The Use Of Pulse Wave Doppler To Characterize Embolic Events In A Flow Loop System

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Introduction

Carotid embolectomies and endarterectomies (CEA) previously required large invasive surgeries to prevent perioperative embolization from working sites. Modern approaches including flow reversal and filters still fail to prevent post-CEA strokes, raising many questions including the effectiveness of filters and whether post-CEA infarcts might form via alternate mechanisms. The purpose of this study is to further explore the capabilities and limitations of emboli detection using pulse wave ultrasound (US) including its ability to physically characterize detected emboli with the ultimate goal of continuous noninvasive monitoring of embolic events.

Doppler ultrasound is commonly used to visualize flow of vessels and soft tissue structures, utilizing a difference of frequency or wavelength at an observed point in comparison to a source wave. Pulsed wave Doppler is a form of Doppler ultrasound that alternates between sending and receiving ultrasound signals, which allows for improved resolution of range and localization of signal [1]. This is the predominant method of ultrasound used to assess blood flow in vessels such as in Transcranial Doppler, which uses ultrasound-generated velocity waveforms to identify intravascular microemboli. Transcranial Doppler can also detect embolic signals, using the different acoustic properties of emboli compared to the surrounding blood, that can be identified as a brief, high intensity increase in sound [2].

Methods

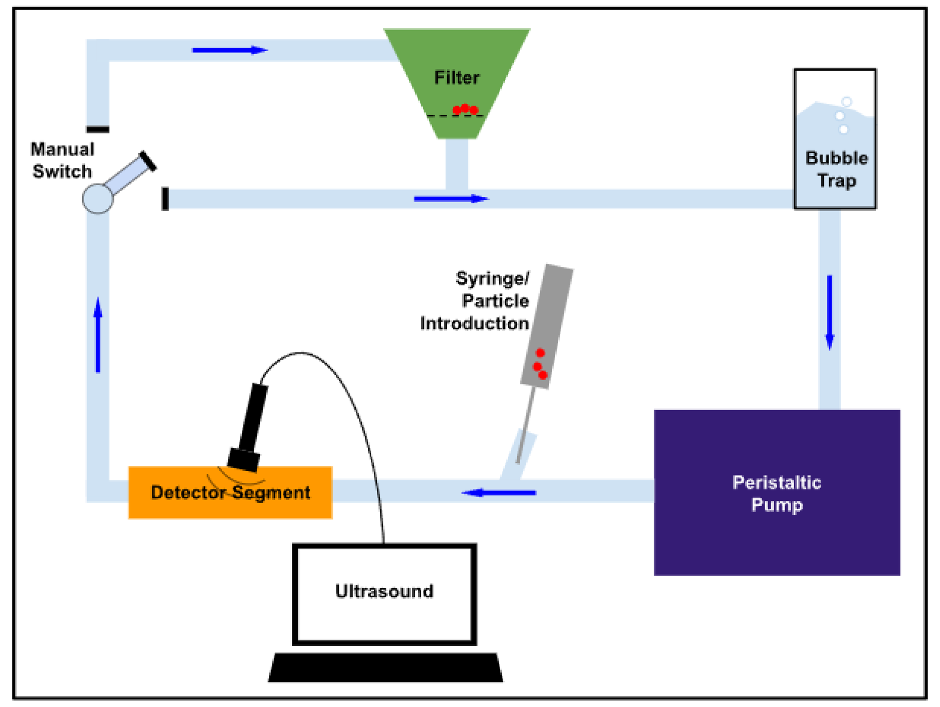
An experimental flow loop system was devised to mimic embolus movement within blood vessels. This setup ensured emboli integrity while enabling solution circulation, contaminant removal, controlled emboli introduction, and emboli detection via ultrasound (Spencer Technologies PMD100). Baseline flow data was collected for 30 seconds at 200 RPM (226 mL/min) using the Kamoer KCM pump. Subsequently, 0.2 mL of Embozene Microspheres were injected, circulating for 1 minute for particle homogeneity and bubble removal. Another 30-second flow dataset was collected before a 1-minute filtration in preparation for subsequent tests. This cycle was repeated thrice for emboli of sizes: 40 μm, 75 μm, 100 μm, 250 μm, 400 μm, 700 μm, 1100 μm, and 1300 μm. These spikes were then individually identified and their characteristics analyzed. Analysis employed MATLAB R2023a and Microsoft Excel.

