A Novel Approach to Thromboembolic Event Detection: An Initial Evaluation

Basil P. Alias[1], Emily Lo[1], Divek Toprani[1], Wesley Lim, M.D[2].
1. School of Engineering Medicine, Texas A&M University, Houston, TX
2. HCA Houston Healthcare West, Houston, TX

Background

- Deep vein thrombi pose a risk of causing pulmonary embolism (PE) due to their direct upstream position to the inferior vena cava (IVC) and subsequent pulmonary arteries
- IVC filters are devices designed to prevent clots from reaching the lungs in patients with contraindications to anticoagulation
- Electrical impedance tomography utilizes the electrical conductivity of a material to generate non-ionizing continuous cross-sectional imaging between a group of electrodes placed equidistant from each other in a conductive solution
- By integrating EIT with IVC filters we hope to improve outcomes for patients by gaining insight into when and what kind of thromboemboli are caught in the filter

Objective

To design a prototype IVC filter that can use electric impedance tomography to detect intraluminal thrombus

Methods

The device is composed of three principal components::
Inferior Vena Cava (IVC) filter/sensor, the signal-directing circuit, and the processing unit

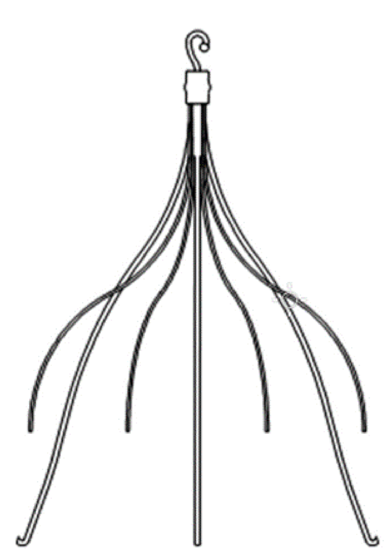

FIGURE 1: EXAMPLE OF IVC FILTER

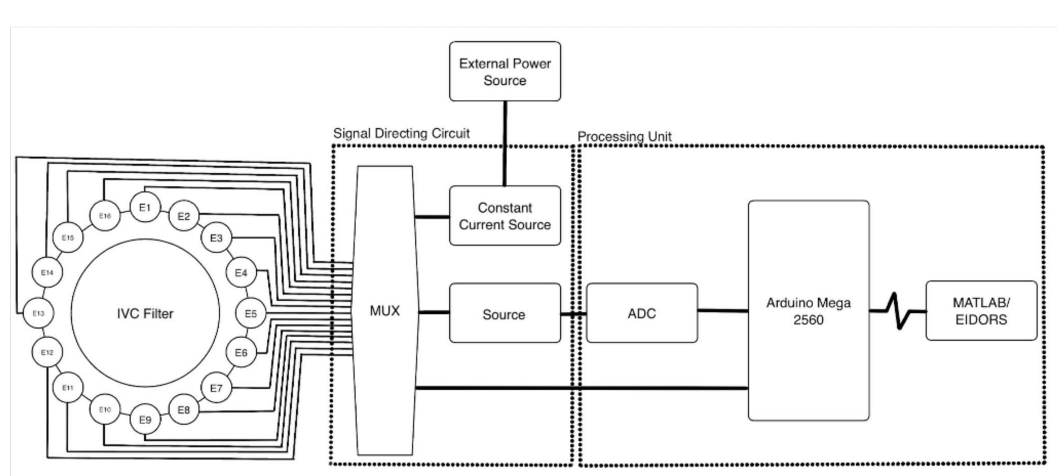

FIGURE 2: OVERVIEW OF ELECTRICAL AND SOFTWARE ARCHITECTURE

- **Testing Goals:**
  - Mimic the mechanical function of current IVC filters
  - enhancing signal collection capabilities and minimize noise
- **Testing Protocol:**
  - the prototype submerged in distilled water
  - 0.5 x 0.5 x 0.5 cm rubber cube to mimic a thrombus
  - A 75mm diameter 3D-printed polylactic acid (PLA) ring for electrode spacing

This research was supported (in whole or in part) by HCA Healthcare and/or an HCA Healthcare affiliated entity. The views expressed in this publication represent those of the author(s) and do not necessarily represent the official views of HCA Healthcare or any of its affiliated entities.

