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Modeling the Skull-Brain Interface Using Sylgard 527 Phantoms

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Abstract

The goal of my research is to create a phantom capable of simulating brain tissue mechanical properties. This phantom will be tested with Magnetic Resonance Elastography (MRE) to retrieve data about the wave-motion taking place in the phantom. During the summer and past few months, I have created a homogenous Sylgard 527 phantom, a simple model, representing only the skull and brain tissue. In addition, I fabricated an interface phantom that simulates the skull, cerebrospinal fluid (CSF) and brain tissue. Upon testing the interface phantom for wave-motion, a large chemical shift was discovered. As a result, it was determined that water was not a suitable liquid medium when contrasted with cured Sylgard 527. Later, a removable lid was constructed and added to the interface phantom to allow the changing of interface materials. After evaluating various substitutes for a liquid medium, it was found that un-polymerized Sylgard Part A contrasted well with cured Sylgard 527.My current research focuses primarily on acquiring data regarding wave-motion and material properties of the homogenous and interface phantoms. The acquired data will allow for the direct comparison between the two phantoms, the phantoms and COMSOL simulations of expected results, as well as human MRE data.

Significance

The purpose of my research is to assess the validity of a phantom that has material properties similar to those of brain tissue to analyze the attenuation of forces between the skull and the brain. Understanding this transmission of force is useful for the purposes of understanding and investigating brain injuries like Traumatic Brain Injury (TBI).

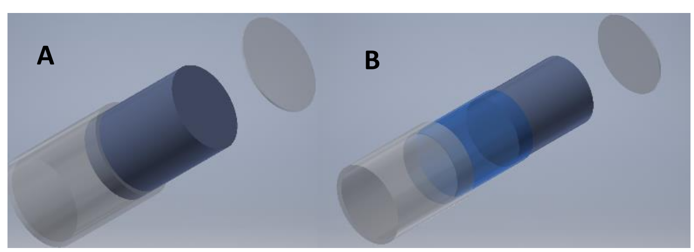

Figure 1: A) Exploded view of a 3D model of the homogenous phantom. B) Exploded view of a 3D model of the interface phantom. Renderings were created in Autodesk Inventor.

In an attempt to simulate the relationship between the skull and the brain I will be creating a phantom out of rigid, acrylic plastic containing a two-part, gelatin-like substance called Sylgard 527 (Figure 1). Acrylic is a better reproduction of the skull than previous iterations of the cylindrical phantom and will enable more accurate boundary effects to be investigated. The Sylgard 527 will be beneficial because it has tunable properties and does not deteriorate, thus creating a permanent model. A second phantom will be created that leaves a gap between the acrylic container and the Sylgard 527 so that a liquid medium can be put in place to represent the cerebrospinal fluid and a more accurate representation of the skull-brain interface. Initially, water was going to be used in the construction of the interface phantom, but it caused a large chemical shift during testing (Figure 2).

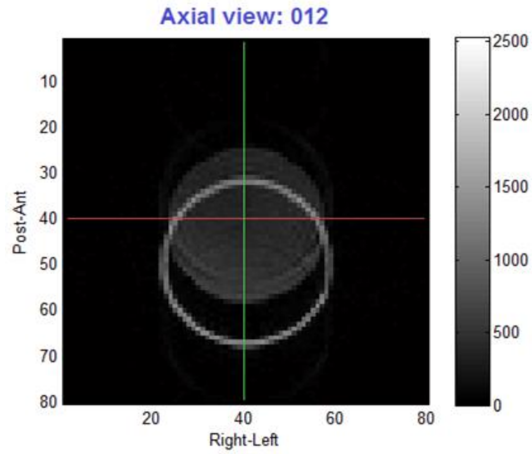

Figure 2: Pictured above is the chemical shift artifact that occurred in the first attempt at an interface phantom. The surrounding water interface was shifted down significantly from the centered, Sylgard 527 cylinder.

Data acquired from these phantoms can be compared with each other to assess interfacial effects. In addition, the phantom data can be compared to computer models, made in COMSOL, as well as actual human data to better model skull motion transmission to the brain.

