“Initial testing of a 3D printed perfusion phantom using digital subtraction angiography”

Computer Integrated Surgery II Seminar Presentation

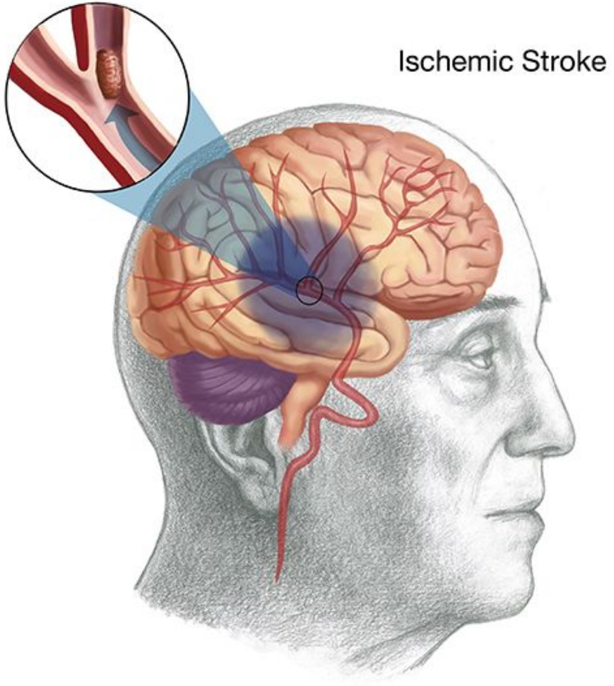
Karthik Chellamuthu and Michael Mow

Project Advisors: Jeff Siewerdsen Ph.D
Wojciech Zbijewski Ph.D
Alejandro Sisniega Ph.D

JOHNS HOPKINS
BIOMEDICAL ENGINEERING

Project Background

- A dedicated Cone-Beam Computed Tomography (CBCT) scanner for the detection and evaluation of intracranial hemorrhage (ICH) is being developed at JHMI
- One established method for the evaluation of ischemic stroke is brain perfusion imaging which describes the passage of blood flow through the brain's vasculature
- Our goal is to develop a digital and physical brain perfusion imaging phantom to evaluate the feasibility of the new CBCT scanner for characterization of perfusion parameters relevant to the detection of ischemic stroke



(N&EA, 2015)

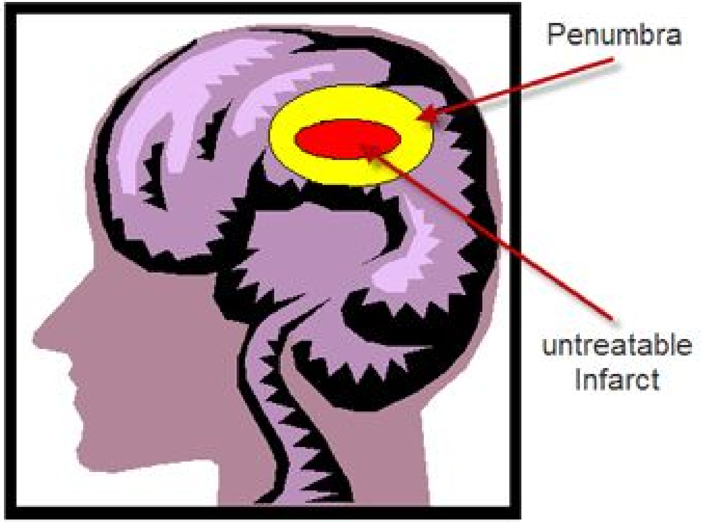
Paper Selection

Wood, R. P., Khobragade, P., Ying, L., Snyder, K., Wack, D., Bednarek, D. R., … Ionita, C. N. (2015). Initial testing of a 3D printed perfusion phantom using digital subtraction angiography, *9417*, 94170V. http://doi.org/10.1117/12.2081471

