Model for Pre-Surgical Intracerebral Hemorrhage Planning

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Advisor: Dr. Paul Campagnola Client: Dr. Walter Block

Abstract

Intracerebral hemorrhaging is most prevalent for individuals who are at high risk of strokes and seizures due to blood clotting. The client has tasked the team to come up with a phantom head model that can be scanned into an MRI, so a neurologist can practice different surgical techniques. The team has decided to come up with a phantom model that will allow the neurosurgeon to use a catheter and drill to remove said blood clot[1]. The testing for the first phantom developed by the team initially showed a contrast of the DICOM images of the non-clot and clot skull models and a difference in the calculated and actual volume of the capsule. The results of the current phantom showed it was found that the team's phantom model was correct in displaying the hemorrhage, but still needed a more transparent capsule to allow the catheter to puncture the mold and more access points for the neurosurgeon to look into during the surgery and models with different locations for the hemorrhage.

Problem Statement

In the past, very little is done for patients with ICH. Goal for this semester was to improve upon the phantom to simulate the interior of a brain with various clots to image and validate the effectiveness of mapping techniques and represent anatomical correctness. Additionally, it was important to improve upon the phantom model to match the conditions indicated by the client.

Previous- work

- Previous UW team
  - Polyacrylamide(PA) gel model phantom
- Last Semester
  - PLA skull chamber
  - Plastic blood blot

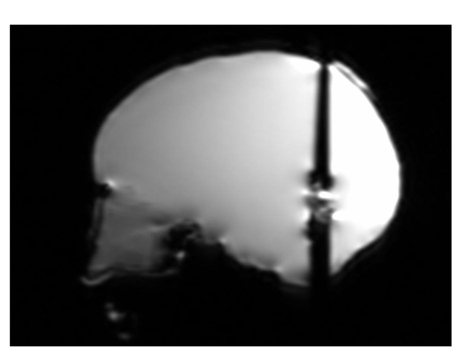

Fig.1 Last semester model

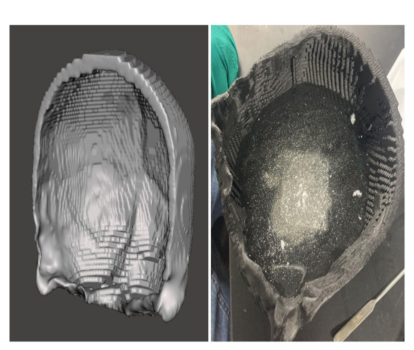

Fig.2 Phantom model by UW team

Background Research

- A brain phantom is used by neurosurgeons to compare the MR scans of the phantom with a scan of their patients' brains[2]
- Current research is focused on removing the clot as much as possible to prevent spread
- Choosing a treatment for blood clot evacuation can be difficult because it is based on the material properties of the blood clot.
- Surgeons need a control that can be imaged with an MRI to create a standard of measurements that can be used to determine the surgical approach.
- The method used to remove is dependent upon the stiffness of the clots which are [3]
  - Suction
  - Drug treatment and then suction

Design Specification

- Skull model should be 3D printed and made of PLA
  - more access points for the neurosurgeon to look into during the surgery
  - different locations for the hemorrhage
- Have an in depth fabrication process so that it can be replicated for commercial purposes
- The phantom should be able to be scanned by MRI
- Enclose model to represent skull pressure

Final Design

- Skull was 3D printed from PLA, matching sinus cavities to make it more realistic
- Skull model was downscaled but with higher infill percentage, with a rubberized sealant spray coating added to remove pores
- Gelatin was prepared to mimic the brain tissue, with internal air pockets modeled in gelatine mold
- Gelatine fabricated by mixing water and gelatine in powder form, 90 °C for 5 min stirring and left to harden for four hours in the skull chamber
- Blood clot was modeled as a silicon capsule that was thermoset in a spherical shape with a silicon sealing to make a self healing polymer
- Swine blood was used to model hemorrhage with a clotting agent, iron chloride, added to make hemorrhage more visible
  - Multiple MRI scan images sets were obtained to visualize the Signal to Noise Ratios apparent within different sections of the DICOM images
  - The first MRI set focused on just the hemorrhage within the skull without the blood within the capsule
  - The second MRI set focused on the hemorrhage within the skull with the blood within the capsule
  - A third MRI scan of the guided probe was performed to analyse the path of the catheter to the blood clot with RT HOC used to change the real time imaging to see the effects in the case based images

