A Structurally Anthropomorphic Brain Phantom

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Target audience: Magnetic Resonance (MR) physicists and engineers who use phantoms to test their methods such as pulse sequence and radio frequency (RF) coils for human brain imaging.

Purpose: Techniques for better MR imaging are being continuously developed. Before applying new techniques on subjects and patients in a scanner, they are tested with cylindrical or spherical phantoms. However, results are not often realistic since the human cerebrum has complex structure with multi-contrast tissues and gyrifications. Some phantoms model electrical [1] and functional properties [2] but a phantom with gray and white matter structure does not exit. The purpose of this study is to show the development of an anthropomorphic phantom to obtain calibration data with simulated cerebral tissues to reduce cost and time by not necessitating *in-vivo* subjects.

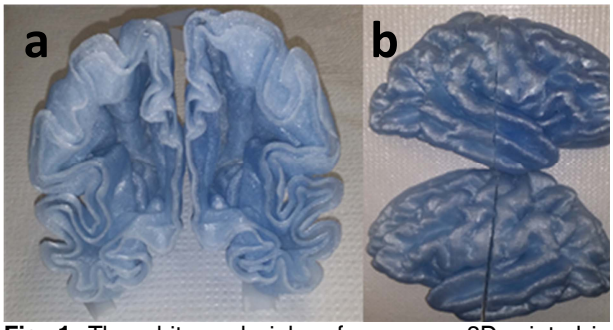

Fig. 1: The white and pial surfaces were 3D printed in tandem (a). Each hemisphere was printed in two pieces, cut in a coronal plane (b).

Methods: A FreeSurfer [3, 4] common surface ("fsaverage"), made by averaging 40 healthy adult subjects' data, was used to create an averaged brain model. The white surface (between gray matter (GM) and white matter (WM)) and the pial surface (between GM and cerebrospinal fluid (CSF)) were thickened to 1.3mm in Autodesk 3ds Max (Autodesk Inc., San Rafael, CA, USA) to allow 3D printing. The pial surface was thickened outward and the white surface was thickened inward to maintain the cortical thickness. After fixing topological errors with netfabb (netfabb GbmH, Parsberg, Germany), each hemisphere was printed (Fig. 1(a) and 1(b)) with Polylactic Acid (PLA) with MakerBot Replicator 2 (MakerBot Industries, Brooklyn, NY, USA). The head was also modeled and printed in four pieces.

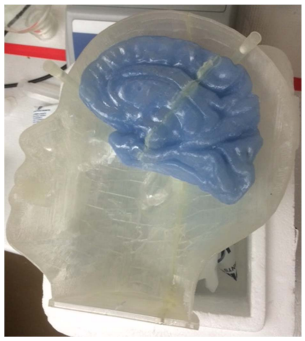

Fig. 2: The printed head models were glued and the hemispheres were fixated to have sufficient CSF contrast between skull and the pial surface.

Three different solutions were made with agar, agarose and manganese chloride ($MnCl_2$), WM/GM/CSF = 0.1 mM of $MnCl_2$ in 3% agarose / 0.05 mM of $MnCl_2$ in 3% agar / 1.5% agarose as reported in the literature [5] with some modifications. To avoid air bubbles, which may cause distortion in the images, all solutions were melted at high temperature (~80 ºC), and then slowly injected with a syringe. The GM solution was first injected in the outer layers of the cerebrum, and the models were tightly sealed with epoxy into hemispheres. Then the WM solution was injected from a small hole and the hemispheres were fixated in the head (Fig. 2). Before injection, all printed models were coated with enamel to avoid leakage of the solutions.

Finally, the phantom was scanned at a 3 Tesla whole-body Tim TRIO MR scanner (Siemens Healthcare, Erlangen, Germany) with 32-channel head receive coil array.

Results and Discussion: The cerebrum and head models were successfully 3D printed and assembled with the solutions inside. The images showed folding patterns, which are close to a human cerebrum (Fig. 3). Several challenges were noted, such as obtaining accurate T1 and T2 values as well as the boundary between GM and WM. The solutions did not dissolve completely, thus they did not appear distinctly in T1 or T2 images. To make the phantom more realistic, we are planning to create a T1 contrast of WM/GM/CSF with different solutions other than agar [6]. In this manner, we may also be able to 3D print directly with the contrast material itself and avoid the boundaries.

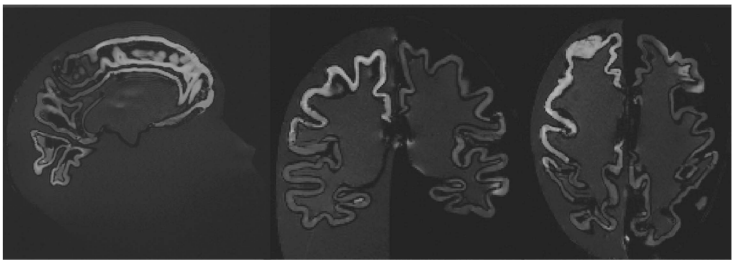

Fig. 3: The phantom images scanned with MP2RAGE sequence.

Conclusion: The structurally anthropomorphic phantom showed shapes of cerebrum models in T1- and T2- weighted images. With some implementations, it is feasible to make more realistic phantom that can be used to calibrate imaging methods before using human subjects.

References: [1] Graedel, *et al.* (2014) *MRM* ahead of print. [2] Nilsson, A. (2006) Master dissertation, Lund University, Sweden. [3] Dale et al. (1999) *NeuroImage* **9**:179. [4] Fischl *et al.* (1999) *NeuroImage* **9**:195. [5] Mathur-de Vre *et al.* (1985) *MRM* **2**:176. [6] Hallerbach *et al.* (2013) *PLOS ONE* **8**:e70343.

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