Brain Modeling to Mimic Functionality Studies of Cerebrospinal Fluid

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Abstract

This paper presents a 3-D model of the human head that continues previous research on human brain modeling. The model created will be used to mimic functionality, respiratory effects, and pulsation of the cerebrospinal fluid (CSF), as well as to investigate the effect of CSF pulsation on the brain using magnetic resonance (MR) imaging. The model consists of three components: the skull, the brain, and the cerebrospinal fluid in the brain’s third ventricle, with the brain and CSF enclosed by a flexible membrane. The skull will be manufactured from WaterShed XC 11122 on the stereolithography machine in the MSOE Rapid Prototyping Center (RPC) from an MR scan of the human head. The flexible membranes are to be manufactured from the flexible polyamide material DuraForm PA on the selective laser sintering machine in the RPC. The brain volume will be agarose gel doped with contrast agent to make it MR visible, and the CSF volume will be modeled by water. The membrane enclosing the CSF will have an inlet and outlet to the exterior of the skull and a pump is to be attached at the inlet to mechanically pulse the CSF for testing. These methods will be used to create the model that will ultimately be used to test the effect of CSF on the human brain. Currently, the computer models of the brain, skull, and CSF volumes have been built, and the focus of this paper is the image processing that was used to create these computer models of the brain, skull, and CSF that will ultimately be used to build the physical 3-D model.

Keywords: Cerebrospinal, Pulsation, Model

1. Introduction

The human brain is surrounded and supported by cerebrospinal fluid, or CSF. The CSF is 97% water and serves to cushion the brain against impact and support it so it does not crush under its own weight. However, the CSF volume in the brain is not static; it is dynamic and pulses rhythmically with respiration (inhalation and exhalation). These pulsations affect the brain volume because the CSF is enclosed only by a thin, flexible membrane. Additionally, there are diseases of the CSF, the most notable being hydrocephalus, which is also known as water on the brain. Hydrocephalus is a condition that causes CSF buildup in the brain, resulting in pressure on the brain and increased head circumference (in children). Hydrocephalus is as common as Down’s Syndrome, affecting 2 out of every 1000 babies born in the United States, and it is the most common reason for brain surgeries in children in the United States, resulting in 40,000 surgeries per year (one every 15 minutes)\(^1\). In order to investigate the normal pulsation of the CSF during pulsation and respiration, a 3-D model of the skull, brain, and CSF will be created. A pump will be attached to the membrane enclosing the CSF to replicate the normal pulsation of the CSF with respiration and pulse, and the effect on the brain volume will be measured using Magnetic Resonance (MR) imaging. This model also has significant implications for hydrocephalus research because it can be used to investigate the effects of the increased pressure on the brain. It is important to note that the goal of this research is development of the 3-D
model; actual testing utilizing the pump and MR machine will be performed if time permits, but the ultimate goal for this research is creation of the actual model.

1.1 rapid prototyping

Rapid prototyping, also known as additive manufacturing, is a manufacturing process that builds three dimensional models by adding layer upon layer of material and bonding each layer together by various mechanisms. Rapid prototyping uses computer aided design (CAD) software to create a design that can then be input into a specific machine to create the 3-D model. Two specific machines in the Milwaukee School of Engineering Rapid Prototyping Center (RPC) will be used to create the 3-D model.

1.1.1 stereolithography apparatus (SLA)

The stereolithography (SLA) machine shown in Figure 1 is the first machine that will be used to create the skull part of the model. This machine uses a UV laser to create successive cross sections of a 3-D object in a vat of liquid photopolymer. The layers are usually 0.005 inches. A platform is placed at the top of the vat filled with the liquid photopolymer and then moved just below the surface of the polymer. The laser then traces the first layer, solidifying the polymer, and the platform moves down and the process repeats. In order for easy removal of the part from the platform, supports that must be removed later are created at the very bottom of the part between the platform and the first layer of the actual model.

![Figure 1: The stereolithography apparatus in the MSOE Rapid Prototyping Center](image)

1.1.2 selective laser sintering (SLS)

The second machine that will be used is the selective laser sintering (SLS) machine. This machine fuses layers of plastic powder together using a CO2 laser, ultimately creating a 3-D object. The machine functions by rolling a thin layer of powder over the product tray and then using the laser to etch the first layer of the object into the powder as shown in Figure 2. Once the first layer is etched, the platform moves down, and the process repeats until the part is completed.
1.2 brain, skull, and CSF anatomy

The brain is enclosed by a layer of CSF, and the brain’s third ventricle, which is deep inside the brain, is filled with CSF. The brain is surrounded by a flexible membrane called the dura, and the CSF in the third ventricle is also enclosed by a flexible membrane.

Figure 3 details the normal anatomy of the brain, skull, and CSF on the right. Note the size of the third ventricle under normal conditions. On the left in Figure 3 is a brain with hydrocephalus and a large increase in size in the third ventricle. The model will be similar to the normal brain scan on the right in Figure 3, and when the pump is attached to the third ventricle, the pressure can be increased to mimic a brain with hydrocephalus.

