Measuring Exercise Systolic Blood Pressure Using Finger Laser Doppler in Kids

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Abstract

Dr. Allen Wilson of UW Health Pediatric Cardiology would like to fabricate a motion-stabilizing device, specifically for the thumb or index finger, for increased accuracy of a laser Doppler that indicates when the child's heart is undergoing systolic blood pressure. Other products that measure blood pressure are only done when the patient is not in motion, which allows easier readings for a systolic peak pressure. Therefore, Dr. Allen's experimenting with laser Doppler technology should be considered as novel, and cannot be directly compared with other competing designs. The design team will fabricate an attached desk to the treadmill that the patient can use while testing to stabilize their hand, which will include Velcro straps for security of the hand and the utilization of a bandpass filter to reject frequencies outside of a preset range.

Problem Statement

A simple auscultatory -cuff method is currently used to measure blood pressure (BP) during treadmill stress testing in adults and kids. With children between the ages of six and twelve, it is often difficult to hear the peak systolic sound that defines systolic pressure. Laser Doppler sampling from the first finger or thumb at rest reads this pressured signal nicely so that it can be used with blood pressure cuffs to find peak systolic BP equivalent. The problem is that laser Doppler signals are motion sensitive. Luckily, when the kids undergo treadmill testing to measure BP, their arms are held off the treadmill. A stabilizing device that holds a laser Doppler probe in place on the first finger or thumb, while stabilizing it from movement that causes artifact on laser Doppler signal, is needed.

Background Information

Project Motivation: Detecting Heart Diseases in Children

According to the Children's Heart Foundation, heart diseases are America's and every other country's number one birth defect, and twice as many children die from congenital heart defects each year than from all forms of childhood cancer combined [1]. Congenital heart diseases are also the most common cause of infant death resulting from birth defects; 27% of infants who die of a birth defect have a heart defect [2]. From an economical standpoint, the cost for inpatient surgery to repair heart defects exceeds to more than $2.2 billion dollars per year [1]. Examples of these diseases include stroke and coronary heart disease. Specifically towards children, hypertension, or high blood pressure, is becoming more and more prevalent within the nation. According to the American Heart Association, BP, pre-HBP and HBP trends in children and adolescents ages 8–17, were downward from 1963–88 and shot upward thereafter [2].

Several methods are executed to check for any type of cardiac abnormalities, such as a computed tomography heart scan, x-rays, and stress tests. During these tests, values such as heart rate and blood pressure are measured. The client of this project specifically targets on measuring blood pressure through such a method: treadmill stress testing. Examinations such as these can search for signs of arrhythmias, or irregular heart rhythms, to search for symptoms of more severe cases. As mentioned before, little to no research has been done with detecting types of blood pressure with laser Doppler technology, so a stabilizing device that will reduce noise of finger movement during treadmill stress testing is desired to have more accurate data when testing for heart disease.

Measuring Blood Pressure

To better understand heart activity while it is undergoing physical work, the physiology of heart blood pressure was studied. Blood pressure is written as two numbers with a ratio of systolic to diastolic, where the units are in mmHg which measure pressure. The heart undergoes systolic pressure when it is being contracted. When the heart contracts, it emits an electrical signal that travels from the top to the bottom of the muscle. An auscultatory cuff is typically placed onto a patient and is initially inflated to a level higher than systolic pressure. The cuff pressure is inflated to reach 30 mmHg higher than systolic pressure, and then air is released at a rate of 5 mmHg per second [3]. During compression, the brachial artery being used to measure blood pressure is undergoing turbulent blood flow, or flowing at high velocities, and vibrates to create audible pulses.

