CT Circulation Phantom to Assess Hyperdynamic Contrast Flow Rates

BME Design Excellence Executive Summary

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Background

Venoarterial extracorporeal membrane oxygenation (VA-ECMO) is a life support device that is implemented in patients experiencing loss of proper function of the heart and/or lungs. In recent years, due to technological advances as well as the COVID-19 pandemic, there has been a significant rise in the number of patients on VA-ECMO in the emergency room. Even before 2020, cardiologists have seen a 458% rise in the use of VA-ECMO since 1990.

Problem and Existing Products

VA-ECMO complicates the fluid dynamics of blood mixing with contrast agents used for CT imaging due to retrograde flow, along with competition between the mechanical support of the VA-ECMO pump and possible partial heart function. These complications lead to irregular mixing and subsequent image artifacts appearing in the aortic arch. It is crucial that this phenomena can be recreated for further research into combating this diagnostic challenge. While there are not any dynamic flow circulation phantoms on the market, there are several that have been fabricated and utilized in research and clinical settings.

Design

The design consists of a 3D printed aortic arch made of Elastic 50A Resin, connected tubing that allows for the fluid to flow through the aorta, a roller pump which generates force to push the fluid through the circuit, and a large reservoir of fluid. The design mimics VA-ECMO procedures and supports adjustable flow rates. This phantom utilizes a pump that supports flow rates up to 5 L/min and is secured to ensure that there is no leakage of fluid throughout the circuit. This design provides radiologists with a safe and user-friendly solution to the diagnostic problem from using VA-ECMO in CT imaging.

Prototype Testing

The prototype was tested to ensure that it produces accurate flow rates, is entirely leak proof, and accurately represents the contrast mixing seen in patients on VA-ECMO. The flow rates were tested by submerging one end of tubing in a liter of water and having the other end transfer the water into an empty reservoir. The speed was calculated by dividing the volume of water moved by the total time it took to move. To ensure that it was leak proof, the phantom and circuit was filled with water and observed for any leakage. Lastly, to test if the design was an accurate representation of a patient, the phantom and circuit was put into a CT scanner, injected with iodinated contrast, and analyzed through the images that were produced. These images were analyzed by similarity to physiological conditions including attenuation coefficient and appearance of iodinated contrast in the phantom. The prototype met all desired criteria.

Impact

Per emergency room and ICU protocol, patients on VA-ECMO require extensive CT scanning. A CT circulation phantom that mimics the fluid-dynamic qualities of a patient on VA-ECMO is crucial for future research that results in the development of CT protocol and medical standards for scanning such patients.