a problem by a factor of seven.

Image marker for the QC tests

QC tests use **imaging markers** to quantify the attributes associated with poor quality MRI data. Imaging markers are MR acquisition references that provide reliable, consistent, and representative information on the performance of the MR scanner and the fidelity of the MRI.
An overview of three types of commonly used imaging markers for QC with their advantages and limitations can be found in Table 1 of the Addendum.

MRI QC generally involves monitoring of system performance using phantom scans. A regular phantom scan followed by quantitative analysis provides the ability to detect subtle changes in image quality at an early stage, and to monitor long-term artefacts.

Possible approaches

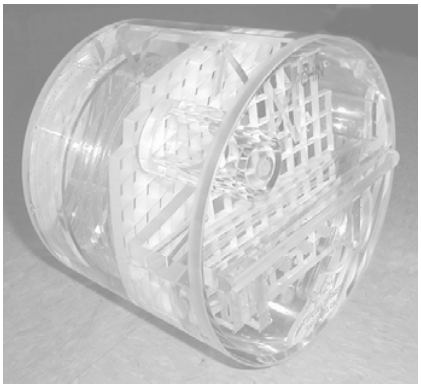
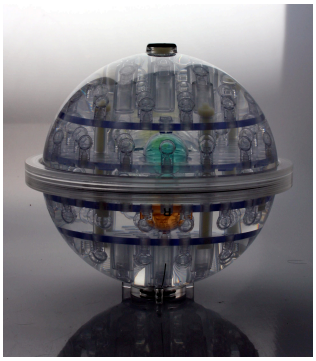
Summary of available phantoms for QC tests

There are two generally used phantoms on the market (see Table 2):

1. American College of Radiology (ACR) MRI phantom: this phantom is used for the quality control program that is part of the MRI accreditation program provided by ACR.
2. Magphan® Quantitative Imaging MRI phantom: this phantom was specially designed for the ADNI study that involves multiple MRI facilities. Within the study, the phantom is used for MRI site qualification.

Research is ongoing to develop standard, validated phantoms and processes for quantitative MR data (e.g. ISMRM-NIST phantom).

Table 2: Overview of the available phantoms

ACR phantom	Magphan® Quantitative Imaging phantom
	
General QC Measurements: ▪ Geometric Distortion ▪ Spatial Resolution ▪ Slice thickness and position ▪ Interslice Gap ▪ Estimate of Image Bandwidth ▪ Low Contrast Detectability ▪ Image Uniformity ▪ Signal-to-Noise Ratio (SNR) ▪ Physical and Electronic Slice Offset ▪ Landmark	QC Measurements: ▪ Precise Geometric Distortion across most of FOV ▪ Signal-to-Noise Ratio (SNR) ▪ T1 mapping (?)
Pro: • Accepted standards and documentation • Pulse sequences as compatible as possible with all commercial MRI scanners • Relatively cheap: US$2000 with carrier Cons: • Geometric distortion does not include whole FOV	Pro: • Detailed mapping of imaging distortion • Has been used in multi-site studies Cons: • Expensive: US$8000 • No general standards yet

References:

1. ACRIN – CQIE MR Procedures
   Source:
   http://www.acrin.org/CORELABS/NCICQIEQUALIFICATIONPROGRAM/SITEQUALIFICATIONMATERIALS.aspx
2. American College of Radiology website – MRI accreditation
   Source:
   www.acr.org/Quality-Safety/Accreditation/MRI
3. Gedamu E. 2011. Guidelines for Developing Automated Quality Control Procedures for Brain Magnetic Resonance Images Acquired in Multi-Centre Clinical Trials. Department of Biomedical Engineering and Montreal Neurological Institute, McGill University, Canada.
   Source:
   www.intechopen.com/download/pdf/14840
4. Georgetown MRI Reading Center (GMRC)
   Source:
   http://ebookbrowse.com/gmrc-sprint-mind-proposal-v4-doc-d31605880
5. Kuijer j et al. Protocol for regular Quality Control of MRI scanners in a clinical setting. Abstract ISMRM 2010
   Source:
   eta2.bio.cmu.edu/ISMRM/.../files/5074_1310.pdf
6. Bell RA. 2003. MRI QC: Nuisance or necessity. Imaging Economic
   Source:
   http://www.imagingeconomics.com/issues/articles/2003-11_12.asp
7. Wikipedia – The Free Encyclopaedia: definition on Quality Assurance and Quality Control.
   Sources:
   http://en.wikipedia.org/wiki/Quality_assurance
   http://en.wikipedia.org/wiki/Quality_control

ADDENDUM

Table 1. Overview of commonly used imaging markers

	Phantom	External Markers	MRI data itself
What	Phantom is brain-like in size and shape; fabricated using materials with relaxation properties conductive to MRI	small objects (e.g. cylinders, spheres); fabricated using materials with relaxation properties conductive to MRI	MRIs of normal control subjects or subjects enrolled in the trial
GOAL	Images should be: 1. consistent with images obtained at different sites 2. consistent over time at a given site	Properties of the markers are known: 1. tracking morphology and intensity changes over time 2. comparing QC parameters for different scanners	Images represent the actual imaging properties of the brain under the same scanning conditions. QC may be performed using image characteristics that would not be changed by the presence of pathology
How	Imaging of phantom at regular intervals using the same sequences; before and after every scanner-associated upgrade	External marker is placed with the subject at the time of acquisition.	Images are acquired regularly with identical sequences as prescribed by the protocol.
Advantages	• precise measurements of MR scanner performance parameters can be used for correcting MRI geometric distortions caused by magnetic field inhomogeneities and gradient nonlinearities in the scanner (Jovicich et al., 2006).	• Scanned at the same time as the subject • Markers are readily available • More feasible to implement in multi-centre clinical trials	• MRIs from subjects enrolled in the clinical trial may itself be used for QC • all scans for each modality are readily available • the measured QC parameters are indicative of the quality of the image from which the brain pathology metrics will be calculated

Limitations	• financial and time feasibility of phantom production and repeated scanning • variability in the fabrication procedure and composition of the construction materials (affects site-to-site measurements) • degradation of construction material over time (adds errors to longitudinal measurements) • the inability to represent the anatomical structures of real brain MRIs accurately (adds uncertainty to the interpretation of phantom based measurements in the context of real brain MRIs)	• variability in the fabrication procedure and composition of the construction materials (affects site-to-site measurements) • degradation of construction material over time (adds errors to longitudinal measurements) • the inability to represent the anatomical structures of real brain MRIs accurately (adds uncertainty to the interpretation of phantom based measurements in the context of real brain MRIs) • cannot detect spatially varying errors within the brain • necessity for consistent positioning to minimize spatial variability	• the ground truth of the normal control subject images is not known, but the biology is assumed to be stable and normal.
Examples	• American College of Radiology (ACR) MRI accreditation program – ACR phantom • European Community Concerted Action, National Electrical Manufacturers Association • (NEMA) • American Association of Physicists in Medicine (AAPM) • Alzheimer's Disease Neuroimaging Initiative (ADNI) – ADNI phantom • International Society for Magnetic Resonance in Medicine (ISMRM) – NIST phantom (under development)	• tubes filled with manganese chloride solution • tubes filled with copper sulfate solution • agar	