Computational Flow Dynamics for Patient Specific Pediatric Congenital Heart Anatomy

Disproportional Effect of Congenital Heart Disease on People of Low Socioeconomic Status

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Congenital Heart Disease (CHD) involves abnormalities that develop in the heart before birth and is the most common type of birth defect in the world (CDC, 2019). Pediatric CHD is a heterogeneous field with complex medical anatomy, surgical procedures and catheter based interventional care. Approximately 40,000 babies are born with congenital heart disease each year in the United States and it affects around 1% of all live births worldwide, making it one of the most prevalent conditions amongst newborns (CDC, 2023). These patients hardly ever have the same treatment course and thus the surgeons, cardiologist, and interventional doctors must tailor their treatments and procedures to the individual patient. Currently, doctors rely heavily on subjective judgment when looking at CT angiogram scans and various other imaging techniques to determine further steps of care for patients, specifically when it comes to catheterization procedures. While in diseases where there's minimal variability among patients, this wouldn't typically pose an issue, but the highly diverse nature of congenital heart defects between individuals can present challenges for cardiologists when devising treatment strategies and leads to patients needing more medical scans done such as a nuclear lung perfusion scan (Fathala, 2010). It can also lead to incorrect diagnoses and the need for longer or even multiple catheterization procedures, all of which can put unnecessary stress on a young child's heart and body.

Given the variability and uncertainty in treatment plans between congenital heart disease patients, it is imperative that pediatric cardiologists use every tool at their disposal to create more accurate diagnoses and treatment actions. The technical side of my project aims to take an element of this subjectivity out by creating a machine learning algorithm that can take in a CT angiogram scan, create a 3-dimensional model out of it, and quantify blood flow to different parts of the lung. This output of the program would be the same output of performing a nuclear lung perfusion scan, but only requires the patient needing a single CT scan which is done as standard practice anyways. Not only will this allow a pediatric cardiologist to get a better quantitative grasp of a CHD diagnosis, but it will also eliminate the need for nuclear lung perfusion scans and allow quick blood flow data before, after, and even during catheterization procedures, ultimately reducing patient cost and improving clinical outcomes.

Transitioning to a more social lens on the issue of CHD, my STS portion of the project aims to explore the disparities seen with congenital heart disease disproportionally affecting individuals who are part of a lower socioeconomic status. A population-based retrospective cohort study conducted in Canada found that infants born to mothers living in low-income neighborhoods were more at risk for developing CHD compared to infants born to mothers living in high-income neighborhoods (Tran et al., 2023). This trend is seen in other studies as well performed across various geographies, and there is a clear global trend. Given that congenital heat disease is a genetic disease, that begs the exploration of what epigenetic factors are affecting those of lower socioeconomic status that is leading to this disparity in CHD. My STS research will identify these epigenetic factors and explore the systemic reasons why people of lower socioeconomic status experience these factors leading to the disparities seen in CHD.

Technical Project: Computational Flow Dynamics for CHD

Congenital heart disease is diagnosed with imaging techniques like CT scans and nuclear lung perfusion scans, and is most often treated through cardiac catheterization procedures which play a crucial role in the treatment of most current heart diseases. However, the current standard for determining the success of catheterization procedures dealing with CHD involves a nuclear lung perfusion scan before and after the procedure. For this scan radioactive contrast is injected intravenously, and a gamma camera is used to take scans at multiple angles (Mirza & Hashmi, 2023). My technical project aims to eliminate the need for nuclear lung perfusion scans by leveraging a machine learning pipeline on CT scans, thereby quantifying the assessment process and improving patient care.

Importantly, pediatric patient data including CT scans and nuclear lung perfusion scans post and pre-catheterization have already been collected by Dr. Shorofsky and IRB approved, allowing our team to get started right away. With this data, we plan to segment the CT angiogram scans into detailed 3-dimensional models capable of being processed in further fluid dynamic software. To accomplish this, we will use a 3-dimensional slicing software capable of creating detailed cardiac models from CT scans as well as allowing doctors to explore the patient's heart in virtual reality. The model will then be smoothed in order to get rid of abnormalities and be compatible for processing in the further software.

Once the 3-dimensional models of the pulmonary vasculature are created, the project moves forward to the next stage, where a machine learning model for Computational Fluid Dynamics (CFD) is built. This step leverages Dr. Dong's lab's proprietary machine learning software in conjunction with Maya which is an existing computational fluid dynamics software. The software processes the segmented data and will output percentages of blood flow in sections of the lung, essentially producing the same data a nuclear lung perfusion scan would. It further incorporates a user-friendly interface for cardiologists who often might not have an engineering background, making it practical for clinical applications.

The final stage of the project focuses on validating the machine learning algorithm by comparing its CFD-generated data with the outcomes of nuclear lung perfusion scans. The success of the project is demonstrated by ensuring the algorithm's consistent replication of data with an accuracy rate exceeding 95%. Furthermore, the algorithm will be applied to a more extensive patient base, both pre- and post-catheterization, to gather data for potential publication. This rigorous comparison between the results will showcase the reliability and practicality of the algorithm in clinical settings.

