Quantitative Magnetic Resonance Imaging Phantoms: a Review and the Need for a System Phantom

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Abstract: Clinical use of quantitative imaging can be facilitated through the use of standard system phantoms (calibration/standard reference objects) to assess performance of MRI machines. The ISMRM Ad hoc Committee on Standards for Quantitative Magnetic Resonance (SQMR) was established in February 2007 to provide a framework for MR phantoms. This contribution summarizes a paper, written by members of the SQMR, about the state of the art and the need, requirements, and implementation plan for a standard system phantom for quantitative MRI.

Zusammenfassung: Standardisierte System-Phantome (Kalibrierungsobjekte) für die Bewertung der Leistungsfähigkeit von MR-Tomographen können zur einer verstärkten klinischen Anwendung quantitativer Bildgebung beitragen. Für die Entwicklung von Rahmenvorgaben für Phantome wurde im Februar 2007 das „Ad hoc Committee on Standards for Quantitative Magnetic Resonance (SQMR)" der ISMRM gegründet. Dieser Konferenzbeitrag ist eine Zusammenfassung eines von SQMR-Mitgliedern geschriebenen Papers, das zum einen den Stand der Technik von MR-Phantomen beschreibt und zum anderen auf die Notwendigkeit und die Erfordernisse eines Standard-System-Phantoms für quantitative MR-Bildgebung eingeht.

Introduction

Over the past two decades, interest in the use of magnetic resonance (MR) biological markers (or "biomarkers") to provide information critical to the development of novel therapeutic agents and improved clinical diagnostics has grown. Biomarkers (1) are objectively measured parameters that indicate biological state, biological/pathobiological processes or pharmacologic responses to treatment. Examples of MR biomarkers include tumor volume, brain volume, functional network connectivity, isotropic or anisotropic water diffusion constants, local metabolite concentrations, blood flow fields, fat fraction, lung function, temperature, tissue elasticity and relaxation times (T1,T2). Measuring these biomarkers requires quality assurance using MRI phantoms (cf. Fig.1).

System Phantom Design Considerations

The following quantities can affect the accuracy or precision of measurement in MRI studies and are candidate quantities to be evaluated by a system phantom. Some quantities such as B_0, B_1, and gradient non-uniformity are primary factors that affect other quantities, such as SNR, slice profile, etc.

- B_1 (Transmit) Non-uniformity
- B_1 (Receive) Non-uniformity
- B_0 Non-uniformity
- SNR
- Image Uniformity
- Gradient amplitude
- Geometric linearity
- Slice position and profile
- Contrast compartments
- High contrast resolution
- System constancy

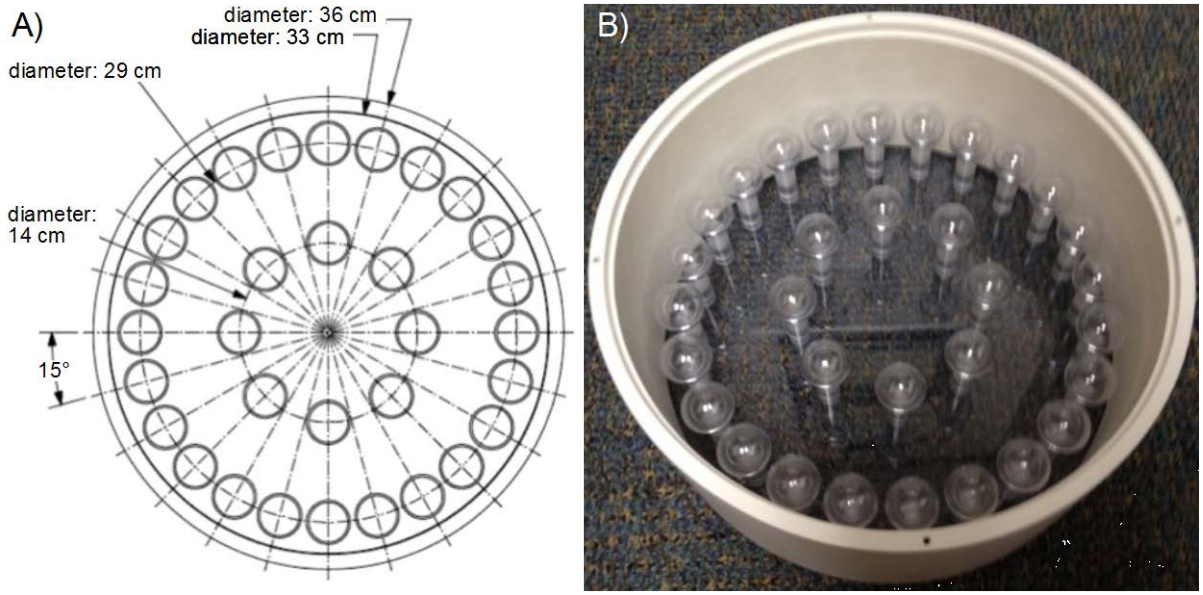

Fig. 1: A diagram (A) and an image (B) of the QIBA DCE-MRI Phantom. The inner set of 8 spheres, referred to as the vascular input function (VIF) spheres, is distributed around a 14.0 cm diameter circle. The remaining 24 spheres are uniformly distributed around a 29.0 cm diameter circle, and consist of 3 sets of 8 "tissue spheres" spaced at 45° increments, with each set having an R1 (=1/T1) range of 0.67 – 7.54 s^{-1}. The lowest R1 sphere in each set of 8 was positioned at 0°, 105°, and 210°, respectively, to produce three virtual rotations of the three sets of tissue spheres to facilitate the investigation of spatial signal dependencies arising within phased-array coils without the need to physically rotate the phantom between acquisitions.

The SQMR group has agreed on 15 specific design criteria that should be matched by MR phantoms, e.g. that all components should be in the public domain, including the phantom design, solid models, and material properties.

Current MRI Phantoms

The following developments have been reviewed: structural brain imaging phantoms, dynamic contrast enhanced MRI perfusion phantom, diffusion phantoms (cf. (2)), flow phantom, breast phantom, and proton density fat fraction phantom.

Conclusion

MRI system stability is required for implementation of quantitative MRI, especially to enable biomarkers for diagnostic use. A standardized MR system phantom will support the efforts of the quantitative MRI community, including RSNA QIBA and the NCI QIN. Research developments will be enabled by the system phantom, for example, acquisition and modeling for relaxometry (cf. (3)). A standard system phantom, with SI-traceable components that will be monitored for long-term stability by a national metrology institute, will further facilitate the use of MRI measurements as a biomarker. Most importantly, to support clinical use of quantitative MRI, such a phantom must be adopted by the user community and equipment manufacturers for regular use.

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