Results

The electrical output was then visualized as a heatmap, reflecting the circular configuration of the IVC filter's electrodes
A comparative computer simulation of the test environment was conducted, incorporating a proportionally scaled cross-sectional area with a zone of increased resistance, emulating the presence of the rubber cube.

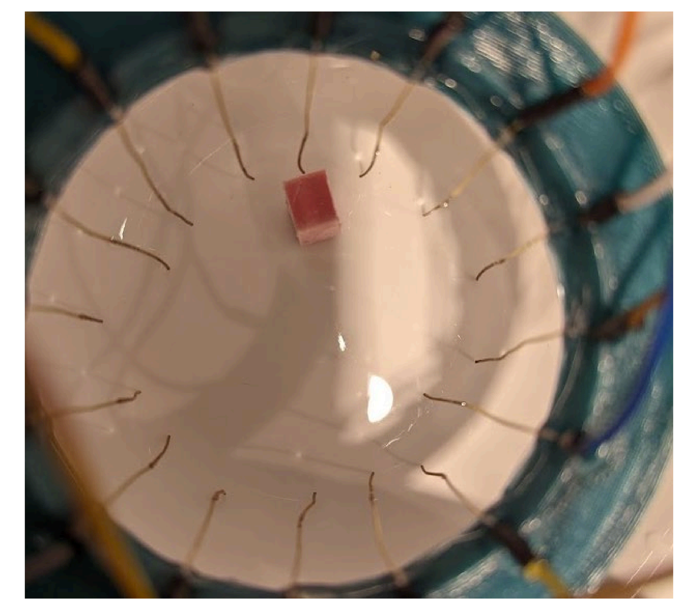

FIGURE 3: Test setup with electrodes submerged in distilled water

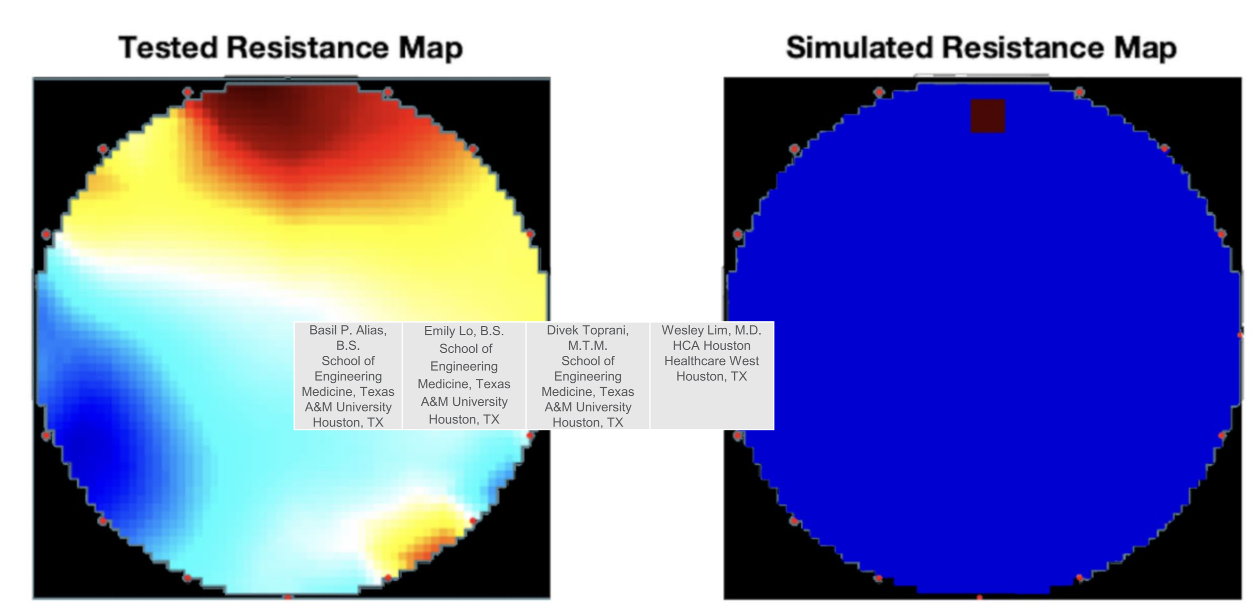

FIGURE 4: Generated cross-sectional heat map of resistance (left) and simulated ideal resistance heatmap (right)

