Protocol for Regular Quality Control of MRI Scanners in a Clinical Setting

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Introduction

MRI Quality Control (QC) testing involves monitoring of system performance using phantom scans. While the most direct QC is provided by an attentive technician continuously monitoring the clinical images for artefacts, 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 trends. In addition, geometric accuracy, relevant for e.g. radiotherapy treatment planning, can only be monitored by measuring phantom dimensions. The American College of Radiology (ACR) introduced an accreditation program in the United States in 1996, which includes weekly QC testing [1] with a dedicated phantom. While the manual image evaluation has proven feasible, a streamlined work flow including automated image analysis has potential to improve reproducibility and reduce workload. In literature, several set-ups for automated analysis have been published. However these involved long scanning times with multiple phantoms or phantom positions [2-3], manual image analysis combined with automated calculations and trend analysis [4] or were targeted at QC for multi-centre (brain) studies, lacking an on-site evaluation directly following the image acquisition [5-6]. Vendor-provided QC protocols are often available, but usually require phantom change or repositioning and do not allow easy review of trends.

The target of the current study was to develop a 15-minute clinical QC protocol including phantom set-up, (automatic) image evaluation, testing against action limits and administration of results. The ACR phantom was chosen because it has become a field standard for QC testing, and allows for accurate assessment of geometry along all gradient axes without phantom repositioning. The protocol was recently implemented in our hospital for weekly QC testing by our technicians, and for QC testing after a service action, on four MRI scanners from two different vendors.

Methods

Phantom set-up The ACR phantom was used [1]. On each MRI system, one phased array head coil was chosen for QC testing. To create a fast and reproducible phantom set-up, a phantom holder was designed and produced in-house for each coil.

Scan protocol [A] localizer (scan time 7s), [B] mid-saggital (scan time 12s, GRE, TR 20ms, TE 4.5ms, FA 25°, slice thickness 10mm, FoV 250mm^2, matrix 512^2, phase enc. H-F with 2 to 4° in-plane rotation), [C] 11-slice tra (scan time 2:12s, T1-w SE, TR 500ms, TE 20ms, slice thk/spc 5/5mm, FoV 256mm^2, matrix 256^2), [D] single tra slice at plain water section of the phantom with same parameters (scan time 2:12s), but with uncombined coil images and no correction of geometrical distortion (in case correction is required for accurate geometry on series B and C). Total scan time was less than 5 minutes.

Image analysis Images were sent to a server by DICOM transfer. The analysis software includes a DICOM receiver (DCMTK), image analysis modules (written in Matlab, The Mathworks) and web-based reporting. This allowed review the QC results within 2 minutes after scanning. The reports included trend plots for easy review of historical data in relation to action limits. The following parameters were included: transmitter amplitude and frequency, SNR for combined and uncombined coil images (calculated on series D from mean in phantom signal ROI and SD in background ROI, see Fig. 1 for ROI positions), ghosting, and percent image uniformity (PIU), all as defined in the ACR manual [1]. Geometry was measured using edge-detection en ellipse fitting on the transverse images to quantify the horizontal (X) and vertical (Y) diameter of the phantom, and using edge detection followed by a Radon transform for the saggital image to measure the length (Z) of the phantom. The Radon transform makes the analysis insensitive for in-plane rotation, which was deliberately introduced to allow sub-sampling of the phantom edges.

Action limits Action limits were based on either a deviation from a reference period (constancy testing, e.g. for SNR) or absolute specifications (e.g. for geometry). The action limit definitions were chosen at 'clinically relevant' levels. This implies that the chosen values for action limits are debatable and dependent on both scanner performance and clinical application. For example, a scanner of which the images are used for treatment planning of stereotaxy or gamma-knife (radiotherapy), or navigated neurosurgery, require a higher degree of geometrical accuracy.

Reproducibility QC testing is only sensitive and specific if the reproducibility is good when compared to the action limits. The total variance of repeated measurements including phantom repositioning, planning of slices, random (image) noise and short term stability of one scanner was estimated by repeating the protocol ten times.

Results

The described protocol has been implemented on 4 clinical scanners from two vendors. The results of the reproducibility study of one scanner are presented in Table 1. Generally the short term reproducibility shows that "acceptable" action limits are set at 3 SD or more. Most critical parameters are probably SNR and the geometry limits of ±1mm when images are used for stereotaxy. Preliminary results for long-term reproducibility indicate similar results on the other three scanners.

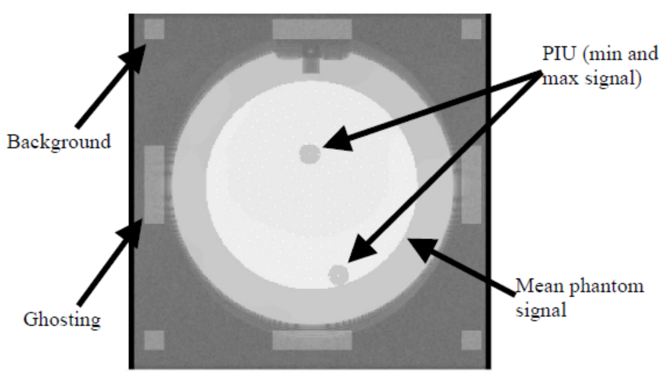

Figure 1: Overlay of ROI positions on plain water section of the ACR phantom.

	Mean	SD {% of mean}	Action limits (acceptable / critical)
Tx Frequency [MHz]	127.76	4.90 ·10^{-6}	0.04 / 0.1% per month
Tx Amplitude [a.u.]	125	0	15 / 30% *
SNR combined image	612	20 {3.3%}	10 / 20% *
SNR uncombined image	340	8.5 {2.5%}	15 / 30% *
Ghosting PE [%]	0.14	0.04	0.5 / 1
Ghosting FE [%]	0.13	0.01	0.5 / 1
Image Uniformity [%]	84	0.24 {0.3%}	2 / 5%
Diameter X [mm]	190.07	0.01	190 ± 2 / 3 **
Diameter Y [mm]	189.74	0.03	190 ± 2 / 3 **
Length Z [mm]	147.36	0.02	148 ± 2 / 3 **

Table 1: Short term reproducibility of one scanner and proposed action limits. Action limits in % are percentage of mean of a 'reference' period.. for quantitative MRS: 5 / 10% ** for stereotactic treatment planning in radiotherapy: 0.5 / 1mm*

Conclusions

The presented protocol is a vendor-independent solution for fast and automated QC testing. Most but not all parameters of the weekly ACR protocol were included. The contrast-resolution analysis was not implemented because it is covered by other tests (SNR, ghosting) that are much easier to implement in automated image analysis. Even though our protocol was largely based on the ACR protocol and phantom, all parameters apart from the Z-geometry may also be obtained with the same automated analysis methods, using other phantoms such as standard vendor-supplied spherical or cylindrical phantoms. The method also complies with IEC 62464-1 for constancy based QC testing. Scan protocols and analysis for B_0 mapping are currently being developed (scan time ~30s). For fMRI research, additional tests such as Weisskoff plots [7] may be added. The server-based QC pipeline can also be extended for other imaging modalities such as CT and mammography.

References

[1] ACR 2004 MRI Quality Control Manual. [2] Firbank et. al, Br J Radiol (2000) 73:376. [3] Ihalainen et al, Eur Radiol (2004) 14:1859. [4] Di Nallo et al, J Exp Clin Cancer Res (2006) 25:121. [5] Fu et al, MICCAI (2006), LNCS 4191:144. [6] Gunter et al, Proc ISMRM (2007) 15: 2105. [7] Weisskoff, MRM (1996) 36:643.