- Developed a phantom to standardize the protocol associated with existing perfusion systems
- Novelty from other existing phantoms is the comparable capillary size to human brain tissue.
- I chose this paper because of the similarity in goals to our physical phantom
- In the end, we decided to replicate the major aspects of this phantom and incorporate their research into our project

Paper Background

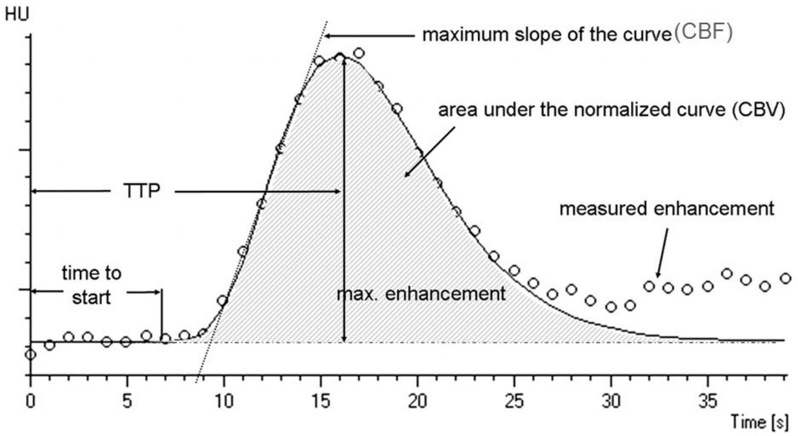
- About 2 million neurons become damaged every minute post stroke and thus the diagnosis time is very important
- Imaging techniques using a contrast agent are used to assist clinicians in identifying the site of an ischemic stroke
- Lack of the contrast agent’s signal indicates blood supply to the tissue is almost zero (labeled as ischemic core)
- Low signal indicates blood supply is quenched, but salvageable (labeled as penumbra)
- It is critical to determine the actual size and location of the penumbra to successfully treat the patients.



Paper Background

Perfusion Parameters:

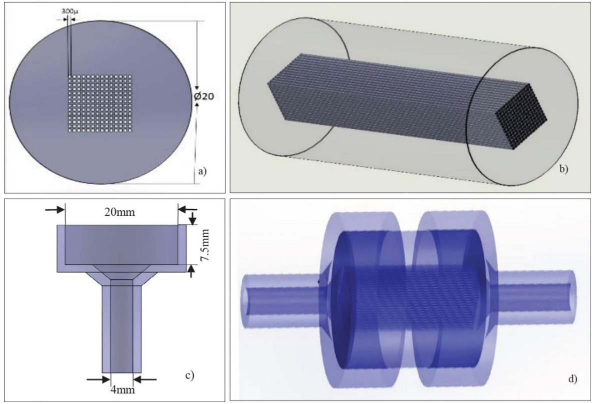
- Cerebral Blood Flow - blood flowing through unit brain per unit time
  - 60-100mL/min/100g in normal tissue
  - 12-25mL/min/100g in penumbra
  - Less than 10mL/min/100g in ischemic core
- Cerebral Blood Volume - volume of blood present per unit volume of brain
- Mean Transit Time - average time for blood to flow through a region of brain



Materials and Methods

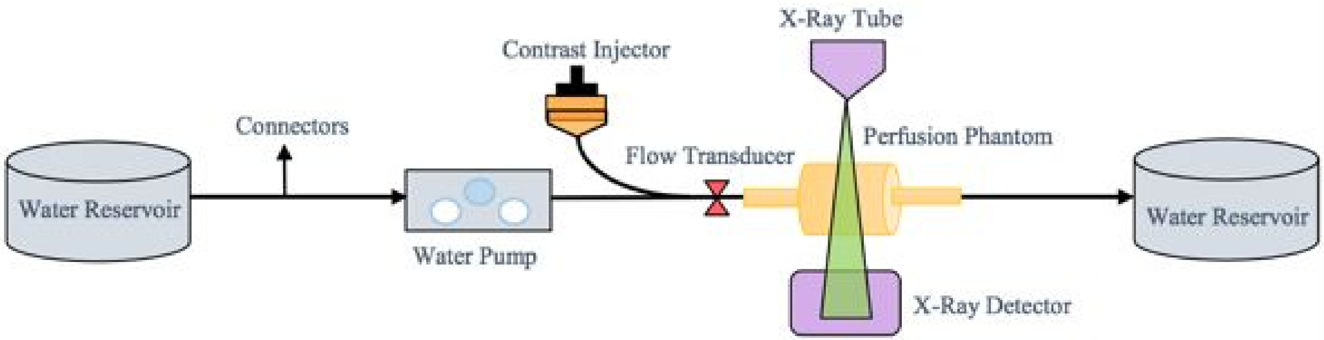
- Phantom was designed on SolidWorks and built with the Objet Eden 260V Stratasys printer

