CBCT Brain Perfusion: Digital Simulator and Physical Phantom

Computer Integrated Surgery II, Spring 2016

Karthik Chellamuthu and Michael Mow, under the auspices of Jeff Siewerdsen Ph.D., Wojciech Zbijewski Ph.D., and Alejandro Sisniega Ph.D.

Introduction

We developed a physical brain perfusion phantom and a digital simulator to evaluate the feasibility and performance of a new CBCT head scanner for characterization of perfusion parameters relevant to the detection of ischemic stroke. Working towards the goal of obtaining CT image data collection, our phantom was designed, 3D-printed and incorporated into an open loop flow system for initial validation. Optimized for robustness and computational efficiency, our digital simulator creates a 4D image representation of time attenuation and demonstrates the tradeoff between spatial resolution and temporal sampling. The goal is to validate a new CBCT head scanner for ischemic stroke detection and ultimately validate any CT scanner for perfusion imaging.

The Problem

- Due to the slow rotation speed of a CBCT system, inadequate temporal sampling of time attenuation may not be feasible for perfusion imaging.
- To evaluate this problem, a digital simulator is useful to characterize tradeoffs in varying scanning parameters and perfusion parameters that describe time attenuation.
- A physical phantom is also necessary to obtain real data for a wide range of perfusion cases. Most existing perfusion phantoms are not physiologically similar to brain capillary action and thus a specialized perfusion phantom for our CBCT system is necessary.

The Solution

- We developed a digital simulator of brain perfusion imaging using CUDA Tools GPU implementation. Our simulator takes in a wide range of inputs describing regions of interest, time attenuation, and scanner geometry inputs. A fast forward projection algorithm was implemented and then reconstructed using filtered backprojection.
- With the goal of simplicity, reproducibility, quality of results, and physiological realism, we based our physical phantom on the approach proposed by Wood et al. 2015. The phantom was 3D printed and incorporated into our schematic (Fig.1).

