Implementation of Quality Assurance program for Diffusion Weighted Imaging, employing ACR phantom, in large medical center setting.

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Introduction

Diffusion weighted imaging and measurement of apparent diffusion coefficient (ADC) is widely used in clinical diagnosis and treatment evaluation [1]. Therefore, it is important to perform quality assurance tests to ensure the measured ADC value is reliable. Recently, an ACR phantom based DWI QA method has been developed and validated [2]. Compared with QIBA DWI QA procedure, the new DWI QA is easier to implement and therefore more feasible in the clinical setting. In this work, we present the preliminary results of DWI QA using ACR phantom on a large fleet of clinical MR scanners. We demonstrate practicality and usefulness of this technique.

Methods

An ACR phantom based DWI QA procedure was integrated into the annual QA of clinical MR scanners. The scanning parameters were identical with our prior work [2] with minor adjustments: number of averages is 2, b=0, 500, and 1000 s/mm^2 (Table 1). The DWI QA scan was performed twice with different phase encoding directions (AP, RL). A total of 4 scans per scanner have been acquired. For each acquisition, three sets of images were reconstructed: source images, diffusion weighted (trace) images, and Apparent Diffusion Coefficient (ADC) maps. The temperature of the ACR phantom was measured pre-/post-scan with a commercial NIST traceable thermometer [Digi-Sense] (accuracy ±0.3°C) to calculate the expected ADC value. A total of 16 scanners including both 1.5T and 3.0T as well as 60cm and 70cm bore size, were surveyed and evaluated.

Bore size \ Field Strength	1.5T	3T
60 cm	5	2
70 cm	4	5

Four parameters were measured to evaluate the quality of DWI:

- ADC Accuracy,
- ADC Spatial Variation,
- DWI Geometry Accuracy (Image Misregistration and Distortion),
- DWI Percent Signal Ghosting (PSG)

ADC values were measured from five regions of interest (ROI's) at one central and four peripheral locations (Fig.1a) from the ADC map of a uniform region of the ACR phantom (slice #7). The measured mean ADC value (the average of five ROIs) was compared with the expected water diffusion coefficient corrected for phantom temperature [3].

ADC Spatial Variation was evaluated in both AP and RL direction (Fig. 1a).

$$SV_{AP/RL} = 100 \times \left(\frac{ROI_{Top/Right} - ROI_{Bottom/Left}}{ROI_{Top/Right} + ROI_{Bottom/Left}}\right)$$

DWI Misregistration was defined as a position shift in the phase encoding direction of the diffusion weighted image with b=1000 relative to the position of conventional spin-echo image (Fig. 1b and 1c).

Horizontal and vertical distortions were analyzed for the diffusion weighted image with b=1000. Image distortion is defined as a percent error of vertical and horizontal diameter relative to the actual phantom size of 190mm (Fig. 1b and 1c).

$$D_{AP/RL} = 100 \times \left|\frac{Diameter_{horiz/vert} - 190}{190}\right|$$

The DWI PSG was calculated (Fig. 1d) by placing four ROI's outside the phantom on the image with b=1000, in the same manner as recommended by ACR.

$$PSG = 100 \times \left|\frac{\frac{ROI_{right}+ROI_{left}}{2} + \frac{ROI_{top}+ROI_{bot}}{2}}{ROI_{center}}\right|$$

Results

The percent error of ADC value over 16 scanners was analyzed with respect to field strength and bore size (Fig. 2). There was no statistical correlation between ADC accuracy and field strength. However, ADC values for the 60 cm bore size demonstrated clear underestimation of ADC values, while the 70 cm bore scanners overestimated ADC values with a higher absolute error (-0.77% vs 1.12% respectively). Absolute error of ADC uniformity in vertical (AP) and horizontal (RL) directions were 0.59% and 0.4% respectively. Image uniformity didn't show statistical correlation with phase encoding direction, bore size, or field strength. Image Misregistration and Distortion have a better performance in the horizontal (RL) direction compared to the vertical (AP Mean Shift = 0.89 mm, RL Mean Shift = 0.62 mm, AP Distortion = 0.8 mm, and RL Distortion = 0.61 mm). Image ghosting demonstrated strong dependence on field strength. Mean PSG for 1.5T scanners was 1.75% while 3T showed significantly better performance with PSG = 0.76%. Graphical statistics of our data is shown on Fig. 2. Two scanners with mean ADC values of 1.7% and 2.5% (short bore) were considered for additional evaluation and recalibration. Short bore scanners showed low performance for all evaluated parameters and may be due to scanner design.

