Design of MRI-MRS Fused Phantom for Quantitative Evaluation of Metabolites and Enhanced Quality Assurance Testing

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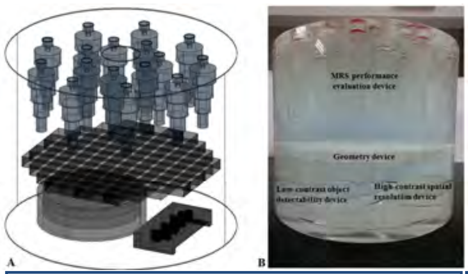

Fig. 1. (A) A scheme of perspective view of the MRI-MRS phantom, and (B) a photograph of the inserted phantom evaluation device

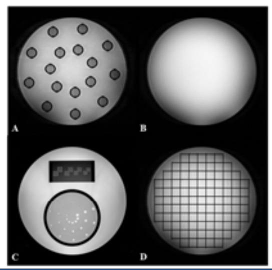

Fig. 2. T2-weighted images obtained from 2nd (A), 10th (B), 21st (C), and12th (D) slice.

TARGET AUDIENCE: Researchers and medical doctors interested in magnetic resonance imaging and spectroscopy (MRI-MRS)

PURPOSE: MR scanner is vulnerable to image quality problems, and quality assurance (QA) of the scanner is necessary. However, both quality control (QC) and QA protocols were not simultaneously implemented to obtain information on both MR images and spectra, and were performed on either images or spectra alone with MR phantom. Thus, the objectives of this study are to develop an MRI-MRS fused phantom along with the inserts for metabolite quantification and to conduct quantitative analysis and evaluation of the layered vials of brain-mimicking solution for QA performance, according to the localization sequence.

MATERIALS AND METHODS:

MRI performance evaluation The outer cylindrical phantom body (outer diameter: 210 mm, inner diameter: 190 mm, outer height: 170 mm, inner height: 150 mm) is made of acrylic materials (see Fig. 1). The section other than where the inner vials are located was filled with copper sulfate ($CuSO_4$, 0.7 g/L) and diluted with water so as to reduce the T1 relaxation time.[1] Reducing the T1 relaxation time allowed for stronger signal acquisition and decreased temperature dependence. In addition, sodium chloride (NaCl, 3.6 g/L) was included to provide conductivity similar to the human body.[2] The bottom part of the phantom was equipped with an array of high-contrast spatial resolution and low-contrast object detectability in order to evaluate both contrast and spatial resolution simultaneously. All measurements of MRI and MRS were made using a 3.0 T scanner (Achiva Tx 3.0 T; Philips Medical Systems, Netherlands) with a 32-channel sensitivity encoding (SENSE) head coil. The QA of MR imaging with the MRI-MRS phantom was referenced to the Phantom Test Guidance for the American college of radiology (ACR) MRI Accreditation Program. The MRI scan parameters were as follows: (1) spin echo (SE) T1-weighted image: repetition time (TR), 500 ms; echo time (TE), 20 ms; matrix, 256 × 256; field of view (FOV), 250 mm; gap, 1 mm; number of signal averages (NSA), 1; (2) SE T2-weighted image: TR, 2,500 ms; TE, 80 ms; matrix, 256 × 256; FOV, 250 mm; gap, 1 mm; NSA, 1; 23 slice images were obtained with slice thickness of 5 mm. Measurements of the MRI QA factors were conducted with the image processing toolbox in Matrix Laboratory (MATLAB, version 2012b).