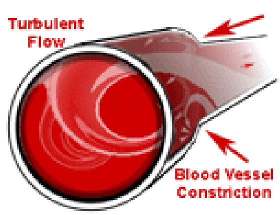


Figure 1: Brachial artery under compression experiencing turbulent flow [3]

Sounds that are heard during this time signal systolic pressure. Once audio beats from the measuring have disappeared, the heart is in diastolic pressure, or relaxed. The actual physics of blood flow was analyzed to have a better understanding of the process (see Appendix A)

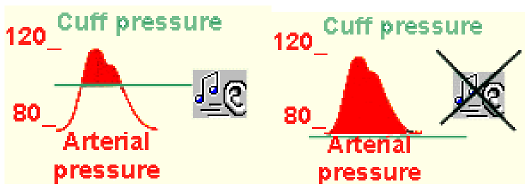


Figure 2: Visual representation of systolic and diastolic pressure [3]

Treadmill Stress Testing

Treadmill stress testing is conducted to determine how well the patient's heart works and adjusts to different levels of activity. The test involves the usage of an electrocardiogram (ECG) machine, and the patient's blood pressure and ECG are both measured. Before taking the test, patients should not eat or smoke at least two hours prior [4]. One's ECG is measured by applied electrodes, which are cleansed with alcohol, to the user on the targeted skin areas. A total of ten electrodes are applied to the body; the right and left arm electrodes are placed each below each clavicle, and the left and right leg electrodes are placed below the rib cage. The rest of them, labeled "V" electrodes, are placed among the chest. These electrodes are positioned according to American Heart Association guidelines [5].

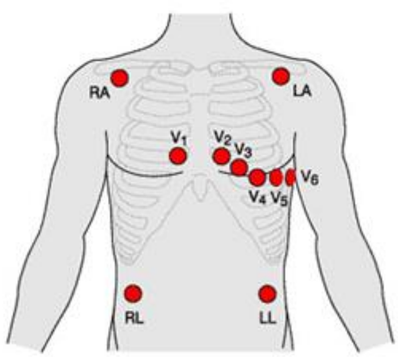


Figure 3: Correct Electrode Placement [4]

The test itself lasts for about ten to fifteen minutes, and the doctor regulates gradual speed or resistance of the treadmill with even intervals. The speed is usually measured in kilometers per hour. The patient will continue running on the treadmill until their specific target heart rate is achieved.

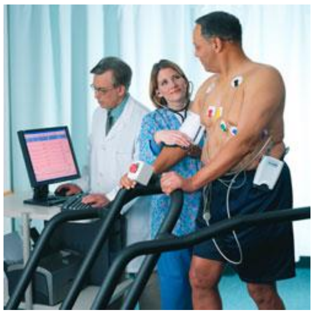


Figure 4: Typical setup during treadmill testing [5]

Current Methods

Treadmill stress testing is currently used in clinical settings with adults. Blood pressure is measured with the traditional cuff and stethoscope. Because of the aforementioned difficulty in hearing auditory pulses in children, a laser Doppler is introduced.

A single frequency beam from the laser is split into a probe and reference beam. The probe beam is directed at a moving target. A portion of the light reflects off of the target and is recollected. The speed of the target can be determined from measurements with respect to each beam of the amplitudes at these two frequencies [6].

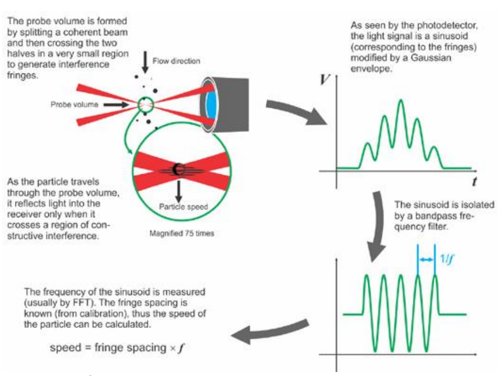


Figure 5. Schematic of how blood velocity id measured using laser Doppler [7]

The velocity of blood in the skin is then displayed on an oscilloscope monitored by the doctor. Cues in the waveform replace the auditory cues from the stethoscope to prompt the doctor to begin reading the pressure gauge on the cuff.

