Monitoring Arterial Stiffness Using a Laser Doppler Approach to Measure Pulse Wave Velocity

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Pulse wave velocity is a commonly used quantity for measuring arterial stiffness, which is often a signifier of cardiovascular health. Many diseases and ailments such as hypertension, chronic kidney disease, Kawasaki disease, or atherosclerosis can be diagnosed through the measurement of arterial stiffness among other variables. Pulse wave velocity has been shown to be measurable through the use of Laser Doppler flowmetry, which, in the simplest terms, uses shifting frequencies of light to measure the flow of red blood cells as they pass a fixed point. This study uses two laser Doppler probes, which were placed along various points on the left hand, to measure pulse wave velocity. Three key locations were tested, each using the tip of the index finger for one probe and either the palm, wrist, or base of the index finger for the second probe. Various combinations of these points were tested to determine the optimal locations for the two probes, one being more distal relative to the other. The data was then collected and analyzed through the time delay of the peaks and the distance between the two probes. It was found that the index finger and wrist location is the most precise and repeatable location to measure pulse wave velocity.

Keywords: arterial stiffness, pulse wave velocity, Laser Doppler flowmetry, cardiovascular disease

A technique to measure PWV using laser Doppler will greatly impact the field of pediatric cardiology. Since this technique will allow for the monitoring of arterial stiffness in patients who have had cardiac conditions in the past, doctors will be able to determine at the point of care whether patients have recovered or need further treatment. The disease relevance for this measurement technique is very broad as it will be useful for patients who have had hypertension, chronic kidney disease, Kawasaki disease, or atherosclerosis, to name a few. If subjects are at risk of developing any of these conditions, the measurement of PWV will allow for detection of cardiac abnormalities early on. Consequently, this early detection will decrease health care expenditures since these conditions would be identified before they manifest into conditions that are difficult to treat. The efficiency of doctor visits would also be improved because the entire time for treadmill stress testing (before and after the test) will be used to obtain multiple PWV measurements instead of having separate appointments to obtain these values. As a result, the time patients spend with their doctor during appointments will be maximized.

Laser Doppler Flowmetry

Laser Doppler Flowmetry is a noninvasive method used to measure blood perfusion. The term "Doppler" refers to the frequency shift the single frequency wavelength undergoes when it hits the moving blood cells [1]. The probe used in this study is a BLF22 Transonic laser Doppler probe, which outputs a single wavelength of 785 nm. Part of this wavelength hits the moving red blood cells that cause the Doppler shift and some of the wavelength hits the static tissue surrounding the blood vessel and does not undergo any change in wavelength. This frequency distribution of backscattered light is picked up by the receiver in the laser Doppler and translated into blood flow and is measured in blood perfusion units. Figure 1 depicts how the laser Doppler emits and receives light wavelengths.

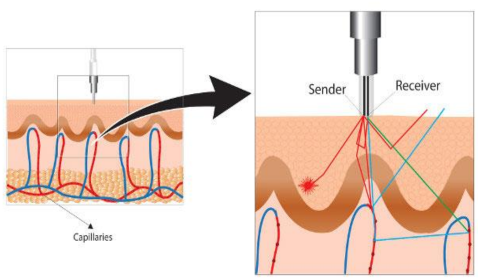

Figure 1. The light hitting the moving blood cells undergo a change in wavelength while the light hitting static tissue does not change. This frequency distribution is used to measure blood perfusion [1].

Pulse Wave Velocity

Pulse wave velocity is defined as the rate of which blood pressure waves travel through blood vessels [2]. By using two laser Doppler probes, blood flow can be captured in two different locations and used to measure pulse wave velocity. Pulse wave velocity is measured by taking the distance between two blood flow readings and dividing it by the time it take for the pulse wave to be captured by Probe A to travel and be captured by the more distal Probe B as shown in figure 2.