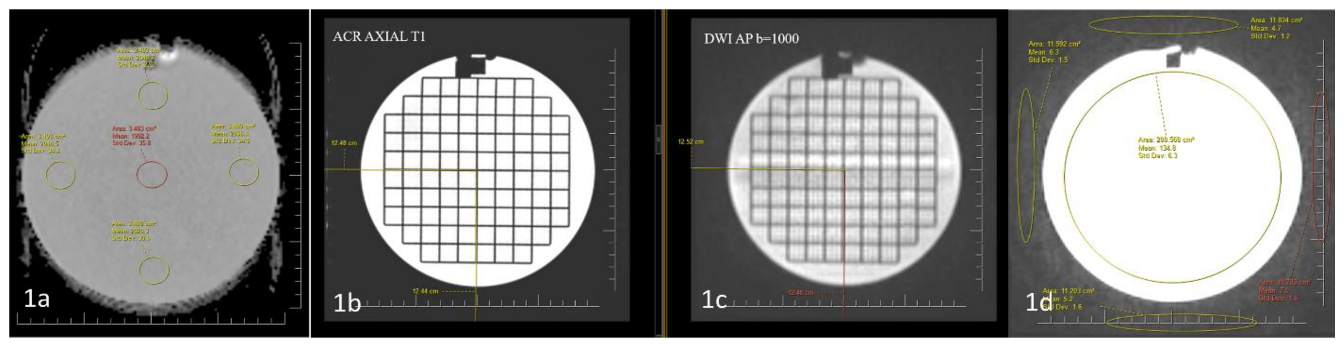

Figure 1a: ADC map of slice #7of the ACR phantom.
Figure 1b and 1c: Image Misregistration measurements on slice #5 of ACR phantom.
Figure 1d: DWI with b=1000 of slice #7 of ACR phantom.

Scan orientation	Axial
Sequence	Echo Planar (EP)
FOV	250x250 mm
Sequence variant	Segmented k-space/spoiled
Scan option	Partial Fourier – Phase/Fat sat
TR	5000 ms
TE	87 ms
Number of Averages	2
Number of phase encoding steps	95
Echo Train Length	47
Acquisition Matrix	128x128
Phase encoding direction	AP, RL
Slice thickness	5 mm
Spacing between slices	10 mm
Pixel Bandwidth	1395 Hz/px
b values	0,500,1000
Gradient mode	Fast

Table 1. Major scanning parameters for DWI QA procedure.