Product Design Specifications

The client requires a right-handed design that stabilizes motion during testing in order to provide an accurate signal to an oscilloscope. The design must be adjustable to accommodate hand sizes of children ages 6 to 12. The device should not affect the stress testing. It should also be safe for the wearer by not restricting blood flow, not causing irritation, and eliminating the possibility of injury. Lastly it should be fabricated within a budget of $1000. More detailed specifications can be seen in Appendix B.

Design Alternatives

Design 1: Splint

Figure 6. The splint design will wrap around the probe along with the wire connecting to the oscilloscope to further prevent any movement by the probe[8].

The first design alternative provides mostly mechanical support for the user. An aluminum bar will be placed along the length of the thumb, restricting any joint movements. The aluminum will be kept in place by a flexible neoprene wrap which will be both comfortable for the user to wear, and allow for easy application and adjustment to different size hands. Velcro will be sewn into the end of the wrap to keep the neoprene in place. The probe will be kept as a separate entity so that the client can easily adjust its placement, but it will be wrapped within the splint to increase stability as shown in figure 5.

Design 2: Splint with Bandpass Filter

Figure 7. The probe will still be wrapped within the splint, but the signal will first be sent through a bandpass filter to further reduce any potential noise[9].

The second design alternative provides the same mechanical support as the first design, but has the added feature of a bandpass filter to further decrease any noise within the signal. Although the splint decreases the amount of joint movement within the thumb, it will not eliminate it all. Since the MLT1010 Piezo Element Transducer has a frequency response of 2.5 Hz to 5 KHz, the bandpass filter would allow these frequencies to pass through while eliminating any frequency outside of this range [6].

Design 3: Desk with Bandpass Filter

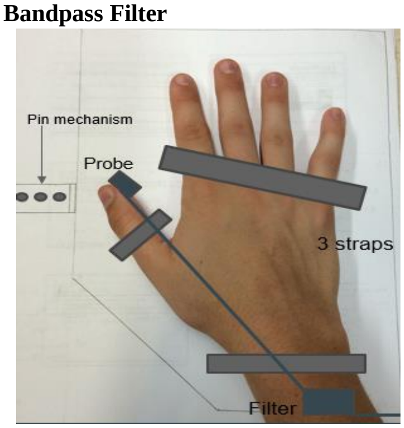
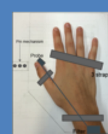


Figure 8. The desk design will provide the necessary mechanical support along with a filter to help eliminate any noise that may be caused by movement of the probe.

The final design alternative provides both mechanical support and a filter for the signal. A 33 x 25 x 2 cm desk will be attached to the preexisting bar of the treadmill, along with a lock and pin mechanism that will move the desk horizontally along the treadmill to a position most comfortable for the user. The desk will have a laminate surface making it waterproof and therefore easy to sanitize. The user's hand will be placed on the desk and held in place by a strap of Velcro across the wrist, upper hand and thumb as shown in figure 7. The probe will be separately velcroed to the user's thumb and the signal will be run through a bandpass filter to eliminate as much noise in the signal as possible.

Design Matrix

Criteria	Design 1: Splint		Design 2: Splint with Filter		Design 3: Desk with Filter	
						
Accuracy of Signal (25)	(2/5)	10	(4/5)	20	(5/5)	25
Feasibility (20)	(3/5)	12	(2/5)	8	(4/5)	16
Ease of Use (20)	(3/5)	12	(3/5)	12	(4/5)	16
Safety (15)	(5/5)	15	(4/5)	12	(3/5)	6
Comfort (10)	(4/5)	8	(4/5)	8	(3/5)	6
Cost (10)	(5/5)	10	(4/5)	8	(3/5)	6
TOTAL		67		68		76

In order to select a proposed final design, a design matrix was used to evaluate the designs. In the design matrix, six criteria were assessed: accuracy of signal, feasibility, ease of use, safety, comfort, and cost.

The first and most heavily weighted category was accuracy of signal. This category refers to how well the selected device filters out noise from the Blood Pressure waveform. The Desk with Filter design won this category with 25 points due to its ability to stabilize the thumb and other joints, while including a bandpass filter to further reduce noise from the signal.