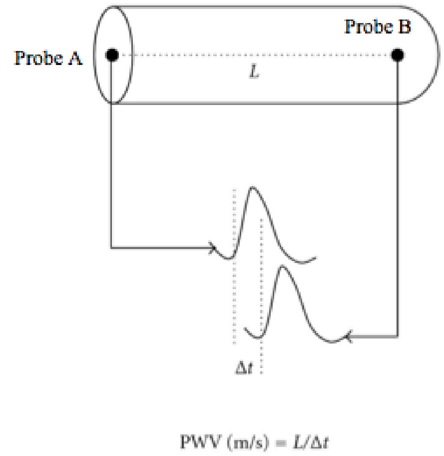

Figure 2. Laser Doppler is used to measure flow at two points. Distance between points is divided by change in time to find pulse wave velocity [3].

By measuring pulse wave velocity, doctors can measure arterial stiffness. The stiffer the artery, the greater the pulse wave velocity. Conditions such as hypertension, diabetes, renal disease and Kawasaki syndrome can be diagnosed through measuring arterial stiffness through pulse wave velocity[4].

Design Constraints

When developing a technique to measure PWV, several design constraints must be considered. The major consideration is patient comfort while measurements are being obtained. Since pediatric patients will be the subjects, it is imperative that the equipment does not appear obtrusive to them. Additionally, the measurement technique must be designed in such a way as to discourage patients from moving around during the screening. Not only must the technique be comfortable for patients, but it should also be easy to use for practitioners. With the consideration that doctors see multiple patients daily, it is crucial that the technique to measure PWV is consistent and easy to perform. A cumbersome setup or data analysis method is to be avoided. Furthermore, the PWV traces obtained must be clear and accurate, and a laser Doppler probe is to be incorporated into the design as opposed to other pressure sensor devices. The use of the laser Doppler technique will enable a pilot study to be conducted in order to assess the feasibility of this method to measure PWV.

Methods

Participants

The participants in this pilot study will be the authors. The ages of the authors are 21 to 22 years old, and they are deemed healthy with no abnormalities with artery stiffness. Each author will have their pulse wave velocity measured before and after exercise to determine arterial stiffness. However, after the pilot study is conducted, future iterations plan to be carried out on children with ages ranging from six to twelve years with varying artery stiffnesses.

(a) (b) (c)

Figure 3. Index finger tip & palm position, (b) Index finger tip & wrist position, (c) Index finger tip & index finger base position.

Measuring Pulse Wave Velocity

Pulses over time will be measured before and after exercise using Laser Doppler flowmetry. There will be three combinations of laser Doppler probes tested, with the probes located at varying points on the left arm and hand. The initial pulse will be measured proximally, while the latter pulse will be measured distally. These points could include but are not limited to: the index finger, base of the thumb, wrist, and inner elbow. The distance between probes will be measured, and, using an excel file, the pulse wave velocity calculated based on the distance between probes divided by the time it takes one pulse from the proximal probe to reach the distal probe.

Results

Each combination of probes underwent three iterations of measuring pulses over time on a total of four individuals, for a total of thirty-four trials. These measurements were then collected and exported to an excel file, where the operator of the procedure was able to access the data. The data from the excel file was then analyzed. The analysis procedure began by identifying a common waveform peak between the two probe locations, followed by selecting the appropriate time for the peak of the wave. The peak of the wave was defined to be a series of four or more values close to the maximum amplitude of the wave, as shown in Figure 4.

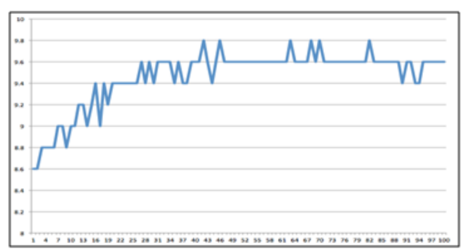

Figure 4. Method for determining the peak of each wave.

PWV was averaged for each location by dividing the time delay between wave peaks by the distance between probes for each subject. As illustrated in Figure 5, the mean PWV velocity was the highest when the second probe was placed at the base of the finger (3.47 m/s +/- 0.99), second highest at the palm (3.37 m/s +/- 1.07) and lowest at the wrist (2.51 m/s +/- 0.48). Since the PWV has the smallest standard deviation at the wrist, that is decided to be the optimal location of the second probe for measurement of peripheral pulse wave velocity. The small standard deviation indicates that this probe location yields repeatable results, which is crucial for accurately assessing arterial stiffness.