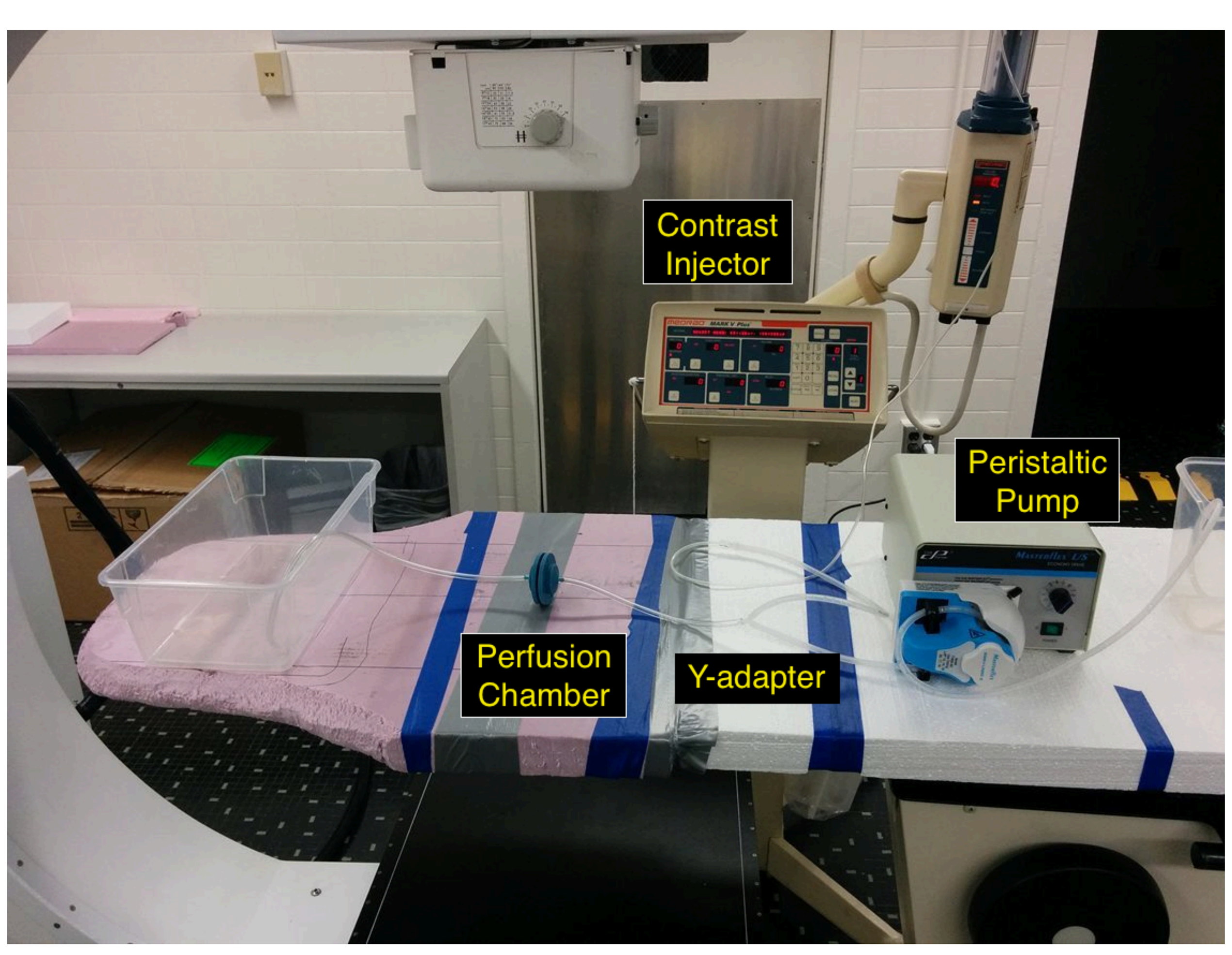

Figure 1. Schematic of Physical phantom

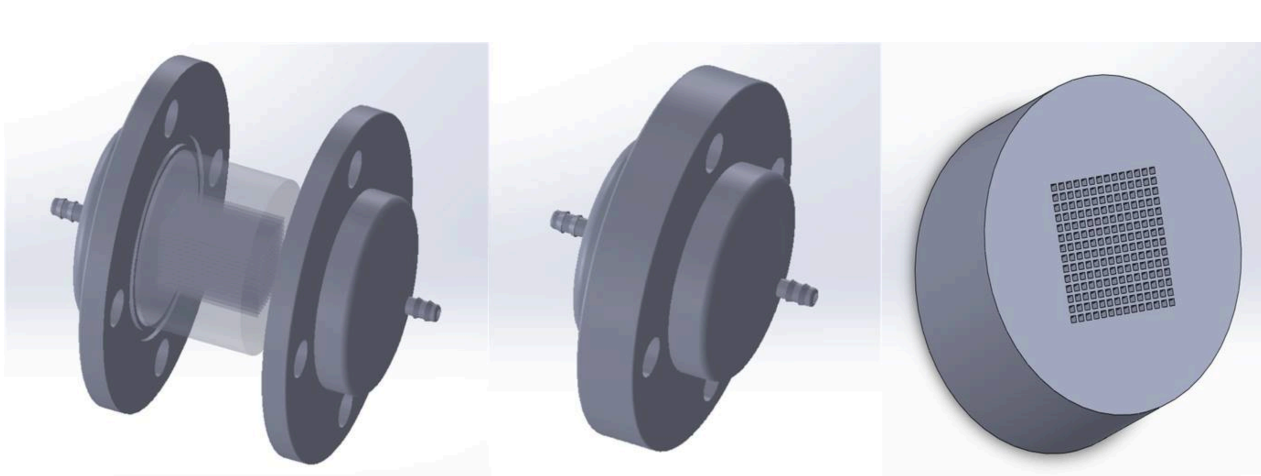

Figure 2. CAD renderings of physical phantom

Outcomes and Results

- We achieve a 10-fold increase in computation efficiency with our faster scaling forward projection implementation in our digital simulator. The tradeoff between spatial resolution and temporal sampling is also observed (Fig. 3-4) with an increase in RMSE for longer scan times between the fitted curve and the original TAC.
- Observing similar flow rates with and without the chamber in the flow loop (Fig.5), our physical phantom design is validated and ready to transition to CT scans.

