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Circle of Willis Model for Transcranial Doppler Ultrasound Training

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Background

The Circle of Willis is an anastomosis of the major blood vessels of the brain. It sits at the base of the cerebellum and anterior to the brain stem. Monitoring this structure is effective in determining adequacy of brain blood flow [1].

Transcranial Doppler (TCD) ultrasound is a method of observing functional blood flow velocities in cerebral arteries. It is a noninvasive procedure useful for pathological analysis and blood flow lateralization. It can easily observe the Circle of Willis and any blood flow changes in real time. [2].

Learning how to effectively use and interpret TCD ultrasound is a difficult process. The ability to practice on a realistic model can improve proficiency of medical professionals with TCD [3].

Design

The model is an anatomically accurate representation of the Circle of Willis. Arterial diameter is based off of average size measurements taken on adults [3].

An AutoCAD software was used to design the model and served as the template for 3D printing. The printing material is called TangoPlus and was used because it mimics the flexibility of cerebral arteries.

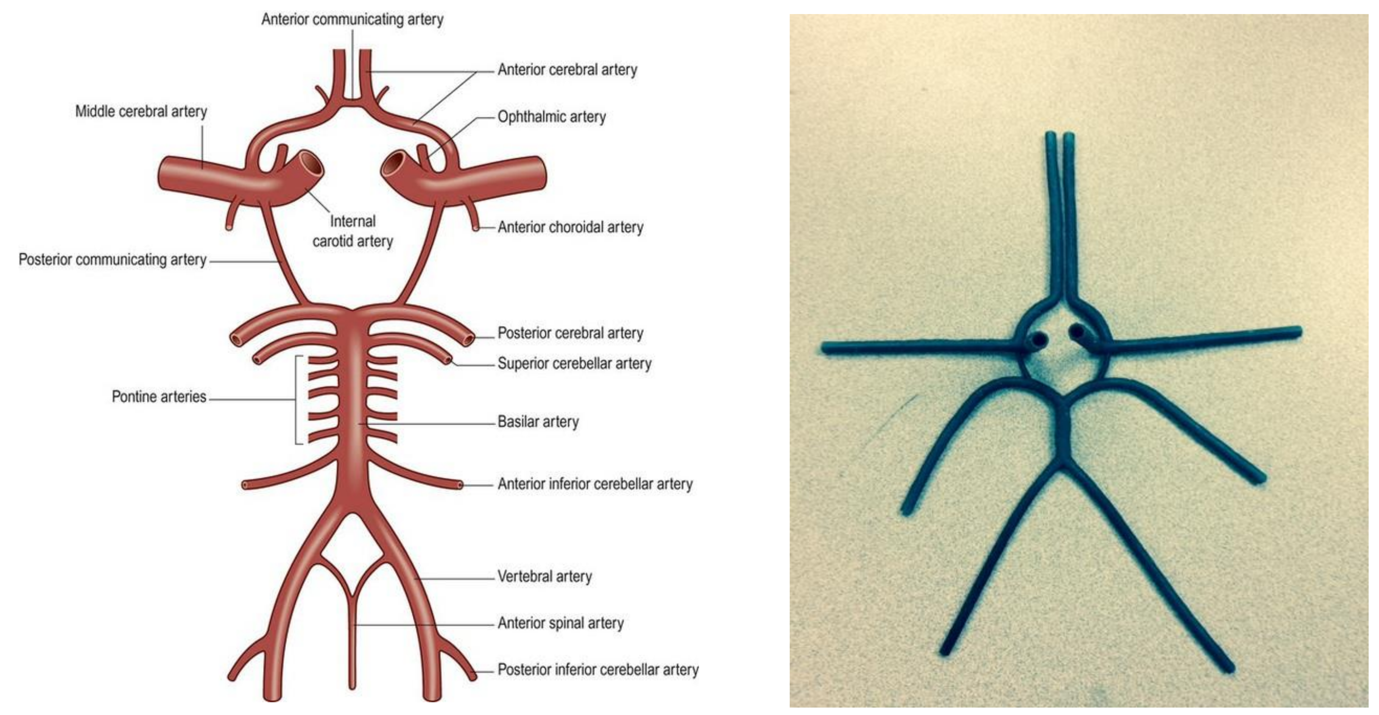

Figure 1: Anatomical Depiction of real Circle of Willis (left) compared to the created model (right). Major arteries have been included in the structure.
[image source: clinicalgate.com]

Methods and Instrumentation

After printing, the model was secured in physiological orientation inside of a plastic skull. A gelatin mixture was then poured through the foramen magnum to create a brain-like phantom. A mixture of dehydrated milk and water was pumped though the model to simulate the scattering effect of blood on TCD frequencies. Flow patterns were analyzed using TCD ultrasound applied directly to the phantom.

Figure 2: Inferior view of the model inside the skull. Milk is pumped upwards through the vertebral and carotid arteries into the model, and out from the top.

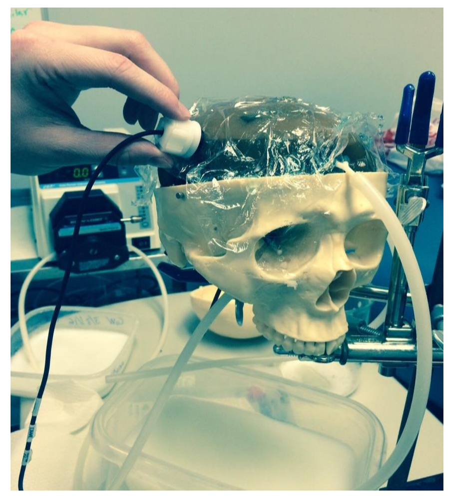

Figure 3: TCD ultrasound procedure performed on the anterior cerebral artery of the model, using milk as a blood phantom and a peristaltic pump.