- Dimensions:
- Diameter: 20mm
- Length: 20mm or 30mm
- Capillaries: 196 300umx300um channels



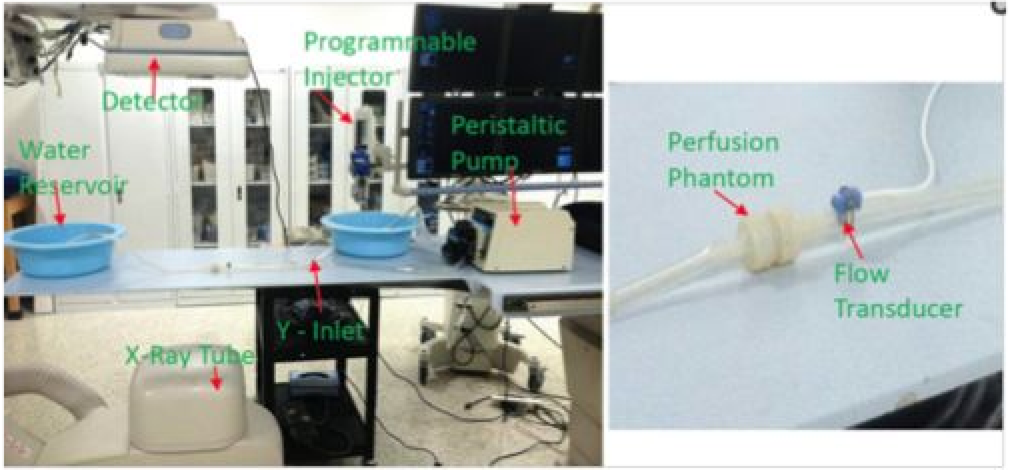
Materials and Methods

- Peristaltic pump: Masterflex Model 77201-62
- Contrast agent: Omnipaque NDC 0407-1414-94
- Contrast injector: Medrad Mark V ProVis PPD 104548
- Flow transducer: Harvard Apparatus GmbH D-79232



Materials and Methods

- Images acquired using Toshiba Infinix VF-i/BP CBCT scanner
- 80 kVp, 160mA, 122cm SAD, 12.5cmx17.5cm FOV, 2 frames/sec frame rate
- Flow rates used: 250, 300, 350 mL/min
- Contrast concentration measured at arterial input, venous output, and capillary region