Results

For each test 30 seconds of baseline flow data and 30 seconds of flow with emboli data were collected. Using the baseline data to filter the background signal from the emboli data revealed velocity spikes as the emboli passed the US transducer. For each spike, 4 parameters were generated: Maximum Slope, Maximum Velocity, Area Under the Curve, and Total Time (Figure 1b). Parameters were analyzed with a t-test between sample averages to determine if the difference between samples was significant.

Results of the study indicate that particle size varies inversely with both Displacement and Average Time per Spike. There is no significant difference between emboli from 40 to 250. Universally significant differences appear for emboli at 400, 700, 1100 and

1a.



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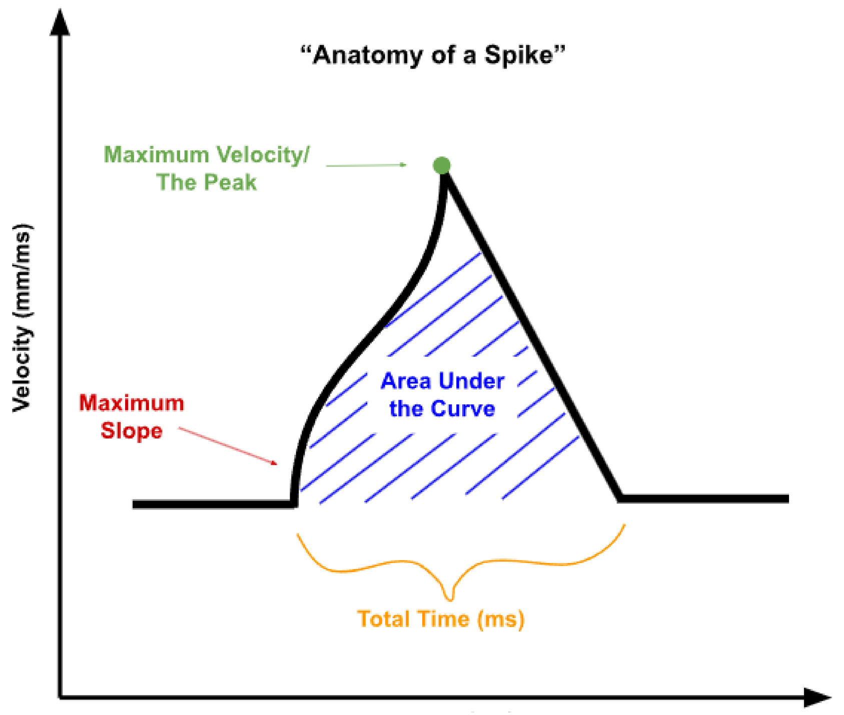

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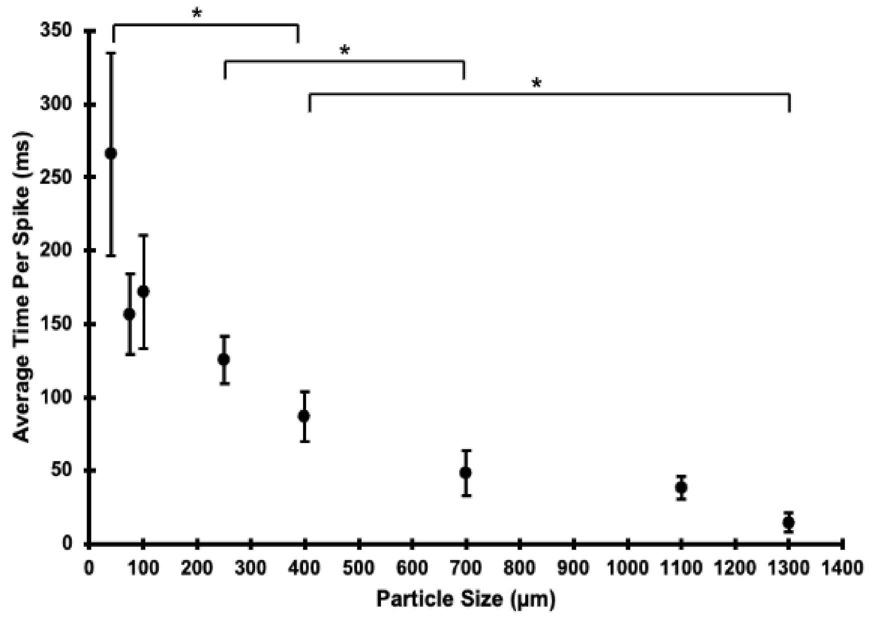

