Quality Assurance of MR scanner on Diffusion Tensor Imaging

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Introduction:

Diffusion Tensor Imaging (DTI) is prone to artifacts [1] associated with EPI and strong diffusion encoding gradients. The eddy current and field inhomogeneity can cause significant deformation of the DTI images. The fast switching gradients in the DTI sequence leads to mechanical vibration [2] which degrades the quality of the DTI image and eventually causes inaccuracies in the of apparent diffusion coefficient (ADC) and fractional anisotropy (FA) values. Therefore, periodically assessing the performance of the scanner on the DTI sequence is the key to ensure a good quality of the DTI images and consistent results for longitudinal studies. To restrict the free flow of water and achieve the same ADC value as that of human brain, we used a spherical glycerin-gel phantom. which could be constructed to be similar to the human brain in (ADC, T2 and T1. Because ADC is very sensitive to temperature, the temperature of the phantom is controlled in the DTI quality assurance (QA) procedure.

Material and Methods:

A series of gel tube phantoms were made with a range of glycerin concentrations to determine the change of ADC and T2 accordingly. In addition, a 2 liter spherical phantom has also been made with a selected concentration: 1% Agarose, 15% glycerol and 84% distilled water. All studies were performed with an 8-element SENSE head coil at a Philips Achieva 3T scanner with gradient strength of 80 mT/m. The temperature controller (Neslab heat bath/circulator) was situated outside the scanner room circulating warm water through a plastic tube surrounding the phantom. The temperature distribution inside phantom was monitored by 2D spectroscopic imaging with FOV = 160 mm, matrix = 12*12, voxel size = 13.3*13.3*15 mm^3, TR = 2000 ms, TE = 35 ms. In each voxel, the frequency difference of the water peak (near 4.7 ppm and glycerin peak (3.57 ppm) reflected the local temperature, utilizing the temperature coefficient (0.0107 ppm/^oC) of the water proton frequency shift in pure water [3]. The DTI data were collected with the following parameters: 30 gradient direction [4] signal-shot spin-echo echo-planar DTI, FOV = 224 mm, in-plane matrix = 112*112, reconstruction voxel size = 1.75*1.75 mm^2, thickness = 2.00 mm, SENSE reduction = 2.0 along AP, TE = 51 ms, TR = 6318 ms, two b value, high b-factor = 1000. The T2 data were collected with a sequence described in the following: 2D spin-echo, eight echoes (20-160 ms, step = 20 ms), TR = 4000 ms, FOV = 130 mm, in-plane matrix = 128*128, reconstruction voxel size = 0.78*0.78 mm^2, thickness = 4.0 mm. The T1 of the samples was measured with an EPI inversion recovery method with multiple TIs from 100 to 5000 ms. Both phantoms were placed in the same room overnight to equalize the temperature. The region of interest (ROI) was selected manually at the center of each phantom, in each ROI the average intensity was computed for all eight images of different echoes, following by T2-value calculation through single-exponential least-square curve fit over the eight average intensities. The Philips Fiber Tracking software 4.1 Beta 4 has been used for ADC and FA calculations at the center of each phantom. To assess the image distortion, the distance between the center of b0 image and the center of each high-b image was calculated, which indicates the image shift under different diffusion gradients. The distortion of each DTI image can be measured individually by calculating the root-means-square of the difference (RMSD) between the ideal circle with averaged radius and real boundary of the image. The boundary detection and RMSD calculation were processed by home-made software written in IDL. The lowest limitation of the RMSD, which is not zero because of the pixelization of the DTI images, was calculated on a simulated image.

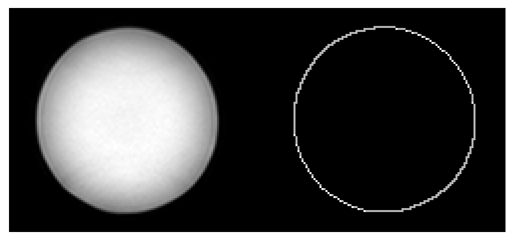


Figure 1: b0 image and the detected boundary.

Result and Discussions:

The T2 and ADC results on the series phantoms have been listed in the table 1. The result shows that ADC change significantly with the glycerol concentration, but only varies slightly with the agarose. The agarose concentration has major effect on T2 values. Mixing these two components together with the right concentration (gly 33% and agar 1%) gives us a value close to the physiological number on the white matter, i.e. ADC = 0.89 and T2 = 83.9 ms. The fractional anisotropy (FA) was small for all phantoms, which was expected for a homogenous phantom. Figure 1 shows the DTI b0 image of the sphere phantom and the detected boundary. The calculated radius is 45.70 mm and RMSD is 0.48 mm. Because of the pixelization of the DTI image, the limitation of the lowest RMSD is, in this case, 0.33 instead of 0.0 mm. After subtracting the RMSD limitation, the resultant relative RMSD was 0.15, which is a reasonable measure for the image distortion. The center shift and RMSD of high-b images were presented in Figure 2. Using the temperature control system, we raised the phantom temperature from 16^oC (magnetic room temperature) to 23 ^oC. After 90 minutes of equilibration, the temperature difference between the center and peripheral of the phantom drop from 7^oC to 2^oC.

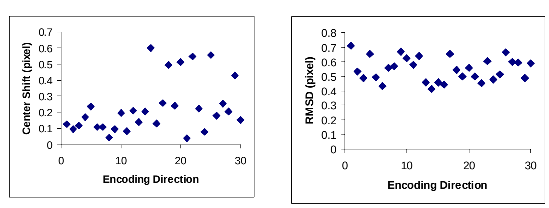
Table 1: phantoms with different concentrations of glycerin and agarose, and corresponding T2s and ADCs.

	1	2	3	4	5	6	7	8
distilled water (%)	100	98	99	89	84	79	74	66
glycerine (%)	0	0	0	10	15	20	25	33
agarose (%)	0	2	1	1	1	1	1	1
T2	2220	65.16	118.62	63.71	62.51	60.19	60.74	83.91
T1	3000	2700	2830	2330	1980	1850	1670	1310
ADC (10^{-3} mm^2/s)	2.17(0.01)	2.13(0.03)	2.11(0.02)	1.67(0.03)	1.52(0.02)	1.29(0.02)	1.17(0.04)	0.89(0.05)
FA	0.03(0.01)	0.05(0.02)	0.04(0.01)	0.05(0.02)	0.05(0.01)	0.08(0.03)	0.12(0.03)	0.02(0.06)

Conclusions:

Periodically acquiring the ADC, FA and RMSD values of a phantom provides a tracking record of a machine performance on the DTI sequence. The ADC value reflects the stability of a scanner on measuring diffusivity while the RMS represents the distortion of the DTI image. Both of them are essential to a quantitative DTI study. This work shows that a glycerol gel-filled spherical phantom is a feasible approach for the DTI QA.

Reference: 1. Ardekani S et al, .Magn Reson Med. 2005;54(5):1163-71; 2. Hiltunen J et al, Neuroimage 2006;32(1):93-103; 3. Hindman JC et al, J Chem Phys 1966;44:4582-4592; 3. Jones DK, Magn Reson Med. 2004;51(4):807-15;



Figire 2. Left is the center shift versus encoding directions while right is the RMSD against encoding directions.