Monitoring Arterial Stiffness by Measuring Pulse Wave Velocity Using Laser Doppler Flowmetry

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Abstract

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.

Motivation in Pediatric Cardiology

- Create measurement technique to monitor arterial stiffness in patients who have had cardiac conditions in the past: detect abnormalities early on
- Broad disease relevance: useful for patients who have had hypertension, chronic kidney disease, Kawasaki disease, or atherosclerosis
- Improve efficiency of doctor visits: entire time for treadmill stress testing (before and after test) will be used to obtain multiple PWV measurements
- Determine at the point of care whether patients have recovered or need further treatment
- Decrease health care expenditures since conditions would be identified before they manifest into conditions that are difficult to treat

Background

Laser Doppler Flowmetry

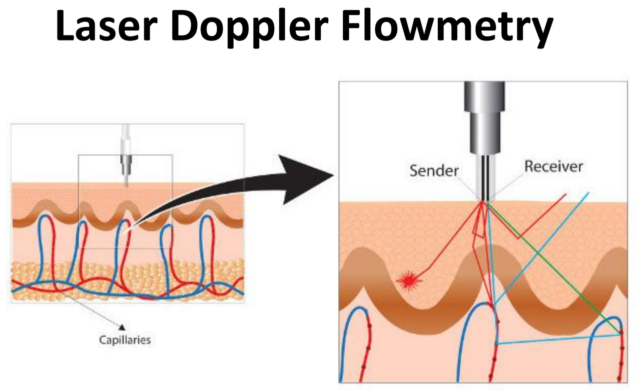

Figure 1. Light hitting moving blood cells undergoes a change in wavelength while the light hitting static tissue does not change. Frequency distribution is used to measure blood perfusion [1].

- Noninvasive method to measure blood perfusion [1]
- BLF21 Transonic Tissue Perfusion Monitor outputs a wavelength that hits moving red blood cells, resulting in a Doppler shift
- Receiver picks up frequency distribution of backscattered light

Pulse Wave Velocity

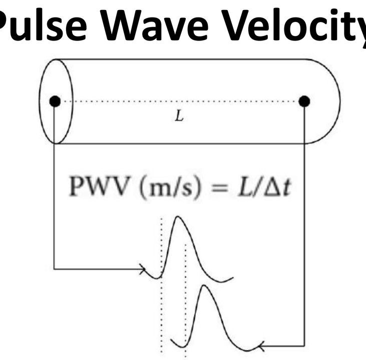

Figure 2. Laser Doppler is used to measure flow at two points. Distance between points is divided by change in time to find pulse wave velocity [2].

- Rate at which blood pressure waves move through blood vessels
- Measure blood flow at two points and divide distance by time delay
- Pulse wave velocity is used to measure arterial stiffness
- PWV increases as vessels become stiffer with age or due to changes in the arterial wall

Design Criteria

- Patient comfort while measurements are being obtained
- Equipment must not appear obtrusive to pediatric patients
- Discourage patients from moving around during the screening
- Easy to use for practitioners: repeatable and easy to perform technique to measure PWV
- Avoid cumbersome setup or data analysis method
- Laser Doppler probe is to be incorporated into design

Competing Designs

Vicorder (top)
Advantages:
- Fast test, typically in three minutes
- Non-invasive
- Optional export of all results into xls compatible files

Disadvantages:
- Costly: $5,000
- Bulky and uncomfortable
- One size fits all for adults, not children [3]

SphygmoCor system (bottom)
Advantages:
- Easy to perform, painless, and reproducible
- Non-invasive
- Measure blood pressure/PWV on almost any area of the body

Disadvantages:
- PWV is inferred - only one cuff is used
- One size fits all for adults, not children
- Costly: $3,000 [4]