The next category to be assessed was feasibility. This category refers to how manageable it will be to manufacture the chosen device. The Desk with Filter design won for this category as well with 16 points because the materials, skills, and time required to fabricate the device are well within the team's capabilities. The feasibility of the splint designs are lower due to the fact that they would require sewing, a skill that requires time and experience to execute properly.

The ease of use category refers to how easy it is for the user to take the device on and off. The Desk with Filter design again won this category with 16 points because the adjustable straps are easy to secure and release the arm. The splint designs would require the user to be manually strapped into the device before each use, which could be tedious and time consuming.

Safety was the next category to be assessed, which focuses on how safe the selected device is for the user. The splint design won for this category with 15 points because it does not incorporate a filter, and any device involving circuitry poses some risk to patient safety.

For the comfort category, both the splint and splint with filter designs won with 8 points because the elasticity and flexibility associated with the fabric of these designs would be more comfortable than the materials of the Desk with Filter design.

Lastly, the cost associated with each design was assessed. This category was one of the lowest weighted because it is anticipated that each design will be well below the price limit of $1000. The splint design won this category because it has no circuitry, reducing the overall price to make the device.

Proposed Final Design

Based on the design matrix, the team has chosen to move forward with the Desk with Filter design for fabrication. This design will incorporate a bandpass filter, Velcro straps, and a laminate desk that will provide stability for the user and limit joint movement, thereby reducing the amount of noise in the Blood Pressure waveform.

Future Work

The next steps to create the device will include ordering of the materials for the Desk with Filter design, including Velcro straps, a laminate desk, and circuitry elements to create a bandpass filter that will attach to the device. The team is currently looking into alternatives for the Velcro straps to allow for an escape mechanism if a patient were to fall while on the treadmill. One possible option includes using magnetic straps that are adjustable to different hand sizes. Upon ordering these materials, fabrication of the Desk with Filter design will begin.

Commented [1]: does this sound okay?

Commented [2]: Sounds good to me!

Lastly, the team will conduct trials that demonstrate the device's ability to filter noise from the Blood Pressure waveform. For this process, data will be collected from a typical blood pressure device used today, such as a blood pressure cuff, and compared to the data collected from the Desk with Filter device. The trials and data analysis will demonstrate the efficiency and accuracy of the design.

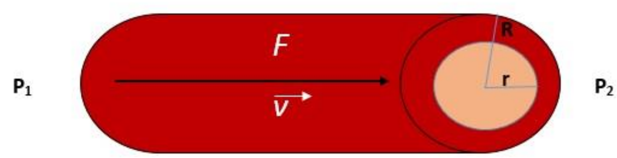
Acknowledgements

Our team would like to thank Professor Thompson for his guidance, advice, and assistance throughout the design project. We would also like to thank our client, Dr. Allen Wilson for his knowledge of pediatrics and time spent communicating with our team. Finally, we would like to thank the University of Wisconsin – Madison Biomedical Engineering department for the opportunity to work on this project and for providing us with the necessary resources to accomplish our design goals.

Appendix A: Cardiovascular Physics

As mentioned before, the brachial artery is undergoing turbulent flow, or experiencing high velocity, when the heart is in systolic pressure. One can visualize the artery as an example of continuous flow:

$$\mathbf{P_1 > P_2}$$



The initial pressure of the flow system, P_1 , can be assumed to have a higher pressure than that at some arbitrary point distant from the heart (P_2). According to the law of fluid continuity, it is also assumed that the flow in will equal the flow out regardless of radius size [10]
The equation for continual flow is the velocity of the electrical signals multiplied by the cross sectional area of the artery:

$$Flow = velocity * \pi \; (R^2 - \; r^2)$$

where *R* and *r* are the outer and inner radii of the artery, respectively. Given this equation, the average velocity of the electrical pulses are inversely proportional to the square of the artery's radius.