This project's endeavor to replace nuclear lung perfusion scans with a machine learning-enhanced CT imaging solution represents a significant step forward in the field pediatric CHD. This approach offers a multitude of benefits, such as reducing radiation exposure, minimizing costs, and most importantly taking away an element of subjectivity for cardiologists and replacing it with quantitative metrics. The proposed technology addresses the overall problem introduced in the beginning by providing a reliable and quantitative method for diagnosing and treating the vastly varying conditions within congenital heart disease. The technological solution offers a reliable and practical alternative to nuclear lung perfusion scans, promising a safer, more efficient, and cost-effective future in the evaluation and treatment of pediatric congenital heart disease.

STS Project: Socioeconomic Disparities Involving Congenital Heart Disease

Congenital heart disease is one of the most common congenital disorders in the world, but it has been identified that this disease disproportionally affects people of a lower socioeconomic status. As mentioned previously a Canadian study found that infants born to mothers living in low-income neighborhoods were more at risk for developing CHD, and a same trend was seen in a California population-based study which concluded that "increased social deprivation and exposure to environmental pollutants are associated with the incidence of live‑born CHD in California" (Peyvandi et al., 2020, pg. 1). There are plenty of studies like these ones that showcase this interesting correlation seen in the patient base of congenital heart disease, and given that congenital heart disease is a genetic disease it begs the exploration of the epigenetic factors that people of a lower socioeconomic status are exposed to that is causing this correlation.

This discovery led me to my STS research question: why are people of a lower socioeconomic status more exposed to the negative epigenetic factors leading to the disparities seen in diagnosis of congenital heart disease? Epigenetic factors such as environmental pollutants and poor diet are large factors in their influence on the human genome and are proven congenital heart disease risk factors (Kalisch-Smith et al., 2020). According to the American Lung Association, these factors are far more prevalent in communities of a lower socioeconomic status, and I am aiming to explore why this is the case and hope to explore the systematic issues that are leading to this disparity (*Disparities in the Impact of Air Pollution*, 2023). Additionally, overall systematic healthcare issues such as distance of residence from tertiary care negatively influences detection of overall health problems, and specifically CHD in this case (Kaur et al., 2022). Systematic factors such as those lead to exposure of negative epigenetic factors and poor healthcare access, causing the trend seen in the disparities of CHD (Khullar & Chokshi, 2018). The disparity of CHD affecting people more of a lower socioeconomic status has been identified, but it is highly important that we get to the root cause of what is causing this trend in order to implement new healthcare practices and overall improve health outcomes for the whole population.

To carry out my research, I plan on performing a literature review by diving into existing research literature and utilizing the resources of Dr. Shorofsky. My capstone advisor is a pediatric cardiologist himself that specializes in congenital heart disease, so I will leverage his knowledge on the disease to better understand the types of patients he mainly sees, and possibly even speak to public health officials he may know at UVA. This will allow me to get a real perspective on the issue and even a head start when it comes to targeting by literature search. I also want to connect with my advisor's cardiologist colleagues and ask if they are aware of the epigenetic risk factors with CHD, and if so how does that change their perspective of care from patient to patient based on their background. Following my initial conversations, I will perform literature research where I will look at papers that are more focused on the systematic issues such as why people of a lower socioeconomic background tend to be forced to live in areas exposed to much higher levels of environmental pollutants as well as factors such as worse access to organic foods which have been a proven factor in affecting the human genome (Franzago et al., 2020). This range of research on systematic issues will allow me to explore the real social reasons behind the disparities seen in congenital heart disease.

In order to analyze the material I gather, I plan to use Pinch & Bijker's (1984) STS theory "The Social Construction of Facts and Artefacts." Their core argument is that the development of facts and artefacts is not just based on scientific knowledge but also influenced by social, political, and economic systems within society. They argue that sociology of science and sociology of technology should collaborate with their schools of thought to understand how these two categories are constructed within social contexts (Pinch & Bijker, 1984). The authors set up the framework for the social construction of technology (SCOT) theory in the paper, and I will use that to relate the social constructs I research and evaluate how that has affected the current technology used in the process of treating congenital heart disease. Specifically, I will draw upon SCOT concepts such as interpretative flexibility and relevant social groups to scrutinize the social constructs influencing the technology currently being used to treat CHD. More importantly, I will relate the STS research I will do on the systematic issues leading to the CHD disparities to the new technology my team is creating in the technical portion by using the SCOT theory. This connection will allow me to reveal how the social constructs have shaped the current technology, but will also reveal how the technological solution which makes diagnosing and treating CHD more accurate and more cost accessible, will contribute to addressing the STS research question and ultimately lead to better healthcare treatment for marginalized groups affected by CHD.

Conclusion

The output of my technical project is a machine learning algorithm that will quantify blood flow percentages in different parts of the lung by only using a CT scan, essentially eliminating the need for nuclear lung perfusion scans. The output of my STS research will be understanding the systemic issues behind why people of a lower socioeconomic status are more exposed to the epigenetic factors that lead to the disparities seen in congenital heart disease diagnosis.

The output of this research will allow cardiologists to make quantifiable decisions when it comes to diagnosis and treatment plans related to congenital heart disease. I hope the STS project will be read by cardiologists allowing them to be aware of the disparities in CHD, the root cause of these disparities, and they will be able to make better patient decisions and use identifying factors to catch CHD diagnoses earlier. Ultimately, these projects combined will lead to better patient outcomes when it comes to treating congenital heart disease, especially for a marginalized group of people affected by CHD.

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