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Design of a fused phantom for quantitative evaluation of brain metabolites and enhanced quality assurance testing for magnetic resonance imaging and spectroscopy

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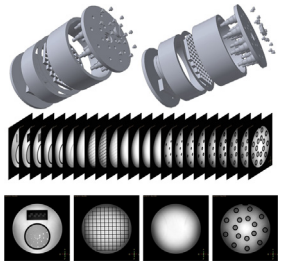
HIGHLIGHTS

- We developed an MRI–MRS fused phantom with metabolite quantification inserts.
- Clinical QA guidance was optimized with performance parameters for both MRI and MRS.
- We conducted quantitative analysis and evaluation in brain-mimicking solution.

GRAPHICAL ABSTRACT



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ABSTRACT

Background: Magnetic resonance imaging and spectroscopy (MRI–MRS) is a useful tool for the identification and evaluation of chemical changes in anatomical regions. Quality assurance (QA) is performed in either images or spectra using QA phantom. Therefore, consistent and uniform technical MRI–MRS QA is crucial.
New method: Here we developed an MRI–MRS fused phantom along with the inserts for metabolite quantification to simultaneously optimize QA parameters for both MRI and MRS. T1- and T2-weighted images were obtained and MRS was performed with point-resolved spectroscopy.
Results: Using the fused phantom, the results of measuring MRI factors were: geometric distortion, <2% and ±2 mm; image intensity uniformity, 83.09 ± 1.33%; percent-signal ghosting, 0.025 ± 0.004; low-contrast object detectability, 27.85 ± 0.80. In addition, the signal-to-noise ratio of *N*-acetyl-aspartate was consistently high (42.00 ± 5.66).
Comparison with existing methods: In previous studies, MR phantoms could not obtain information from both images and spectra in the MR scanner simultaneously. Here we designed and developed a phantom for accurate and consistent QA within the acceptance range. It is important to take into account variations in the QA value using the MRI–MRS phantom, when comparing to other clinical or research MR scanners.
Conclusions: The MRI–MRS QA factors obtained simultaneously using the phantom can facilitate evaluation of both images and spectra, and provide guidelines for obtaining MRI and MRS QA factors simultaneously.

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1. Introduction

Magnetic resonance imaging (MRI) can evaluate the anatomical status of a wide variety of physical and chemical changes that occur in the human body. Moreover, MRI is used as a tool to obtain information on the identification and quantification of metabolites. However, MR scanners are vulnerable to image quality problems (i.e., incorrectly positioned slice errors, B_0 inhomogeneity, low resolution, and ghosting artifacts due to movement or vibration of subjects); thus, quality assurance (QA) is necessary (Ihalainen et al., 2011). Currently, MRI scanner monitoring is generally performed according to the standard American College of Radiology (ACR) (1998) MRI accreditation program (http://www.acr.org). The ACR MRI phantom works using a protocol designed to accurately analyze clinical scanners and interpret their performance results (Chen et al., 2004). The QA protocol for the ACR MRI phantom indicates the acceptable error range using seven important quantitative tests (i.e., high-contrast spatial resolution, geometric, slice thickness and slice position accuracy, image intensity uniformity, percent-signal ghosting, and low-contrast object detectability) in images acquired with an MRI scanner. These quantitative tests are used to assess the clinical and technical quality of images from several MRI scanners in hospitals (Ihalainen et al., 2011).

Specialized MR phantoms such as the human head phantom for functional MRI QA (Adaszewski et al., 2010), the multipurpose phantom for testing radio frequency transmit and receive fields and magnetic field homogeneity (Roe et al., 1996), and the uniformity/linearity phantom (Price et al., 1990) have been developed, and can be applied in clinical MR scanners. The ACR MRI phantom has recently been used for QA of standard and diffusion tensor imaging (DTI) (Wang et al., 2011; Lee et al., 2014). However, the ACR MRI phantom cannot evaluate the performance of advanced MRI, including spectroscopy (Keevil et al., 1995). Although manufacturers of human and animal MRI scanners have provided an MRI and magnetic resonance spectroscopy (MRS) QA phantom, limited evaluation factors are available because the quantification of a specific metabolite cannot be evaluated. Furthermore, little information is available regarding MRS testing, which is a commonly used technique that provides complementary information for the monitoring of disease diagnosis and treatment in patients.