Results and Discussion

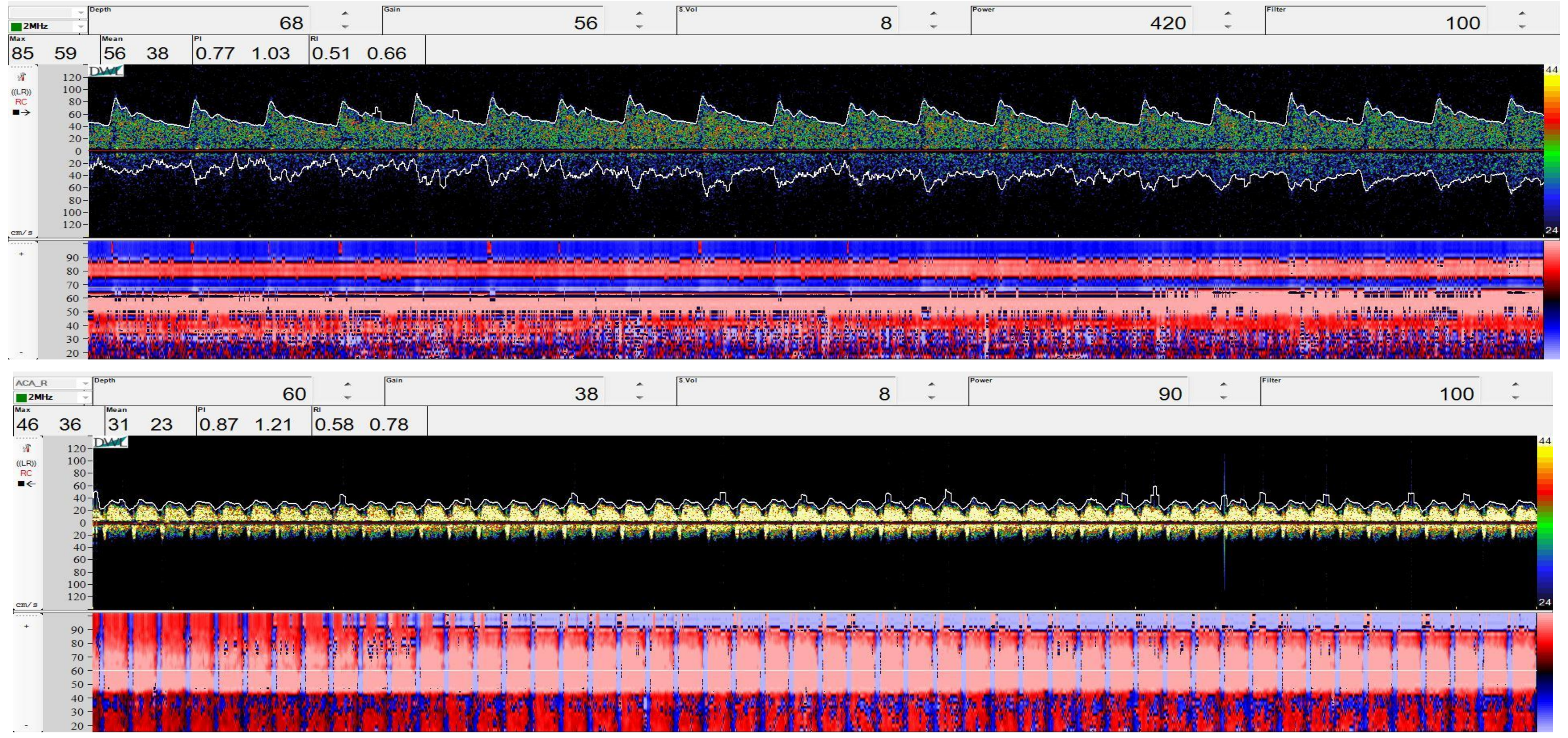

Figure 4: TCD ultrasound waveforms and mmode readings of physiological blood flow (top) and phantom blood flow(bottom) for the left anterior cerebral artery.

- Waveform shape is significantly different between the model and physiological blood flow, due to the use of a peristaltic pump with approximately constant flow.
- Flow moves primarily towards the transducer, supporting consistent movement of the blood phantom through the model.
- The depths of each ultrasound reading are similar, implying the model was in proper orientation inside the skull.

Conclusion and Future Work

The results demonstrate the feasibility of TCD ultrasound to measure flow patterns in a phantom of the Circle of Willis. Further work must be done in simplifying production of the model.

Future efforts will work at optimizing flow rates by increasing pump speed. Waveforms can potentially be normalized using a periodic pump that creates pulsations similar to a human heart. Minimizing vibrations and the effect of tube-model transitions will improve waveforms as well. Other iterations of the model could mimic pathological blood flow in the Circle of Willis, such as an embolus, aneurysm, or a stenosis.

Additional studies may be undertaken to determine effectiveness in teaching medical students how to use TCD ultrasound.

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