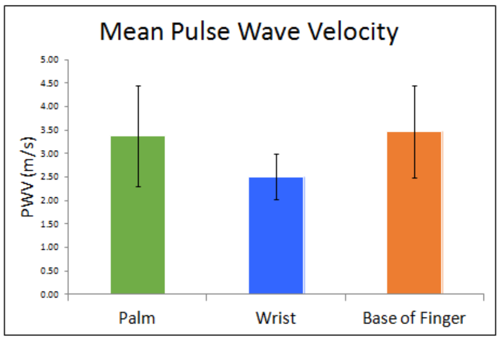

Figure 5. Mean PWV values at the Palm, Wrist, and Base of Finger locations

Discussion

Strengths and Limitations

The main advantage to our method is that it is much more cost effective when compared to other measuring devices of pulse wave velocity, like the SphygmoCor device. Other advantages include that the entire device is reusable and the parts are easy to find. Our device is also comfortable to use, as many competing devices require the user to wear one or multiple large blood pressure cuffs. Disadvantages include that we are relying on a measured distance that may not be the actual arterial distance between our chosen combinations, which could result in error. Therefore, we will need to compare our results to another verified method of measuring pulse wave velocity. In addition, the pulse wave velocity is calculated manually with this method, so we would need to create a file that can easily interpret an input and give pulse wave velocity as the output.

Summary

Cardiovascular disease is very serious in any of its many forms and increases the risk for many other diseases and ailments. Therefore, the sooner it can be caught and diagnosed in children the sooner it can be treated and dealt with. The aim of this project was to take laser Doppler flowmetry and define the best location for the placement of the two probes being used. Thanks to the assistance of Dr. Allen Wilson, a pediatric cardiologist at the University of Wisconsin, the tip of the left index finger was determined to be an ideal choice for measuring PWV because of the strong signal found there. Because of this it was held constant and the second point was the main focus of inquiry. After deliberating, it was chosen to test the base of the index finger, the lower palm and the wrist as the possible second point. After data collection and analysis, it was determined that the wrist gave the best data because it was the most precise with the least amount of standard deviation among the data points and was chosen as the ideal candidate of the three tested.

Future Work

For the future, we would like to create a file that can have the user simply input data and will output a clinically usable value of pulse wave velocity. In addition, other tests should be ran to determine the minimum usable distance between the probes and compared to the current recommended value of five centimeters. An in-depth comparison of our product against competitors is also needed in order to evaluate the efficacy of our method in measuring pulse wave velocity. We would also like to devise a tool to that will measure the distance between probes consistently. We would then like to test this method on a larger population to gain better insight into repeatability and statistical values. Ultimately, we would like to test on the youth (healthy and ill) to determine accuracy as diagnostic tool and run studies to analyze effect of possible variables (proximity of artery, orientation of probe etc.) on pulse wave velocity.

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References

1. Perimed-instruments.com, "Laser Doppler Monitoring - Perimed AB", 2016. [Online]. https://www.perimed-instruments.com/laser-doppler-monitoring. [Accessed: 19- Feb-2016].

2. M. Safar, O. Henry and S. Meaume, "Aortic Pulse Wave Velocity: An Independent Marker of Cardiovascular Risk", *The American Journal of Geriatric Cardiology*, vol. 11, no. 5, pp. 295-304, 2007.

3. F. Mac-Way, A. Leboeuf, and M. Agharazii, "Arterial Stiffness and Dialysis Calcium Concentration," *International Journal of Nephrology,* vol. 2011, p. 6, 2011.

4. Atcormedical.com, "Sphygmocor, Non Invasive & Central Blood Pressures - Atcormedical.com", 2016. [Online]. Available: http://www.atcormedical.com/index.html. [Accessed: 21- Feb- 2016].