MRS performance evaluation The watertight lid of the upper phantom consisted of the plug of the watertight lid, with a rubber-ring to eliminate artifacts such as leaking water and entering air. The inner vials were inserted around the watertight lid center and were intended for quantitative analysis of metabolites by inserting as many as possible to reduce air artifacts of vials, respectively. The water signal of each volume of interest was suppressed by variable pulse power and optimized relaxation delays (VAPOR) applied before the scan.[3] By applying a point-resolved spectroscopy sequence, the MRS scan parameters were as follows: voxel size, 0.8 × 0.8 × 0.8 cm^3; TR, 2,000 ms; TE, 35 ms; NSA, 128. Data analysis using signal processing was conducted with raw data, including time-domain data of the linear combination of model spectra (LCModel; Stephen W. Provencher) for quantitative analysis of the brain-mimicking solution vial for optimal detection.

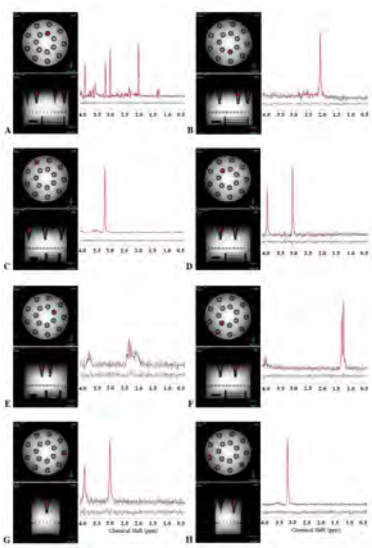

Fig. 3. Representative proton MRS of each vial with brain-mimicking solution

RESULTS: Geometric accuracy with image distortion was conducted with an acceptance value of ± 2 mm in slice 10. Fig. 2 shows a significant error in the sagittal view of end-to-end length (149.68 ± 0.0059 mm) and percentage of distorted length (0.99 ± 0.0059%) due to either a shimming problem or an inhomogeneity distortion in the phantom. The image intensity uniformity in slices 11 and 12 showed little change in mean and standard deviation values (<1%) in the identical position and ROI. The intensity in the T2 image of slice 11 has an equivalent PIU of 83% of the acceptance value (82.61 ± 1.71%), with percent image uniformity (PIU) of the 2nd, 6th, and 7th tests <82%. The PIU of the 1st and 5th tests was 80–82%, and for the 3rd and 4th was >82%, the acceptance value. The ghosting level of T1-weighted images was 0.025 (0.025 ± 0.004%), with a minimum value of 0.018. The average low-contrast object detectability in the T2 series was 28.1 ± 0.8, and for the T1 series was 27.6 ± 0.8, with >27 being the acceptance value for resolved holes in noise. Results of the evaluated MRS QA factors are presented in Table 1 and Fig. 3. The chemical shift stability with the minimum value of 0.065 ppm was compared with the maximum value of 0.121 ppm. The full width at half maximum was measured from the highest value of 3 Hz (2.42 ± 0.53 Hz). The water suppression was more than 99% (99.30 ± 0.20 %). The signal-to-noise (NAA) of the brain-mimicking solution was as follows: 1st test, 46.24; 2nd test, 42.02; 3rd test, 30.32; 4th test, 43.15; 5th test, 45.46; 6th test, 40.19; 7th test, 46.54.

DISCUSSION AND CONCLUSION: The QA of the MRI-MRS phantom was both accurate and consistent within the acceptance range. It is important to consider variation of the QA value using the MRI-MRS phantom in relation to other clinical or research MR scanners. The simultaneously obtained MRI-MRS QA factors derived from the phantom can facilitate evaluation of both images and spectra, suggesting guidelines for obtaining both the MRI and MRS QA factors simultaneously.

Table 1. Analysis of metabolite ratios with CRLB calculated of brain mimicking solution

Metabolite	NAA	Glu	Cr	mIns	Lac	Cho
Ratio (/Cr)	1.24±0.08	1.25±0.08	1.00	0.78±0.06	0.35±0.02	0.25±0.01
%SD	4.71±1.50	9.29±1.80	6.29±3.25	7.71±1.98	13.00±3.42	8.14±3.02
Concentration (mM)	12.47±0.72	12.58±1.04	10.08±0.59	7.94±0.73	3.57±0.41	2.53±0.20

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