Custom Software

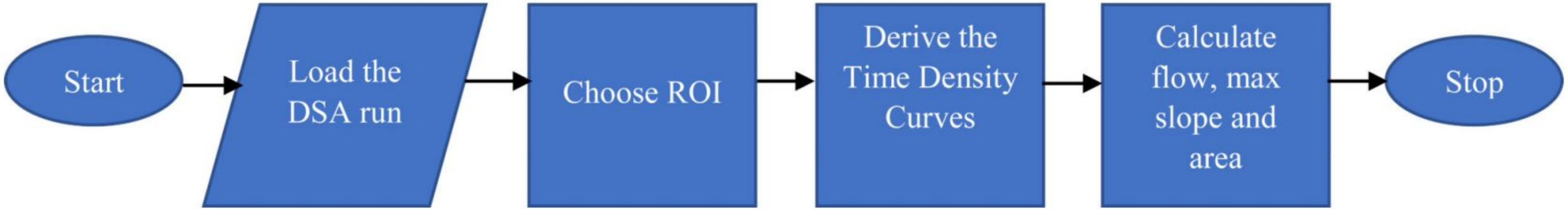
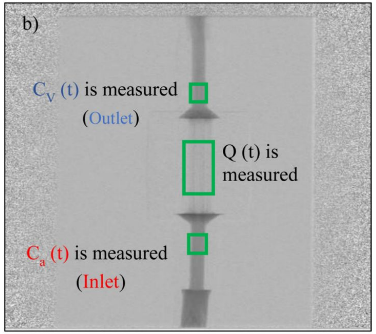
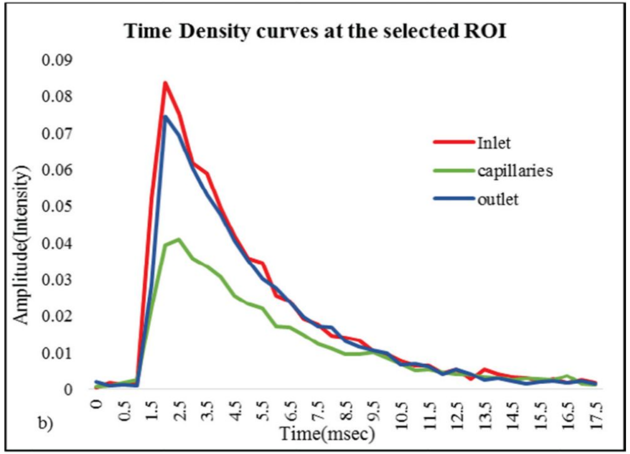


Figure 5.
Flowchart of the algorithm of the custom software developed using LabVIEW

Perfusion Parameter Calculation

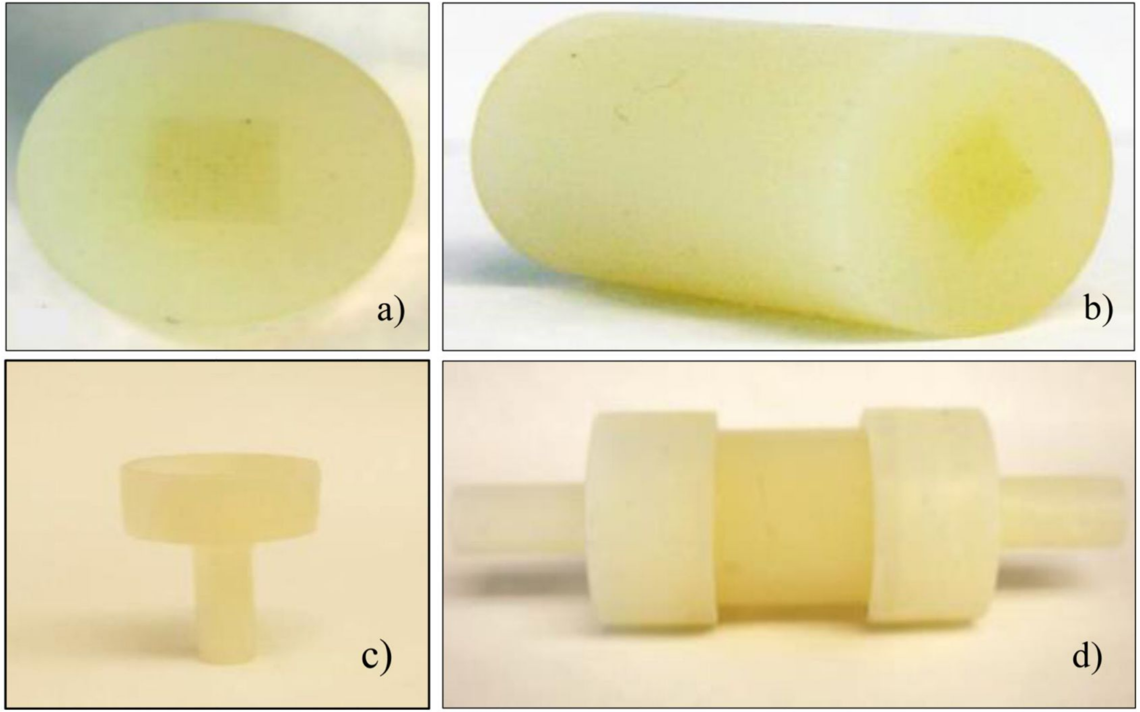
- Accumulated mass given by: $Q(T) = CBF * \int_0^T [C_a(t) - C_v(t)]dt$
  - $C_a(t)$ - contrast concentration at arterial inlet
  - $C_v(t)$ - contrast concentration at venous outlet
  - *CBF* – cerebral blood flow
- Verify system sensitivity by law of conservation of mass:
  - $\int_0^T [C_a(t)]dt = \int_0^T [C_v(t)]dt$
- Maximum Slope: $\frac{d}{dt}[C_a(t)]_{max}$
- Area under curve: $\int_0^T [C_a(t)]dt$, $\int_0^T [Q(t)]dt$, $\int_0^T [C_v(t)]dt$