A QA phantom for MRS, which contains information on biochemical metabolites, was developed to establish a QA test for the quality of clinical devices and to improve MRS QA factors (i.e., signal-to-noise ratio of N-acetyl-aspartate, chemical shift stability, water suppression percent, line width of water peak, volume of interest accuracy, and symmetry) that quantitate the accuracy of metabolite concentration (Bovée et al., 1995; Calvar, 2006; Rice et al., 1998). However, both quality control (QC) and QA protocols are not simultaneously implemented to obtain information from MR images and spectra, but are performed on either images or spectra alone using MR phantom. Therefore, consistent and uniform technical MRI–MRS QA is crucial (Ihalainen et al., 2011).

The aims of this study were: (1) to develop an MRI–MRS fused phantom and containers for metabolite quantification; (2) to simultaneously optimize QA parameters of both MRI and MRS using the fused phantom; and (3) to conduct quantitative analysis and evaluation of the layered containers with a brain-mimicking solution for QA performance, according to the localization sequence.

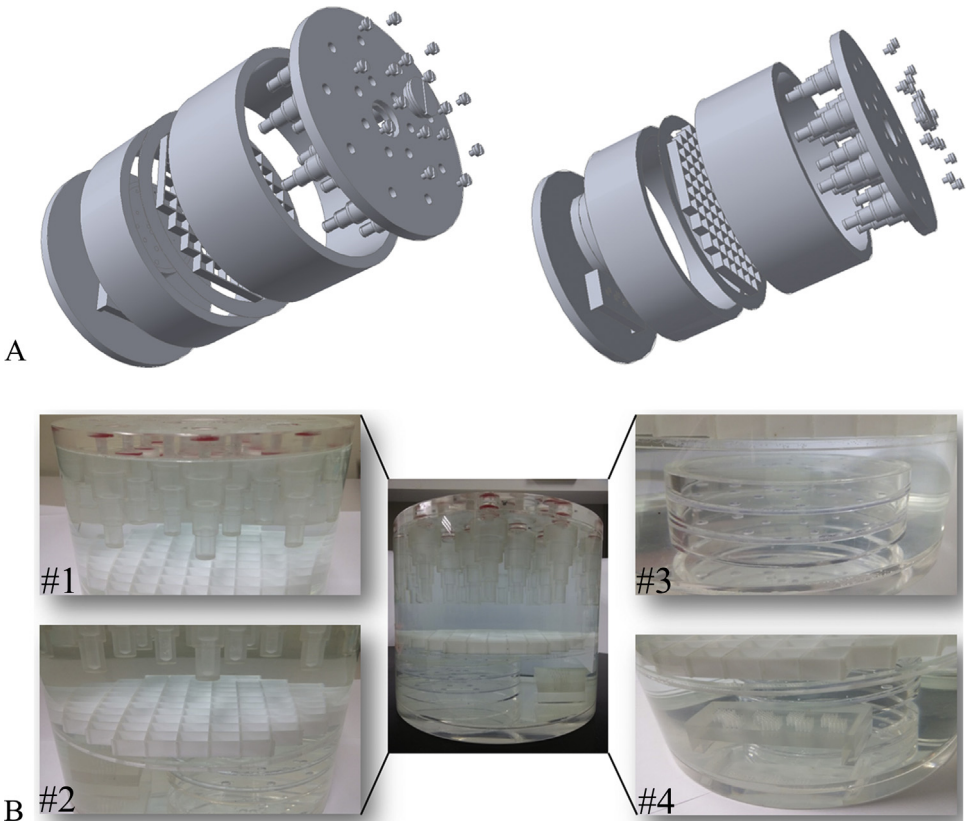

Fig. 1. Phantom design and appearance. (A) A scheme for the MRI–MRS phantom, and (B) a photograph of the phantom (no. 1, MRS performance evaluation device; no. 2, geometry device; no. 3, low-contrast object detectability device; no. 4, high-contrast spatial resolution device).