Methodology

Before the Sylgard 527 can be made to fill the phantom, the acrylic case must be constructed. A 12 inch tube with a 5 in diameter was purchased from McMaster Carr (Part No. 8486K581) and sawed in half to produce two 6 inch tubes. In addition, four acrylic discs (two for each phantom) were also acquired from McMaster Carr (Part No. 1221T75) as well as SCIGRIP acrylic cement (Part No. #10308). Acrylic cement was applied with a syringe to the space between the acrylic disc and tube. A strong, waterproof connection was formed after 48 hours. Given the dimensions of the acrylic cylinder and the desire to leave a free surface at the top of the phantom, the total of Sylgard 527 used for this phantom was 1450 cm^3. With a 1:1.25 ratio, 645 grams of part A and 805 grams of part B will be poured and mixed together. In addition to filling the phantom, it is also beneficial to fill one or two petri dishes to perform additional tests and to compare to the phantom itself. This mainly includes more dynamic shear testing to obtain an estimate of

Figure 3: Degassing Sylgard 527 in a vacuum oven at 75 cm Hg for 4.5 hours. This picture was taken towards the beginning of the process.

the stiffness of the entire phantom. After stirring the mix thoroughly, the Sylgard was poured into the acrylic case and placed into the vacuum chamber at a 75 cm Hg pressure difference for 4.5 hours (Figure 3).A 3D printed cap was printed in the event that the Sylgard 527 began to overflow during the degassing process, but it was not necessary for this container. When almost all of the air bubbles had been removed from the phantom, it was set aside to cure for about a week. Once it was determined that it had cured by touching the surface with a small, metallic spatula and observing if any of the substance had come off on the spatula. After this was done, the other acrylic disc was cemented on the top the same way as before. The methodology for constructed the interface phantom is extremely similar. The main difference is that a smaller, shipping tube was utilized to cure the Sylgard 527, which can be peeled away easily. The Sylgard cylinder is then placed within the acrylic disc and filled with a liquid medium (Figure 4).

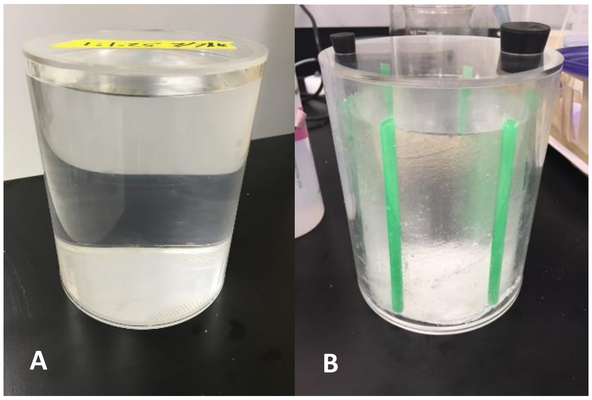

Figure 4. (A) Completed homogenous phantom fabricated with a 1:1.25 base:catalyst ratio. The case is made of acrylic and is adhered together using acrylic cement. **(B)** Completed interface phantom fabricated with a 1:1.25 base:catalyst ratio and a ring of water, representing cerebrospinal fluid, between the Sylgard 527 cylinder and the acrylic casing. Holes were made in the lid so that the water could be refilled or exchanged for another material if need be. The diameter of the Sylgard 527 cylinder was not constant along the height due to the soft nature of the material. Plastic straws were added to the phantom to rectify this issue and maintain even spacing between the cylinder and the disk.

Results

Each phantom was tested using MRE and tests were conducted at with given parameters, 50 Hz with 3% and 5% actuation amplitude. Three accelerometers, one for each axial direction, were used to determine resulting motion in the phantom. From the data collected utilizing the homogenous phantom, it is very clear that there is large wave motion (Figure 5). The figure shows that the wave motion is remarkably symmetric with respect to the horizontal axis of the phantom. The scale conveys that each symmetric half has the same magnitude but opposite sign. However, based on the wavelengths in the figure it seems that the Sylgard 527 is stiffer than anticipated (approximately 3 kPa). It appears that the cylinder is actually approximately 6-8 kPa. As a result, this gave solid evidence that Sylgard 527 was a suitable material for getting wave motion and serving as a representation of brain tissue.

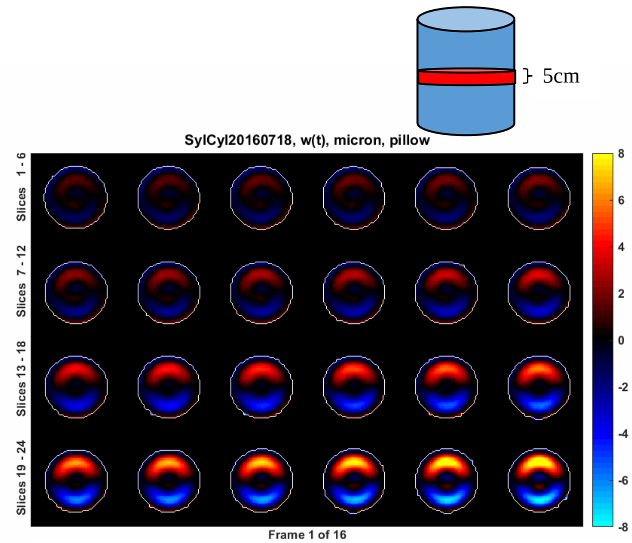

Figure 5: Pictured above is MRE shear wave motion (SI-component) obtained from the homogenous phantom. This test was conducted at 50 Hz with a Motion Encoded Gradient Strength (MEGS) of 10 mT/m using an echo-planar imaging sequence with 3 mm isotropic voxels. The imaging volume (24 slices) was taken from a 5 cm region at the center of the cylinder as shown in the diagram