I-STAR
JOHNS HOPKINS
BIOMEDICAL ENGINEERING

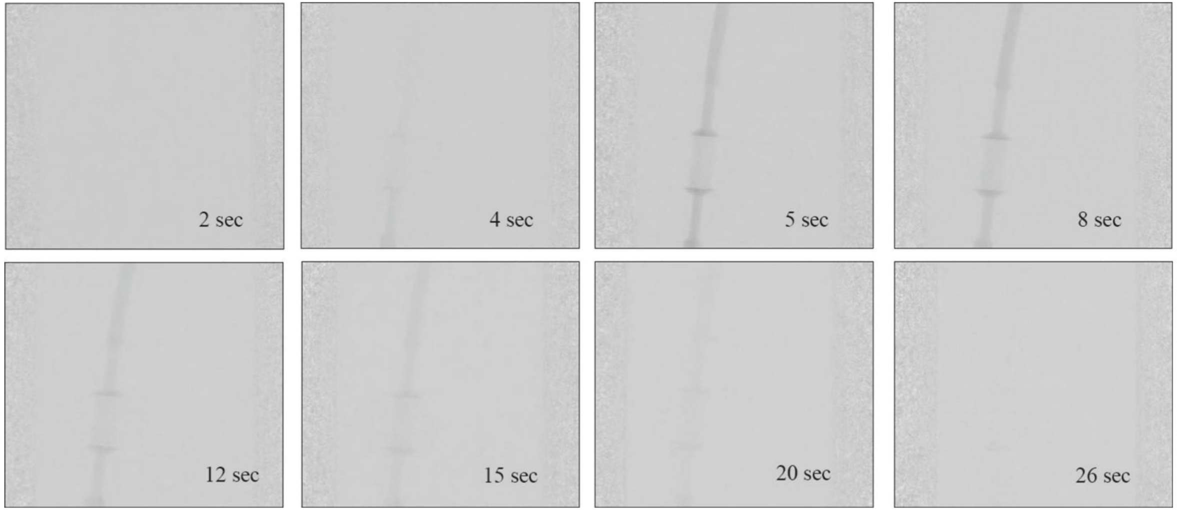
3D Printed Phantom Results

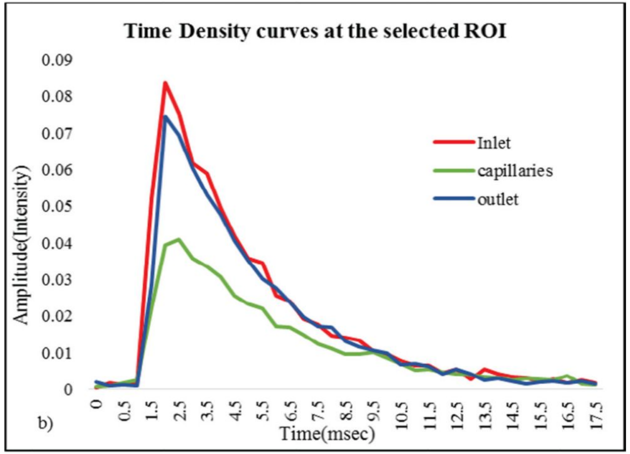


Main Issue

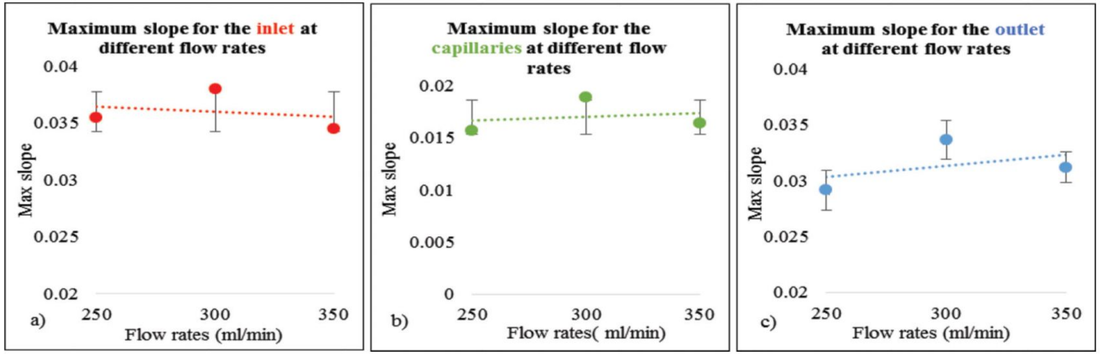
- Took a long time to clean support material out of microchannels

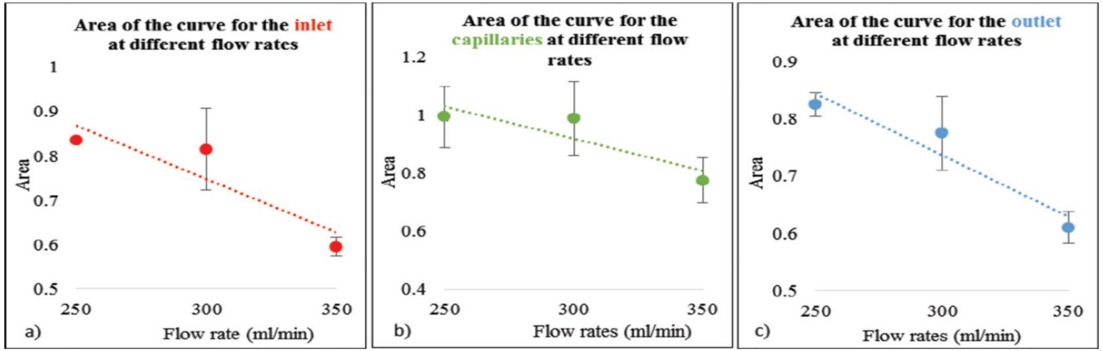
Time Attenuation Results





Perfusion Parameter Results





- Percentage error between inlet and outlet was 1.15%
  - Due to inherent noise in images
- Max slope should linearly increase with higher flow rates
- Area of the curve should decrease with increasing flow rate

Assessment

Pros

- Wood created a perfusion phantom that was physiologically relevant
- Design was simple and easily reproducible
- Produced well behaved time attenuation curves
- 1.15% error in system sensitivity

Cons

- Did not do enough quantitative analysis on results
- Did not vary enough parameters (capillary diameter, other flow rates, contrast concentration)

Relevance To Our Project

- We adapted our CAD design off of the Wood phantom (with minor adjustments to include inserts for tubing and a watertight seal)
- We varied capillary diameter to allow for easier cleaning and a wider range of perfusion parameters
- Our equipment (3D printer, peristaltic pump, contrast injector) is similar or higher quality than used in this paper
- We will perform similar testing as an initial step to validate our phantom