# Developing an Anatomically Accurate Multi-layered Optical Brain Phantom for fNIRS Studies

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**Abstract**: We describe a method to create a complex human brain optical phantom using 3D-printed molds and silicone. The phantom contains 3 tissue layers, including scalp, CSF and grey matter with tissue-like optical properties. © 2018 The Author(s)

**OCIS codes**: (170.3660) Light propagation in tissues; (170.6960) Tomography; (170.7050) Turbid media.

## 1. Introduction

A growing number of research has utilized functional near-infrared spectroscopy (fNIRS) to study brain functions, with the advantage of rich measurement of oxy- and deoxygenated hemoglobin to image brain tissue hemodynamics [1]. Despite its safety and accuracy, fNIRS are limited by the depth in which they can measure [2].

In the past, optical brain phantoms developed to validate fNIRS imaging devices have been oversimplified. For example, a rectangular glass block filled with India ink to optically match received signals from a human forehead [3]. The accuracy of these phantoms can be improved upon strongly. A method that has been tested and worked with creating breast phantoms is a silicone based model using black and white pigments to match optical properties with those of human tissue and small inclusions filled with ink for dynamic studies.

Therefore, we propose to create an anatomically accurate, 3D complex-shaped silicone-based brain phantom with embedded dynamic inclusions to model the scalp, cerebrospinal fluid (CSF) and gray matter layers of the brain for fNIRS imaging. Each layer is designed to have the expected optical properties [4]: absorption coefficient and reduced scattering coefficient by adding corresponding black and white pigments to the silicone.

## 2. Methods

A tetrahedral mesh of a segmented 30-34 years-old atlas head model was generated using our Brain2Mesh workflow [5]. The surface meshes for the layers of scalp, CSF and gray matter were then extracted using the meshing toolbox Iso2mesh and used for the 3D printing. In the case of the gray matter, due to the complex gyrifications, the inner and outer surfaces of each tissue layer were extracted separately for each brain hemisphere. The scalp and CSF surfaces were cut into two-half open surfaces. The gray matter was formed into two-half closed surfaces then each brain hemisphere was cut into two open surfaces for a total of four parts.

Using obtained meshes, molds were 3D printed. An 8mm and 1 cm water soluble wax (Freeman Sol-U-Carv, Avon, Ohio) spheres were fabricated by de-molding from a 3D printed PLA mold. The 8mm and 10mm sphere were glued onto the gray-matter mold one close to the motor cortex area, another near the visual cortex. Then the four grey matter molds were glued with caulk into two hemisphere and a large hole was drilled in to the top of each for injection. Silicone (Smooth-on Ecoflex-0030) was mixed with white and black pigments (Smooth-on Silc Pig White and Black) to simulate the optical properties for specific brain tissues. The gray matter silicone was injected into the two hemispheres and de-molded after 4 hours. The two hemispheres were assembled by Sil-Poxy (Smooth-on) and placed inside the CSF molds before gluing, molding and demolding of that layer. The same procedure was repeated for the scalp layer for the full phantom. Wax spheres were dissolved by 80˚C water once the full phantom was cured.

## 3. Results

The 3D-printed molds with atlas-derived gray-matter, CSF and scalp are shown in Fig 1. After curing, the sample silicone gray-matter phantom is demolded (Fig. 2). This is subsequently placed inside the CSF mold to add the CSF layer. The combined CSF/gray-matter phantom is then put in the scalp mold to create the final full-head phantom.

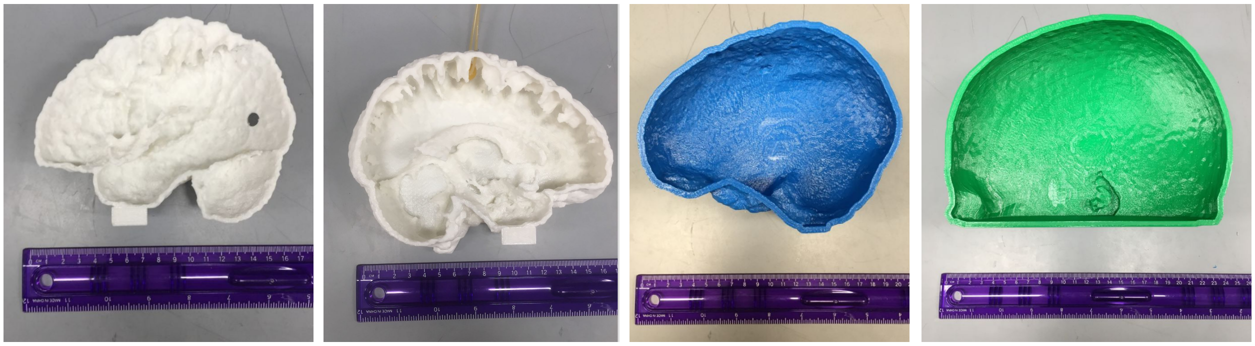

Fig 1. 3D-printed molds of gray matter (for one hemisphere) with water-soluble wax sphere, CSF and scalp layers.

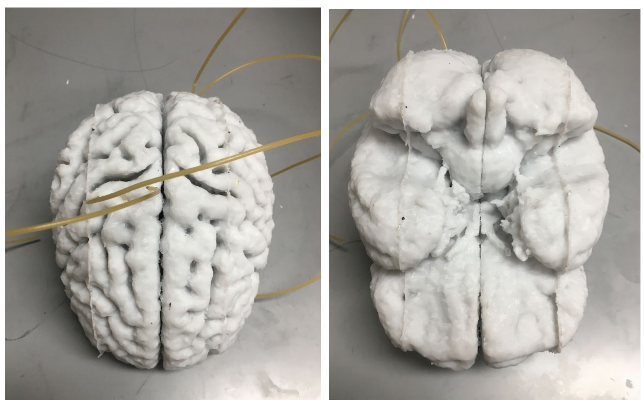

Fig 2. The de-molded gray-matter layer with embedded wax spheres for dynamic contrast.

## 4. Conclusion

In summary, we described a method to build a complex human brain optical phantom using 3D-printed molds and silicone. Our future direction will be utilizing this brain phantom to calibrate and optimize our in-house fNIR device.


## 5. Acknowledgements

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## 6. References


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