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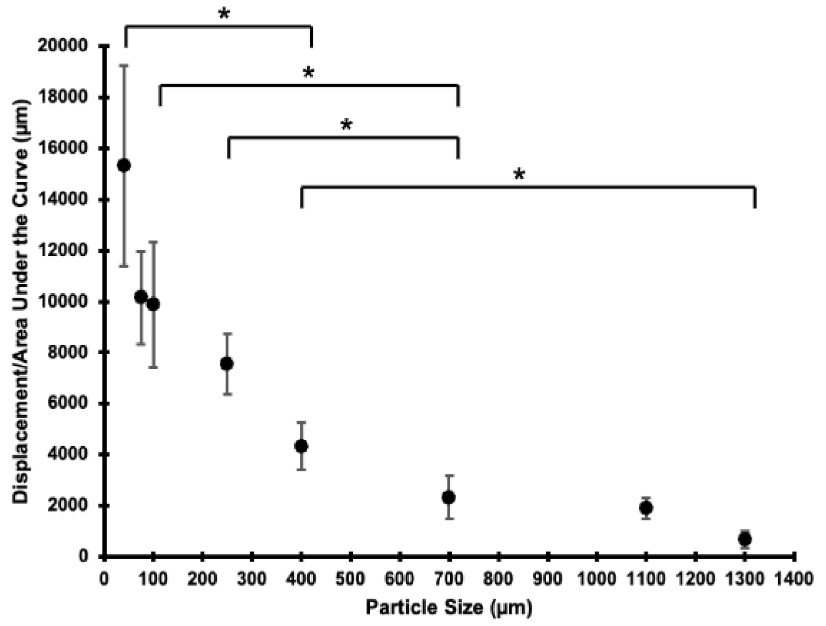

*Figure 1a. "Anatomy of a Spike" Diagram. 1b. Flow Loop Schematic Diagram. 1c. Average Time per Spike vs Particle Size. 1d. Displacement vs Particle Size. Standard errors depicted. * indicates p <0.05.*

Discussion

The study indicates that in aggregate, emboli sizes of 400 and 1300 μm can be distinguished consistently using pulsed-wave doppler. Smaller particle sizes of 40-250 μm increased signal noise and were therefore harder to distinguish from one another. As a unit however these particles appear significantly different from larger sizes.

When reviewing data, the parameters of maximum velocity/peak and maximum slope are not as reliable for indicating particle size. The parameters of displacement (area under the curve) and average time per spike (or total time) may serve as proxy measurements for particle size due to the mathematical relationship between velocity and positional data.

Conclusion

In summary, this paper presents a validation study focused on characterizing particle size using Doppler Ultrasound. The study shows that ultrasound can be used to distinguish particle diameter from 400 to 1300 μm. The study detects particles that are smaller than 400 μm but is unable to determine their diameters. Looking forward, improvements in the study design should look to reduce the signal-noise ratio and optimize the system to generate statistically significant detection of sub-400 μm particles.

Future Directions

Further studies and developments include plans to develop a device and methodology for clinical practice. We plan to increase the accuracy of the data by using two Doppler ultrasound sensors and conducting additional verification studies. As these advancements unfold, the flow loop system is poised to play a key role as a dynamic and immersive platform for medical education, refining techniques, and advancing research.

References & Acknowledgements

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