High contrast between the gel-cylinder and the interface material was seen in the new interface phantom utilizing unpolymerized Sylgard 527 Part A (Figure 6). In addition, the utilization of a new material fixed the chemical shift issue that arose when using water for the interface. Although unpolymerized Sylgard 527 Part A isn't as close to representing the material properties of CSF as water, it still allowed for the analyzation of a phantom containing an interface. Looking at the results of the interface phantom (Figure 7), there appears to be almost no wave motion. It is expected that the addition of an interface dampens forces, but results show almost zero wave motion. As a result, it has been shown that the interface in this experiment attenuates motion significantly.

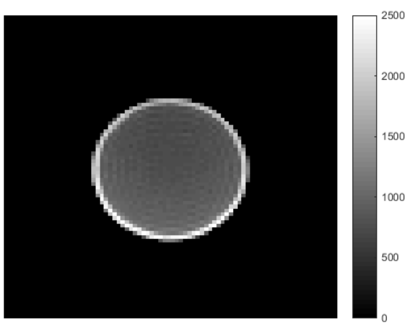

Figure 6: Above shows the contrast between the interface and the Sylgard cylinder. The interface shown is unpolymerized Sylgard Part A.

Discussion

Looking at a direct comparison between the interface and the homogenous phantom (Figure 8), there is a significant difference in wave motion. The addition of an interface appears to have greatly reduced motion of the Sylgard cylinder. Since air bubbles in the interface phantom became trapped in the O-ring, there was no free surface in the interface phantom. The lack of a free surface, unlike the homogenous phantom, could be an explanation to why there is so little wave motion. If this turns proves to be correct, the motion would be primarily rigid body motion because the lack of a free surface would cause the phantom to move as if it were comprised of one continuous material.

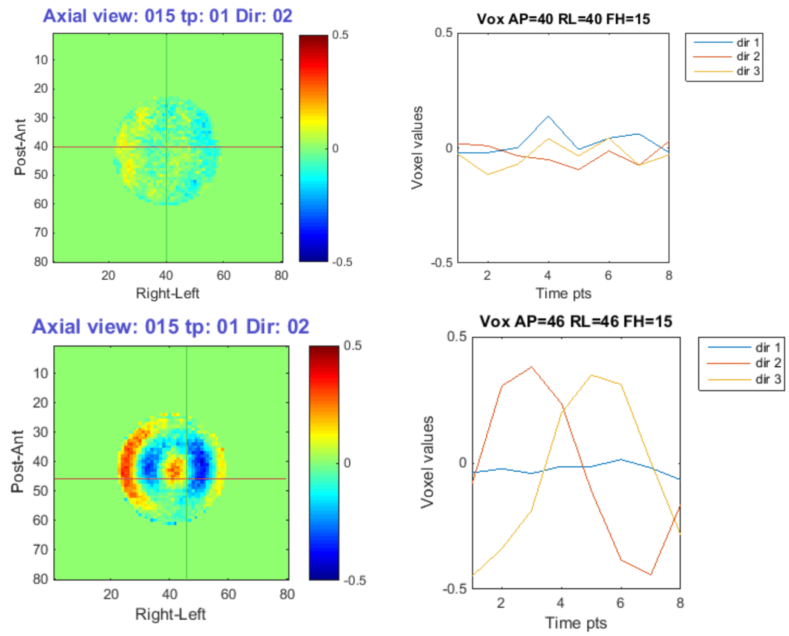

Figure 8: Pictured above are sets of acquired data from the interface phantom, A, and the homogenous phantom, B. The interface phantom was tested with 5 percent actuation amplitude and a MEGS of 7mt/m. The homogeneous phantom was tested with 5 percent actuation amplitude and a MEGS of 10mt/m. Data in this figure represents motion in the Anterior-Posterior (AP) direction, while Figure 5 shows data from motion in the SI direction.

I will be continuing this research by constructing COMSOL models of each phantom to determine if the data we acquired aligns with what is expected from the computer program. Essentially, I plan on discerning if this approach of simulating brain tissue and analyzing motion is a valid approach or a reasonable comparison to real life/computer generated situations.