1.3 previous research and project overview

This research is a continuation of the work of previous REU participants Sung Kwon and Tyler Capek. In 2008, Sung Kwon created a 3-D model of the human brain on a 3-D printer. His model differentiated between the white and gray matter in the human brain\(^4\). In 2012, Tyler Capek expanded on that model by color coding the functional areas of the brain\(^6\). This research has its foundation in the previous research, but it is unique because the model
created will mimic the actual anatomy of the human brain rather than being built of one hard plastic material like the previous two models. The skull will be built of WaterShed XC11122. This material was chosen because it is hard and similar to the material that makes up the skull, and also because it is clear, so the inner brain membrane will be visible during testing. The brain will be made of agarose gel because the gel is similar to the actual brain material. The membranes to hold the brain and CSF volumes will be made of DuraForm PA, which was chosen because it is flexible and watertight when sealed. Additionally, this model will be dynamic because a pump will be attached to simulate the pulsation of the cerebrospinal fluid.

2. Methodology

2.1 data acquisition

Scans of the skull, brain, and CSF were obtained from Dr. Todd Parrish through the Center for Advanced Magnetic Resonance Imaging (CAMRI) at Northwestern University. The scans are open source and public access so no IRB approval was needed. These scans were performed using a Siemens 3 Tesla TIM Trio Magnetic Resonance Imaging (MRI) machine. Three scans were obtained, one each for the skull, the brain, and the CSF, and each scan contained 176 1 mm axial slices. The scans were obtained in .TIFF format.

2.2 image processing

Once the scans were obtained, the scans were converted to .JPEG format in order to be imported into the MIMICS software to create a 3-D model. To convert to JPEG, the scan file was opened in ImageJ and re-saved as an Image Sequence in the .JPEG format. Each slice in this new file was then imported into MIMICS to create a 3-D image. Three files total were imported into MIMICS, so there was an image that was used to create the CSF volume, an image to create the brain volume, and an image to create the skull.

Once the 3-D images were created in MIMICS, they were modified using thresholding and the erase tool. For the CSF volume, the original scan showed the CSF surrounding the brain in addition to the CSF in the third ventricle. The erase tool was used to eliminate the extra CSF surrounding the brain to isolate the third ventricle CSF volume. The scan of the brain was used to obtain the shape of the brain in a membrane form because the brain volume will be filled with agarose gel. To get the shape of the brain, the entire brain volume was isolated using the threshold tool in MIMICS, and then exported to MAGICS where the volume was hollowed out, leaving a membrane 0.5 inches thick. The scan of the skull had both the skull and the skin visible, so the threshold tool was used to isolate the bone part of the skull and then the erase tool used to eliminate all of the skin and muscle in the scan.

2.3 model development

Two machines in the RPC will be used to create the skull and the membranes that will hold the CSF and brain volumes. The stereolithography (SLA) machine will be used to manufacture the skull out of WaterShed XC11122 and the two flexible membranes for the CSF and brain volumes will be manufactured on the selective laser sintering (SLS) machine out of DuraForm PA. The brain volume will be agarose gel, and the CSF volume will be water.

3. Results

Computer models of the brain, skull, and cerebrospinal fluid volumes were created this summer as a result of the research. Figure 4 shows the final computer models of each of the volumes that will be used to manufacture the model in the RPC.
Figure 4: The completed brain volume (left), the skull (middle), and the cerebrospinal fluid volume (right) computer models.

These computer models will be used to create the physical 3-D model to be used during testing. The brain and cerebrospinal fluid volumes are hollow with membranes that are 0.5 inches thick. The skull is also hollow and will house the brain and cerebrospinal fluid volumes.

4. Discussion

The results of this research are valuable, beneficial, and a solid beginning to the creation of a 3-D model of the human head. However, computer issues were encountered during the research that prevented the physical model from being created during the 10 week research period. Once the three computer models were created, the next step was to add the inlet and outlet ports as well as the mechanism that would be used to assemble the model. Just as this point in the research was reached, the only computer that had the required programs of Magics and FreeForm Modeling in the RPC crashed and was not fixed or replaced before the end of the 10 week period. Due to this computer issue, the final model could not be manufactured within the allotted research time.

Although the model was not completed during the summer research, research will continue to finish and test the model. The first step in the continued research will be to add the inlet and outlet ports to the CSF volume. The second step is to send the computer models to Dr. Todd Parrish of Northwestern University to receive his approval and to make any modifications he suggests. Once all modifications are completed, the third step will be to send the models to the RPC for them to manufacture the model. The fourth step is to assemble the model, and the fifth step is to perform testing on the model by attaching it to a pumping mechanism and evaluate the effect of pulsation on the brain.

5. Conclusion

This research successfully investigated the anatomy and function of the human brain, skull, and cerebrospinal fluid, as well as diseases of the cerebrospinal fluid. The creation of a three dimensional model to research the functionality and diseases of cerebrospinal fluid was begun. The computer models were successfully completed and the research will continue to complete and test the model.

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7. References