A Multi-Modal Deep Learning Pipeline Integrating Physics-Informed Neural Networks and 3D Image Processing for Accurate Rupture Prediction and Data-Driven Surgical Planning of Cerebral Aneurysms: Year 3

Vipuil, Eshan (School: West Shore Junior/Senior High School)

Background: Rupture of cerebral aneurysm, an abnormal bulging of the arterial wall, can lead to brain hemorrhage and stroke. Endovascular surgical treatment is highly invasive and poses significant risk to patients, creating a need for accurate rupture risk quantification and informed surgical planning. To achieve this goal, prior work (Years 1-2) focused on developing CFD-based web and virtual-reality tools to visualize and quantify blood flow patterns in diseased arteries; however, derivation and proper interpretation of flow data to accurately determine rupture risk remains challenging. Methods: Year 3 of this work focused on building an end-to-end diagnosis pipeline to detect and estimate the rupture probability of aneurysms using three deep-learning models. A PointNet++ model detects an aneurysm using an open-source dataset of different vascular geometries. Next, an unsteady physics-informed neural network (PINN) derives flow patterns in the artery using the Navier-Stokes equations. Lastly, a multichannel PointNet++ model interprets the flow patterns towards an informed prediction of aneurysm rupture. Results: Statistical analysis using Area Under Curve (AUC) revealed strong success with aneurysm detection (AUC = 0.95). Loss functions indicate that the PINN correction models closely replicate the governing laws of the Navier-Stokes equations (physics loss < 1e-13). A series of modeling strategies were tested to predict rupture, yielding maximum AUC = 0.75. Conclusion: Combining physics-informed neural networks and image processing is a viable strategy to accurately predict aneurysm rupture. Future work will focus on integrating additional parameters such as wall thickness and relative residence time in these deep-learning models to maximize accuracy.

Awards Won:

First Award of $6,000

Lehigh University: Four Scholarships ($20,000 per year for four years)