Exploring quality metrics for MRI imaging: comparing multiple reconstructions and measuring instrument calibration using low cost phantoms

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Introduction. We investigated MRI image quality metrics to help users of SWIFT[1] software validate their installation, and check the performance of their hardware and software. To do this, we compared the results of GRE, SWIFT MRI, and CT images of inexpensive lab-built calibration phantoms. We checked for geometric distortions, PSF, SNR, CNR, artifacts, contrast differences, and short T_2 sensitivity in the images. We also used these phantoms to check instrument calibration. Calibration is regularly tested in clinical settings, but the phantoms used are expensive and may not be available for all research instruments. CT was included in the study because it has standardized methods for measuring image quality, some of which we see as valuable in measuring MRI quality. Phantom build instructions, sample data sets, resulting images, and automated software to perform these checks will be part of the SWIFT software package distribution[2].

Methods. **Phantoms**. We wanted to develop highly accurate, easily reproducible, low cost phantoms (Fig 1). Accurate phantoms allow us to check reconstruction results and check instrument calibration. Easily reproducible and low cost phantoms allow any lab to validate our research, use our methods and validate hardware and reconstruction results. To build these phantoms, we used Legos, an inexpensive and widely available building block manufactured to 2-micron tolerances. We prepared two phantoms consisting of a stack of Lego blocks in an $MnCl_2$ solution sealed in plastic centrifuge tubes. The $MnCl_2$ concentrations were 2mM and 30mM, with T_2 relaxation times of a short 4 ms and very short 250 µs. **CT Images.** We imaged several phantoms using a Siemens MicroPET/CT system at 49 um resolution for geometric and contrast reference. **MRI Images.** We scanned the same phantoms using Varian/Agilent 9.4T-31cm with a lab-built Helmholtz volume coil using both GRE and SWIFT sequences. The SWIFT pulse frequency was applied on resonance with water in the $MnCl_2$ solution. The SWIFT sequence performed 163,840 views and a 5^{o} flip angle using a bandwidth of 125kHz and took approximately 12.5 minutes. The SWIFT data set was then passed through SWIFT reconstruction software programs based on the correlation method. The resulting 3D data sets were approximately 0.167mm in voxel size. We also prepared digital phantom data sets. **Quality Metrics.** A number of image quality metrics were explored to find useful factors for automatic scoring. To evaluate SNR, a section containing only solution and a section outside the phantom were used. A section containing only the Lego material was selected to calculate CNR. A section of each image near the midpoint of a side was selected and an image intensity histogram was taken. To evaluate the point spread function (psf), a slice profile was examined across the slice perpendicular to the surface. To measure sensitivity to short T_2, the psf was measured at the liquid- air boundary and then it was used to separate signal from the polymer in the Lego block area under a slice profile. To measure distortion, the distances between the corners and along the diagonals were checked to determine if the block image was square in the MR image. To find reconstruction artifacts, we compared images with false color image overlays. A Procrustean analysis (finding the linear transformation with limited degrees of freedom that minimizes differences between landmark control points) was performed. This provides a measure of shape dissimilarity or effort required for registration.

Fig.1. $MnCl_2$ Lego phantom.

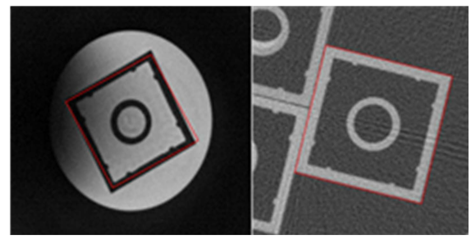

Fig.2. Gradient non-linearity distortion detection. Ideal square shape (red) overlaid with SWIFT 2mM (*left*) and CT *(right)* images.

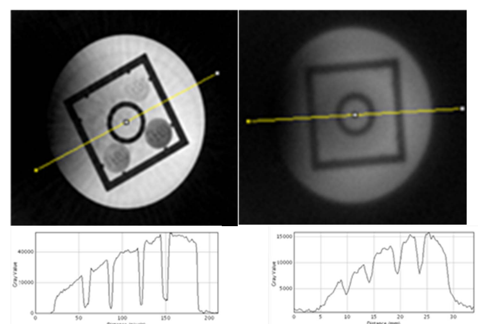

Fig.3. SWIFT images of 2mM and 30mM solutions *(top row)* and slice profile measure profile of contrast at sharp edge transitions *(bottom row)*.

Results and Discussion. The phantoms revealed distortions traced to hardware gradient non-linearity (Fig 2), showing the value of using the phantoms to check instrument calibration. With the most recent data set collected, the coil has a sensitivity drop-off and the 2mM $MnCl_2$ phantom was positioned such that the fourth corner of the block could not always be reliably detected by software in the SWIFT image. This type of hardware-based artifact is clearly a challenge and provides an interesting point of comparison for the reconstruction methods. The estimated psf was obtained by analysis of slice profiles in the presence of sharp boundaries between areas of different intensity (Fig.3). Sensitivity of SWIFT with different excitation bandwidths to short T2 signals also was tested (data are not presented here).

Conclusions. Progress in reconstruction and calibration quality can only come from measuring, finding error, and recognizing improvements in methods. Finding the right quality metrics to guide reconstruction efforts is a worthwhile research goal. It is important to know if a new RF sequence, reconstruction algorithm or imaging protocol is measurably better than previous methods. Measurement of image accuracy against a known standard allows for objective comparison of different reconstruction algorithms. Providing a standard phantom and simple quality metrics standards allows for comparison of quality of methods between and inside of research labs. Making this CT and MR data available allows the development, testing and optimizing of different post-processing methods by researchers without an easily available MR instrument.

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