A PHYSICAL SHEPP-LOGAN HEAD PHANTOM

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Introduction: The numerical Shepp-Logan head phantom is widely used in simulations for medical imaging. It is the sum of ten ellipses with parameters listed in the original paper [1]. The advantage of using this phantom when performing simulations in MRI is that the Fourier transform can be calculated analytically. Thus, an 'exact' version of k-space can be formed. After the addition of white Gaussian noise, the signal is often assumed to be that which would be obtained directly were a real scan of an equivalent physical object performed. We have constructed a physical Shepp-Logan head phantom to confirm that the assumption is reasonable. This phantom can also be used to validate specific simulations performed using the numerical version. To test the effect of motion, a MR-safe platform has been constructed capable of moving the phantom in a reproducible manner.

Method: A physical phantom was constructed using layers of polycarbonate glued together and then mounted inside an acrylic cylinder. Each layer was laser cut to achieve a precise result. The resulting 3D surface has varying thickness as shown in Fig. 1. The phantom was filled with water to generate a signal and 1.25 g/L $CuSO_4.5H_2O$ (5 mmol) was added to reduce T_1 and T_2.

The copper sulfate solution produces a strong signal while the polycarbonate and acrylic produce zero signal. The range of intensities required to produce a realistic Shepp-Logan phantom are generated through the partial volume effect. To achieve this, the phantom must be imaged using a slice thickness of 10 mm and all polycarbonate layers must be contained within one slice.

The phantom was imaged on a 1.5 T GE scanner using a fast spin echo sequence (FSE-XL, 256 × 256 resolution, echo train length = 3), both while stationary and when moving in a pre-programmed sequence. Images were reconstructed directly from the raw data without explicit filtering of k-space.

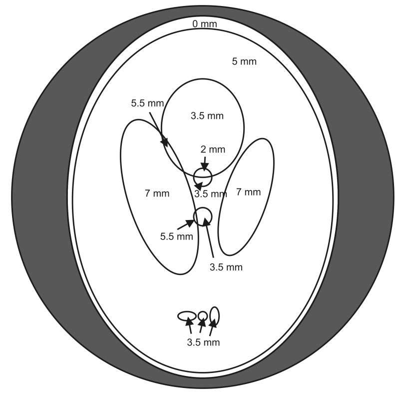

Fig. 1: The physical phantom construction showing thicknesses of polycarbonate in the imaged slice. The solid region is made of acrylic.

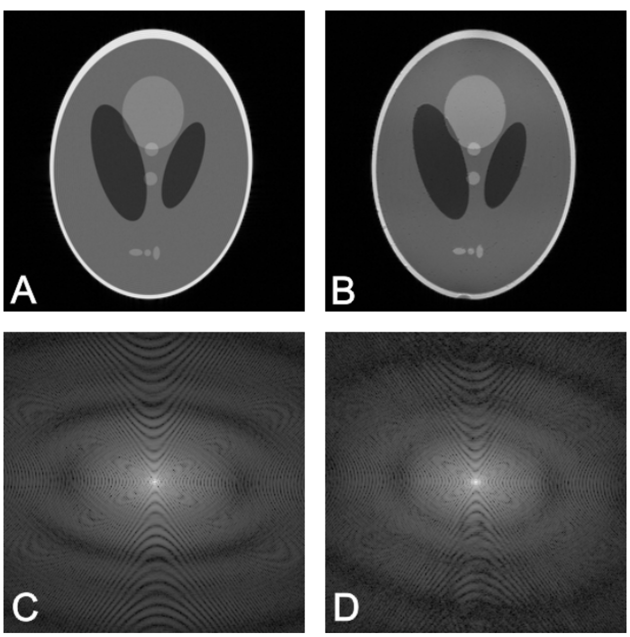

Fig. 2: Comparison of images of the numerical and the physical phantom: A and C, the numerical phantom in image-space and k-space; B and D, the physical phantom in image-space and k-space magnitude (log scale). The resolution in both cases was 256 × 256 pixels.

Results: A comparison of images of the numerical Shepp-Logan phantom and our physical version is shown in Fig. 2. The SNR used was 35 dB, chosen to match the SNR in the image of the physical phantom. Likewise, the numerical phantom was rotated by 2.2° to match the physical phantom. It is evident, from both the image-space and k-space magnitudes, that the two phantoms are very similar. The small imperfection at the base of the phantom in Fig. 2B is caused by an air bubble in the copper sulfate solution. Motion effects obtained using the phantom with the moving platform (not shown here) also match simulations well. One interesting difference, however, is the reduced amount of Gibbs ringing in the physical phantom compared to the numerical phantom in both phase-encode and frequency-encode directions. A cross-section shows this more clearly than the images themselves (Fig. 3). This is taken horizontally through the centre of both images on the left hand side of the outermost ellipse.

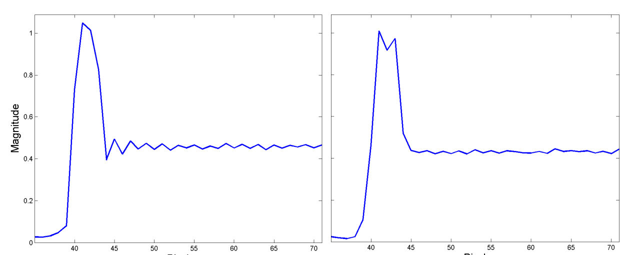

Fig. 3: Magnitude of a cross-section of (left) the numerical phantom and (right) the physical phantom.

Discussion: The physical Shepp-Logan phantom reported here has potential for validating simulation results. Its Fourier transform magnitude is visually similar to the numerical version with the exception of less obvious structure in the higher frequency components. In image-space, Gibbs artifacts are greatly reduced for the physical phantom. This shows that these artifacts, while commonly present in images of numerical phantoms, do not necessarily reflect the situation in the real case. This is possibly due to the perfectly sharp edges present in the numerical version. This may be significant for researchers who use the numerical Shepp-Logan phantom in their simulations, such as in [2]. Windowing k-space reduces Gibbs ringing, thus making the simulated data more realistic.

References: [1] Shepp, Logan, IEEE Trans Nucl Sci NS-21:21 (1974). [2] Archibald, Gelb, IEEE Trans Med Imag, 21(4), pp.305-319 (2002).