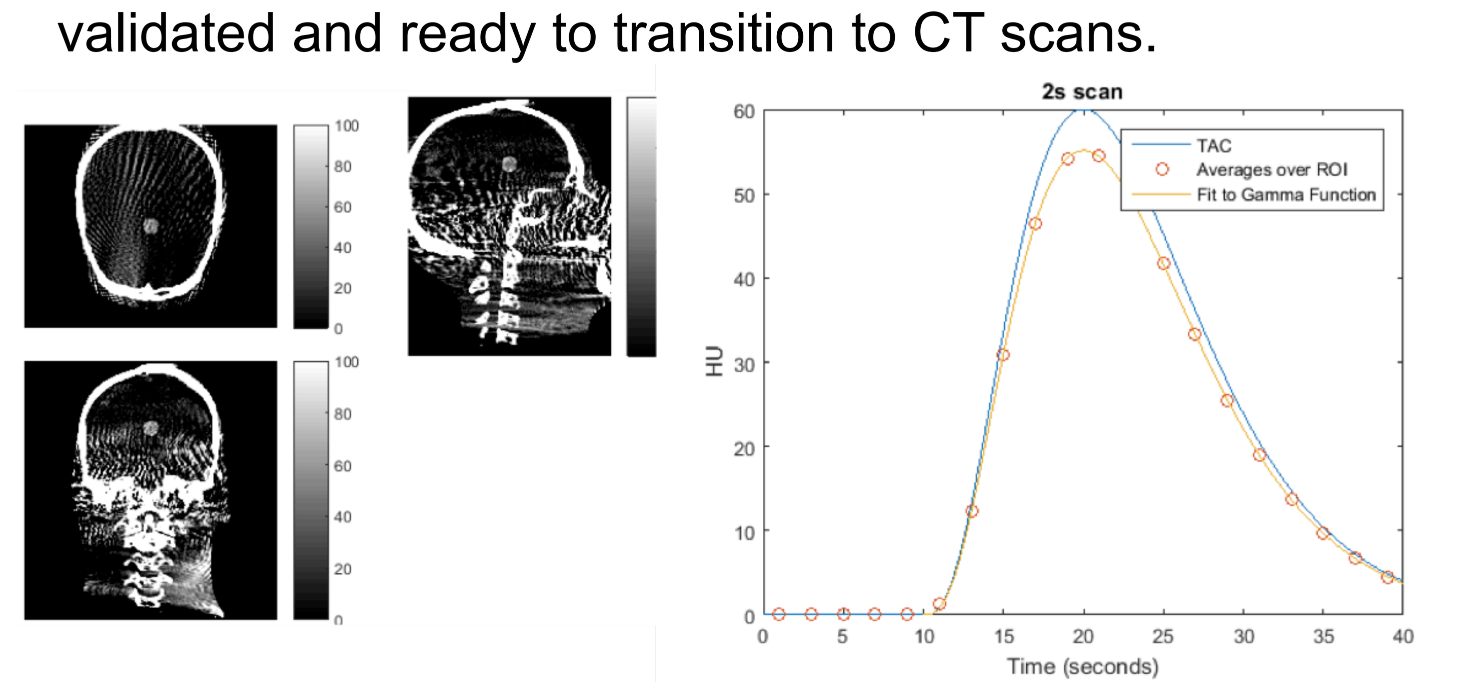

Figure 3. Simulator results from a 2 second scan

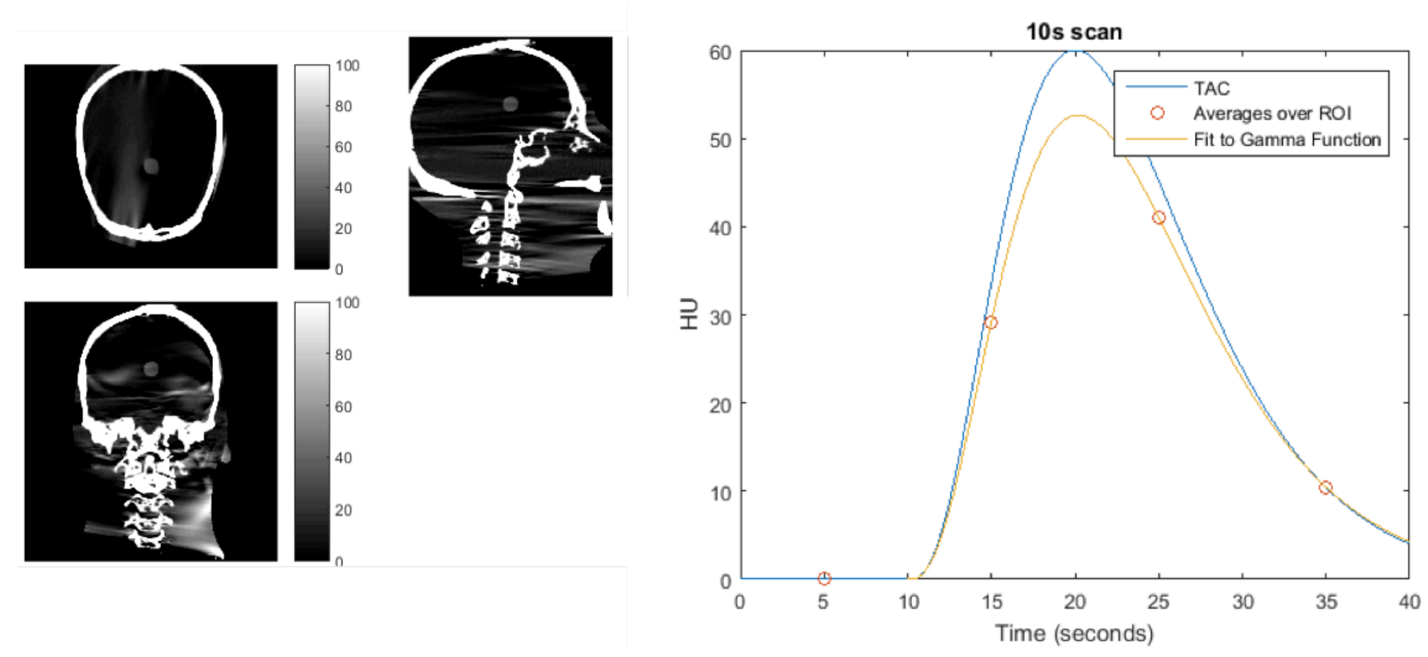

Figure 4. Simulator results from a 10 second scan

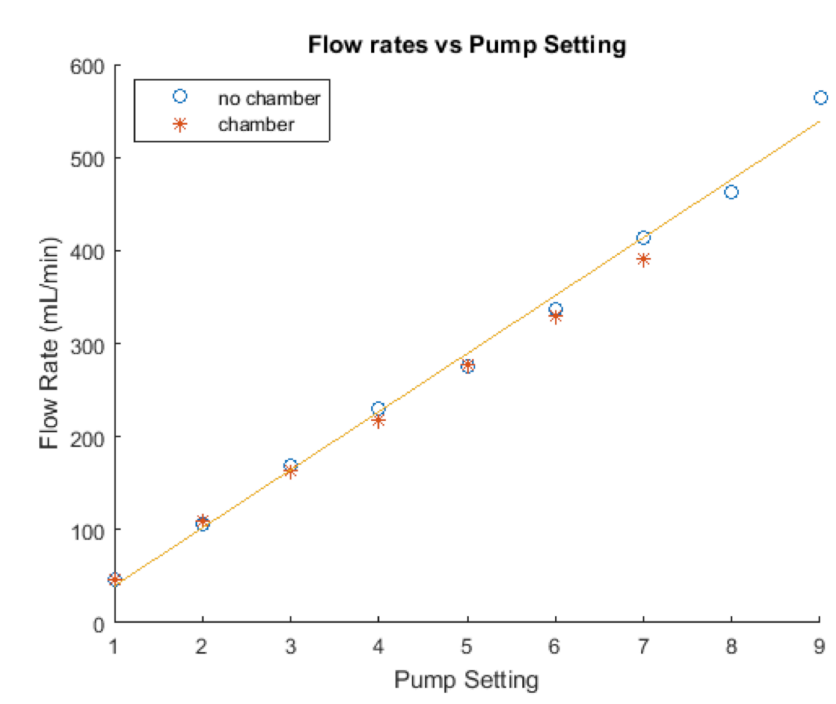

Figure 5. Flow rates with and without perfusion chamber

Future Work

- We will be continuing progress over the summer to further study variation in parameters in the digital simulator and begin testing the physical phantom with a CT scanner.

Lessons Learned

- CUDA Tools GPU implementation, CT image acquisition and reconstruction pipeline
- Design process in designing a phantom and flow system

Credits

- Karthik – Flow system schematic and phantom testing
- Michael – Digital simulator software and CAD

Support by and Acknowledgements

- Thank you to the I-STAR Lab head scanner team and especially our mentors for providing support in the software development and funding for our physical phantom setup.
- Thank you to Russell Taylor Ph.D. for his support through class presentations and feedback.

References

[1] K. A. Miles and M. R. Griffiths, "Perfusion CT: A worthwhile enhancement?" *British Journal of Radiology*, vol. 76, no. 904, pp. 220–231, 2003.

[2] R. P. Wood, P. Khobragade, L. Ying, K. Snyder, D. Wack, D. R. Bednarek, S. Rudin, and C. N. Ionita, "Initial testing of a 3D printed perfusion phantom using digital subtraction angiography," vol. 9417, p. 94170V, 2015.