Testing

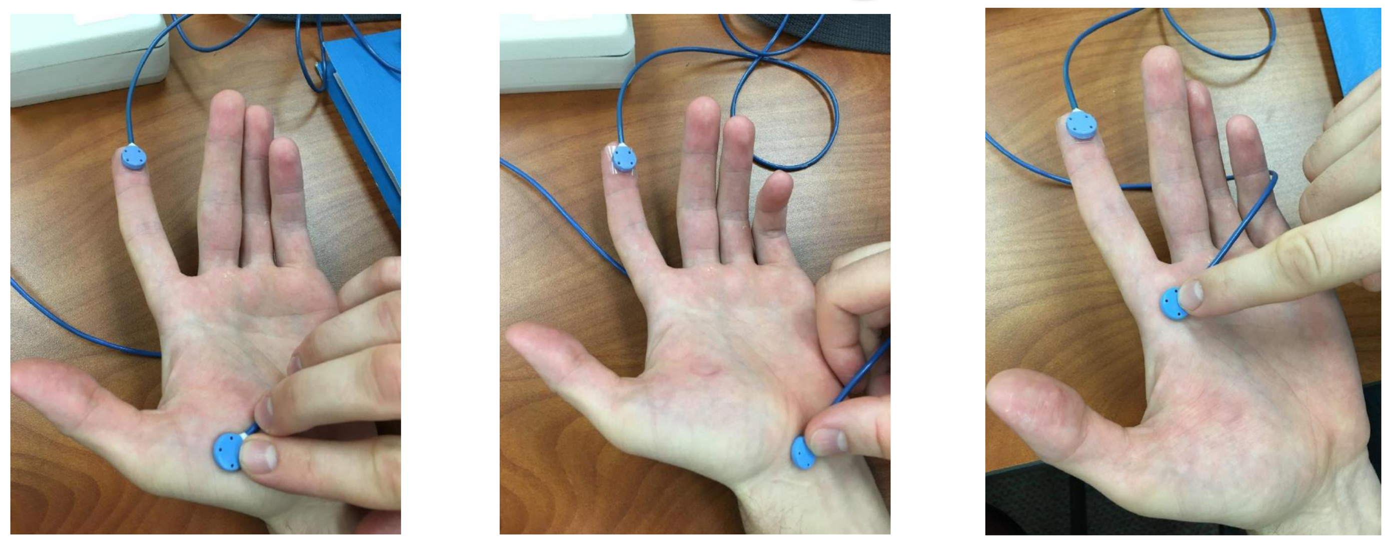

Figure 3. (a) Index finger tip & palm position, (b) Index finger tip & wrist position, (c) Index finger tip & index finger base position

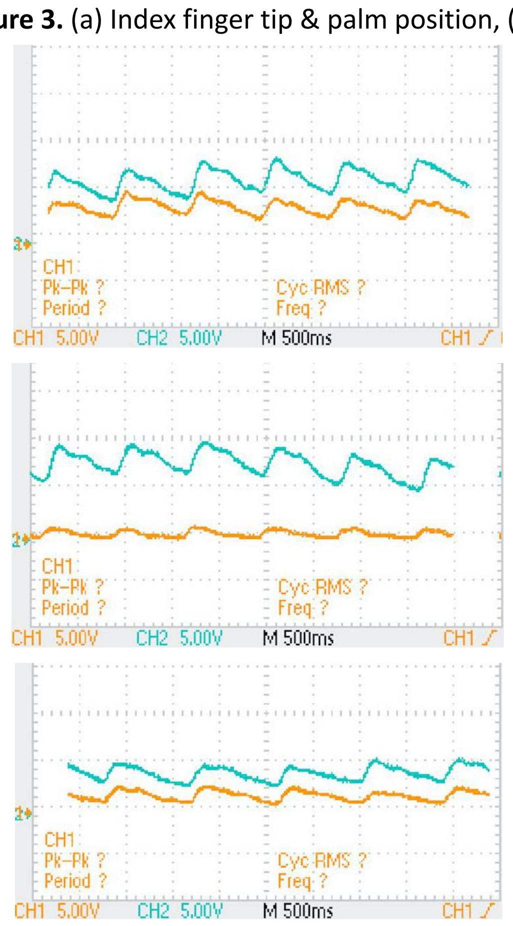

Figure 4. (a) Index finger tip & palm waveform, (b) Index finger tip & wrist waveform, (c) Index finger tip & index finger base waveform

- 3 locations were chosen and tested for the most precise measurement
  - Index Finger Tip & Palm
  - Index Finger Tip & Wrist
  - Index Finger Tip & Index Finger Base
- 3 methods of data analysis were looked at
  - Comparing the differential
  - Looking at peaks
  - MATLAB finddelay function
- Comparing the peaks of each wave was chosen as the method of finding the time delay between the waves

Results

Analyzing the Start of Each Wave

- The peak of the wave was defined to be a series of 4 or more values close to the maximum amplitude of the wave

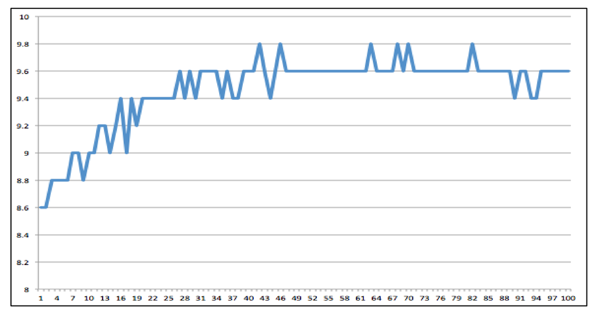

Figure 5. Method for determining the peak of each wave.