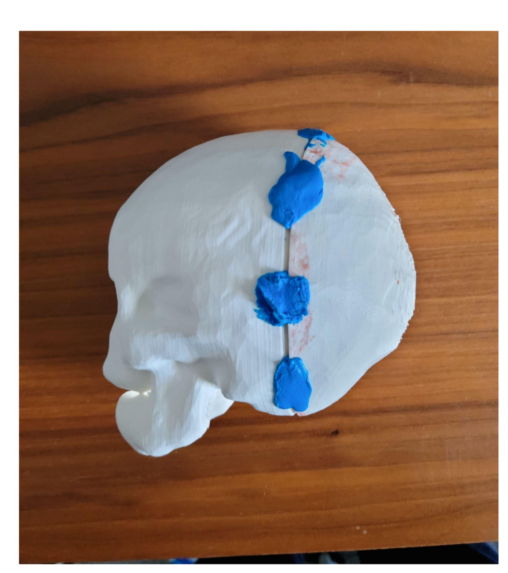

Fig.2. Skull Chamber

Fig 3.1 Coronal crossection clot absent MRI image

Fig 3.2 Coronal cross section Blood Clot(high iron) present

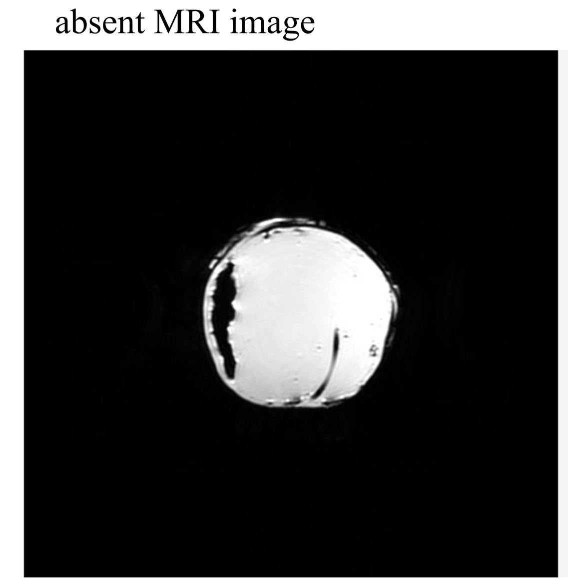

Fig 3.3 Coronal cross section of the guidance probe present

Testing & Setup

- Team tests efficacy of images from MRI by measure of SNR from several DICOM data image sets, in order they were obtained
- Procedure was done in MATLAB by taking the highest quality image slice for a particular image set and then adjusting the dynamic range of the image to center the range to roughly where the hemorrhage was present within the skull
- The results were then found that the image set of the clot within the skull without the hemorrhage added in displayed a value of roughly 18.5, then the clot within the skull of the hemorrhage was found to be 10.1, and the clot within the skull with the catheter puncturing the clot within the skull was found to be 5.3
- Afterwards, a statistical 3-sample t-test was performed to see if there was significant difference between the three different SNR, and a value of 0.032456 was obtained, indicating a statistical difference between the data sets
- This indicates that our data matched the expectations of the data as there was a clear distinction between the different sets of data

Testing in Future

- In future the team should plan to test the final design by having a neurosurgeon practice removing the clot
- Based on how many times the neurosurgeon is successful on removing the clot a set number of times, the team will determine accuracy and efficiency of model
- Null hypothesis: Practicing the surgery on the phantom model led to no change in performance from the initial practice run; Alternative hypothesis: Practicing sequential surgery runs on the phantom model led to a change in performance

Future Work

- Team prints larger, life size skull model to represent an actual human skull
  - Phantom will have access points that match actual surgical conditions
- Will use a pressurized system to match the conditions in the blood, will require more puncture force
- Make more models that have different locations where the air pocket of the hemorrhage will lay
  - Models will have better puncture points, so the catheter can enter in a more accurate setting
- Perform actual statistical testing with physician analysis to determine the efficacy of the positioning of hemorrhage pocketing
  - Potentially involve an electronic transmitter that shows the correct color when surgery is done successfully, or the wrong color and location if the incorrect part of the brain is removed or punctured

References

[1]*Classic human skull model, 3 part - 3B smart anatomy*. Human Skull Model | Plastic Skull Model | Classic Human Skull Model. (n.d.). Retrieved October 14, 2021, from https://www.a3bs.com/classic-human-skull-model-3-part-3b-smart-anatomy-1020159-a20-3b-scientific,p_55_29.html.

[2]Altermatt A, Santini F, Deligianni X, et al. Design and construction of an innovative brain phantom prototype for MRI. Magnetic resonance in medicine. https://www.ncbi.nlm.nih.gov/pubmed/30221790. Published February 2019. Accessed October 13, 2021

[3]Mayo Foundation for Medical Education and Research. (n.d.). Intracerebral hemorrhage. Mayo Clinic. Retrieved October 13, 2021, from https://www.mayoclinic.org/diseases-conditions/brain-avm/multimedia/intracerebral-hemorrhage-image/img-20129861.

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- UW-Madison BME Department

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- Procedure was done in MATLAB by taking the highest quality image slice for a particular image set and then adjusting the dynamic range of the image to center the range to roughly where the hemorrhage was present within the skull
- Following this, the mean signal is obtained and then divided by the random noise or the average standard deviation of pixel intensity from the regions of interest and then multiplying that value by 0.66, the rayleigh distribution correction factor to get the tru SNR
- The results were then found that the image set of the clot within the skull without the hemorrhage added in displayed a value of roughly 18.5, then the clot within the skull of the hemorrhage was found to be 10.1, and the clot within the skull with the catheter puncturing the clot within the skull was found to be 5.3
- Afterwards, a statistical 3-sample t-test was performed to see if there was significant difference between the three different SNR, and a value of 0.032456 was obtained, indicating a statistical difference between the data sets
- This indicates that our data matched the expectations of the data as there was a clear distinction between the different sets of data
- Next semester, the team plans to test the absolute final design by having a neurosurgeon practice removing the clot
- Based on how many times the neurosurgeon is successful on removing the clot a set number of times, the team will determine accuracy and efficiency of model
- Team will make changes based on how well or poorly the physician performs and make adjustments based on that
- From those adjustments the team will test the neurosurgeon again and see the differences in his performance
- Null hypothesis: Practicing the surgery on the phantom model led to no change in performance from the initial practice run; Alternative hypothesis: Practicing sequential surgery runs on the phantom model led to a change in performance

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Testing

- the clot within the skull without the hemmorhage added in, the clot within the skull with the hemmorhage added and the catheter puncturing the clot and trying to remove the hemorhage
- The purpose of obtaining the SNR, Signal-to-noise ratio, is to determine the performance of the MRI system and the images obtained, with a higher value signifying less background noise and meaning a higher image quality
- Following this, the mean signal is obtained and then divided by the random noise or the average standard deviation of pixel intensity from the regions of interest and then multiplying that value by 0.66, the rayleigh distribution correction factor to get the tru SNR
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