This information will be useful as it will help determine which range of velocities should be considered acceptable when using a bandpass filter with the oscilloscope.

Measuring Exercise Systolic BP Using Finger Doppler in Kids

Contents of PDS- September 18, 2015

Madison Boston, Crystal Jimenez, Haley Knapp, and Gabby Laures

Function: A simple auscultatory-cuff method is currently used to measure blood pressure (BP) during treadmill stress testing in adults and kids. With children between the ages of six and twelve, it is often difficult to hear the peak systolic sound that defines systolic pressure. Laser Doppler sampling from the first finger or thumb at rest reads this pressured signal nicely so that it can be used with blood pressure cuffs to find peak systolic BP equivalent. The problem is that laser Doppler signals are motion sensitive. Luckily, when the BPs of kids are exercised, their arms are held off the treadmill. A stabilizing device that holds a laser Doppler probe in place on that first finger or thumb, while stabilizing it from movement that causes artifact on laser Doppler signal, is needed.

Client requirements:

- The MLT1010 Piezoelectric Pulse Transducer is the preferred laser Doppler for usage
- Device must provide oscilloscope with steady BP signal
- Material should be lightweight
- Device should not interfere with stress treadmill testing
- Device should not infringe upon previous patents
- Device should preferably applied onto patient's right hand

Design requirements:

1. Physical and Operational Characteristics

a. Performance requirements: This device will be worn by pediatric patients and must be able to resist movement of probe. It must be unaffected by sweat and movement of the child.

b. Safety: This garment or glove should not restrict blood flow and should not in any way irritate the wearer while in use.

c. Accuracy and Reliability: This device must restrict movement of probe in reference to the finger/thumb to a level that provides a clear signal on the oscilloscope. It must also must maintain this level of accuracy regardless of the age or hand size of the wearer.

d. Life in Service: It must be able to maintain its function for one hour each time a test is being performed and must be able to be used repeatedly for different patients over a lifespan of five years.

e. Shelf Life: While there are no perishable items, any materials that include fabric or elastomeric components should last five years from date of manufacturing.

f. Operating Environment: The device will be mainly used for patients while exercising on a treadmill in hospitals due to arrhythmias.

g. Ergonomics: The setup for attaching and removing the device onto the right hand should take no longer than thirty seconds. When the patient is walking with the device on, the acceptable max operation of the thumb when worn is less than 23 kg.

h. Size: The size of the device should wrap to the patient's extremity as a glove would. The material of the glove should at least slip on top of the thumb or first finger. Anthropometric data will be used to determine the average dimensions of children's' fingers between the ages of six and twelve.

i. Weight: To prevent inhibition of the patient's exercise, the weight of the device should be no greater than 2.5 kg.

j. Materials: The material used needs to be both lightweight and comfortable for patient to wear while running on the treadmill. Also, the material of the device should be hypoallergenic.

k. Aesthetics, Appearance, and Finish: The device is not required to be a specific color. The texture should not be uncomfortable when applying to the hand, and should integrate well with the laser Doppler Dr. Wilson will provide.

2. Production Characteristics

a. Quantity: One device will originally be made to hopefully accommodate a range of children's hand sizes.

b. Target Product Cost: The client has a set budget of $1000. This design, however, will most likely spend significantly less when fabricating.

3. Miscellaneous

a. Standards and Specifications: The device must adhere to FDA standards for Class I devices such as general controls to assure quality, suitability of use, and proper labeling. Specific regulatory standards for Laser Doppler related devices can be found in Code of Federal Regulations Title 21. 21 CFR 1040.10 and 1040.11 discuss the performance standards for light-emitted products.

b. Customer: The device will be made to ensure that customer satisfaction is prioritized. This will be achieved through comfortable materials, elasticity and durability of fabrics, and simplistic design concepts for ease of use.

d. Competition: A similar diagnostic device is the WatchPAT developed by Itamar Medical. This device is similar in its ability to record blood pressure readings from a finger probe. However, this device is used when the patient is sleeping, while our device will be used during exercise testing.

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