Location	*Mean Pulse Wave Velocity (m/s)*
Palm	1.07
Wrist	**0.48**
Base of Finger	0.99

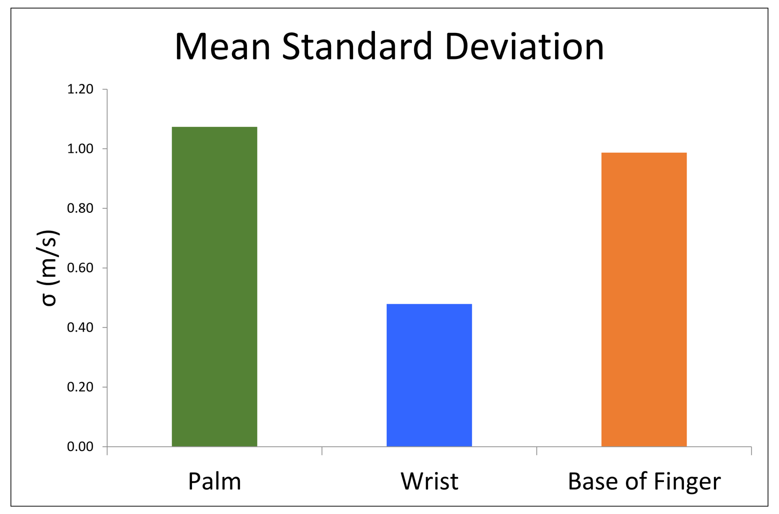

Figure 7. Mean standard deviations at the Palm, Wrist, and Base of Finger locations.

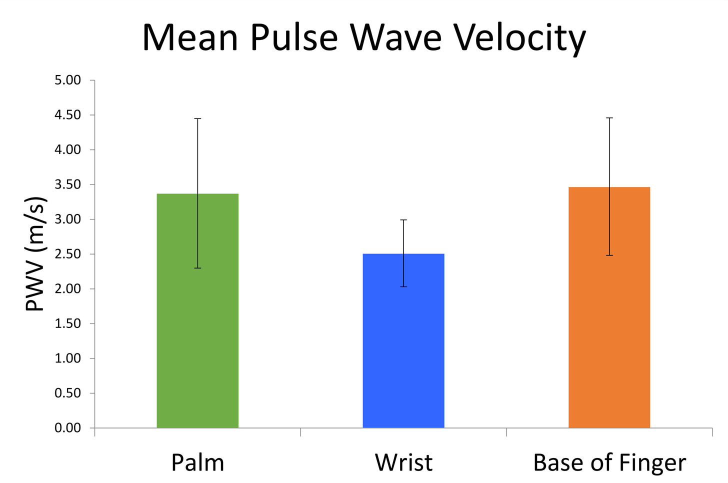

Figure 6. Mean PWV values at the Palm, Wrist, and Base of Finger locations.

Location	*Mean Pulse Wave Velocity (m/s)*
Palm	3.37
Wrist	2.51
Base of Finger	3.47

Data Analysis

- 34 trials total, 1 time delay analyzed from each trial
- PWV was averaged for each location
- Standard deviation was averaged for each mean PWV

Discussion

- Interested in the most precise location for PWV
- Mean standard deviation was lowest at the wrist and index finger location with σ = 0.48
- Results indicate that the most precise and repeatable way to measure PWV is at the wrist and index finger

Future Work

- Create a file to simply input data and output a clinically usable value of PWV.
- Run tests to determine minimum usable distance between probes and compare to current recommended value of 5cm.
- Compare this project to current competition.
- Determine a method, or devise a tool to measure distance between probes consistently.
- Test this method on a larger population to gain better insight into repeatability and statistical values; test on youth (healthy and ill) to determine accuracy as diagnostic tool.
- Run studies to analyze effect of possible variables (proximity of artery, orientation of probe etc.) on PWV.

Acknowledgements

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References

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