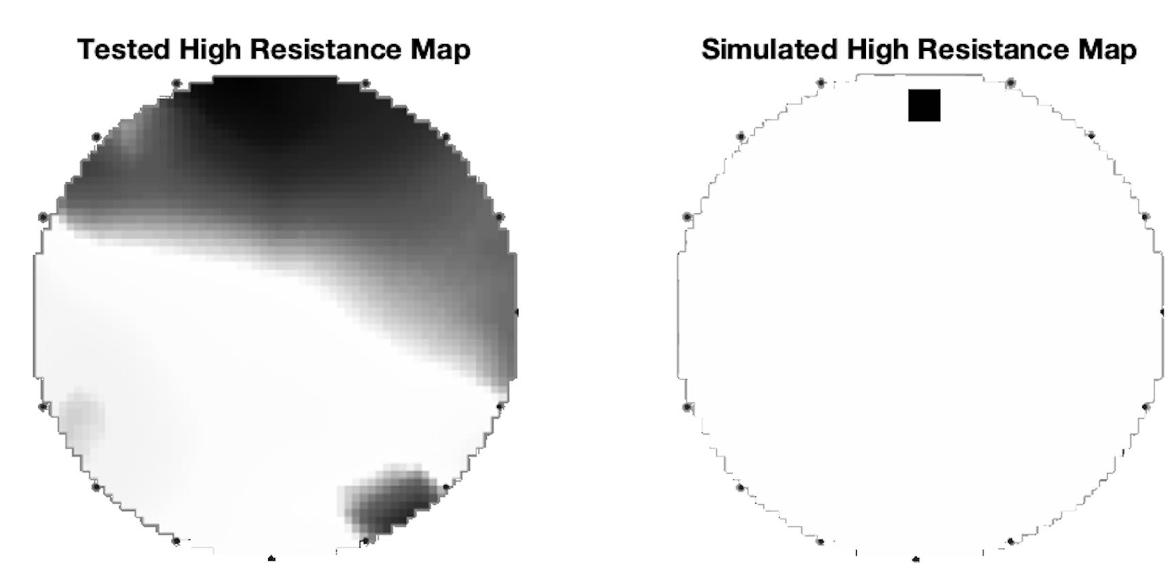

FIGURE 5: Filtered high relative resistance map (left) and simulated ideal resistance map (right)

Comparison	
Correlation Coefficient	0.181
MSE	0.147
Structural Similarity Index	0.513

Discussion

- These metrics did not signify a robust detection capability likely due to the stark contrast in the simulated map between areas of high and low resistance
- Discrepancy in accuracy can be attributed to a few factors, such as the medium of choice and electrode contact area.
- These tests were conducted in distilled water, it would be ideal to run the test in blood, as its conductivity is higher
- Further improvement will focus on increasing reliability during experimentation and reducing signal noise
- Future development involves exploring alternative IVC filter designs to reduce system noise, enhancing image accuracy, and testing performance in a flowing medium
- Challenges for future designs include addressing the increased risk of thrombus formation due to increasing surface area on the device itself and delineating implantation mechanisms
  - ex. miniaturizing the device for transcatheter deployment such that the device does not occlude the vessel lumen
- There are potential applications in other implantable circulatory devices, for example, detecting stent-based complications

Conclusion

- This study demonstrates the potential of electrical impedance tomography as a non-ionizing modality for continuous intraluminal imaging, despite its sensitivity to environmental factors.
- The device is capable of detecting areas of relatively high resistance within a fluid-filled lumen which translates into the ability to detect emboli in an IVC filter.
- Further development and testing are needed to improve the reliability and accuracy, improve injection patterns, and further develop device design and implementation.
- In summary, the TEDID system, leveraging EIT, has the potential to improve current DVT/PE management, offering a safer alternative to traditional treatment modalities.

References

1. Cheney M, Isaacson D, Newell JC. Electrical Impedance Tomography. SIAM Review. 1999;41(1):85-101. doi:https://doi.org/10.1137/s0036144598333613
2. Liu D, Gu D, Smyl D, Khambampati AK, Deng J, Du J. Shape-Driven EIT Reconstruction Using Fourier Representations. IEEE Trans Med Imaging. 2021;40(2):481-490. doi:10.1109/TMI.2020.3030024
3. Chen X, Wang Z, Zhang X, et al. Deep Autoencoder Imaging Method for Electrical Impedance Tomography. IEEE Transactions on Instrumentation and Measurement. 2021;70:1-15. doi:10.1109/TIM.2021.3094834