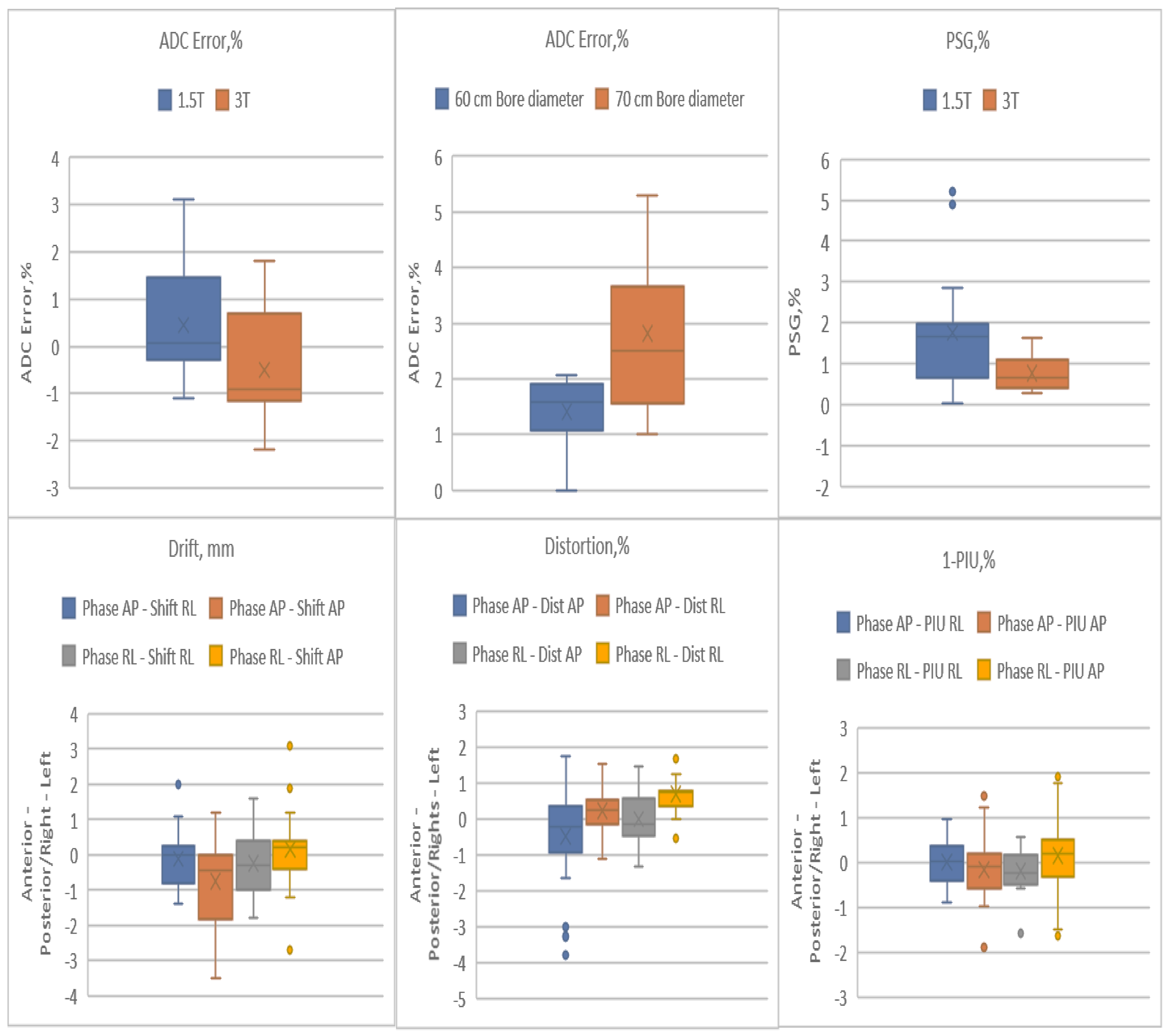

Figure 2. Summary of data collected from 15 clinical scanners. ADC percent error for 1.5T and 3T scanners (top-left). ADC percent error for 60 cm and 70 cm bore size (top-mid). PSG for 1.5T and 3T (top-right). Horizontal and vertical Misregistration (bottom-left) and Distortion (bottom-mid) for AP and RL phase encoding directions. Positive values indicate shift towards Posterior (vertical shift) or Right (horizontal shift). Negative values indicate shift towards Anterior or Left. Image Spatial Variation for AP and RL phase encoding directions (bottom-right).

Conclusion

The ACR phantom is available at many MRI facilities and does not require any preparation. Additional equipment includes an inexpensive thermometer for a phantom temperature measurement. Total acquisition and analysis time does not exceed 10 minutes. This simple, accurate, time efficient procedure is ideal for a routine DWI testing. To the best of our knowledge, this is the first time a DWI QA procedure was tested on a large number of clinical MRI scanners of different makes and models. It can be readily incorporated in the regular weekly, monthly or annual QA tests.

References

1. Dow-Mu Koh, David J. Collins. "Diffusion-Weighted MRI in the Body: Applications and Challenges in Oncology." American Journal of Roentgenology, 188, 1622-1635, 2007.
2. Cameron, Eric. "Quality Assurance of Diffusion Weighted Imaging: Comparison of a New ACR Phantom Based Method with the QIBA Method." RSNA 2017, Radiological Society of North America, Nov 26, 2017, McCormick Place, Chicago, IL. Conference Presentation.
3. Manfred Holz, Stefan R. Heil and Antonio Sacco. "Temperature-dependent Self-Diffusion Coefficients of Water and Six Selected Molecular Liquids for Calibration in Accurate 1H NMR PFG Measurements." Physical Chemistry Chemical Physics, 2000, 2, 4740-4742.

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