Bedside Device to Measure the Jugular Venous Pressure

BME 200/300 – Fall 2012

BIOMEDICAL ENGINEERING DESIGN

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Client:

Dr. Steven Yale

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1. Abstract

This report outlines the non-invasive device that is being developed to measure the jugular venous pressure of a patient with heart failure. The final design incorporates a sensor to measure the absolute distance between the internal jugular vein and sternal angle and an application on a smart phone to measure the angle of elevation. The circumference of the patient's chest will be measured with a tape measure to determine the depth of the right atrium, using a relationship that was found through research. The sensor method was tested for precision using two team members at various angles of elevation but the data set was erroneous because at some angles the ruler method proved to be more precise.

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2. a. Client

The client, Dr. Steven Yale has worked with the Biomedical Engineering Department previously having proposed projects and worked with teams in the past. He is a medical doctor who currently works at the Marshfield Clinic, where he specializes in Internal Medicine and trains residents. He is also Clinical Associate Professor at the UW-Madison School of Medicine and Public Health.

2. b. Problem Statement

A device is needed to measure the jugular venous pressure using a sensor that is placed on the body to measure the patient's absolute distance from the sternal angle to the pulsation of the internal jugular vein. The angle of elevation will be directly measured using a smart phone application. A digital feedback will display these measurements via a computer monitor.

2. c. Background

Heart failure is the leading cause of death in both men and women in the United States, and evaluating the jugular venous pressure is one of the best ways to assess and diagnose heart failure. The heart is made up of four chambers, the left and right atriums and the left and right ventricles. As shown in Figure 1, the right atrium has a large vein, called the superior vena cava that connects the top of the atrium directly to the brain. The superior vena cava brings de-oxygenated blood from the brain and face to the heart, which empties into the right atrium [1]. This vein branches from many veins, including the internal and external jugular veins on both sides of the neck. The internal jugular vein is usually about 1 to 2 cm within the neck, and it is the bigger of the two veins. The external jugular vein can be seen on the surface of the skin. These two veins make great candidates for measuring the pressure in the right atrium because the blood that flows through them goes directly to the heart, instead of circulating through the body before returning to the heart. This relates to blood pressure because the pressure in these veins is literally the pressure in the heart since they have a direct connection to the heart. The internal jugular vein is considered a more preferable candidate since the internal jugular vein is in direct line with the superior vena cava and the right atrium. The external jugular vein has two 90-degree angles between the right atrium and the portion of the vein that runs through the neck, which would slow down the blood. This would cause the blood in this vein to have slightly different pressure then what is in the heart, making it a less ideal candidate [1].

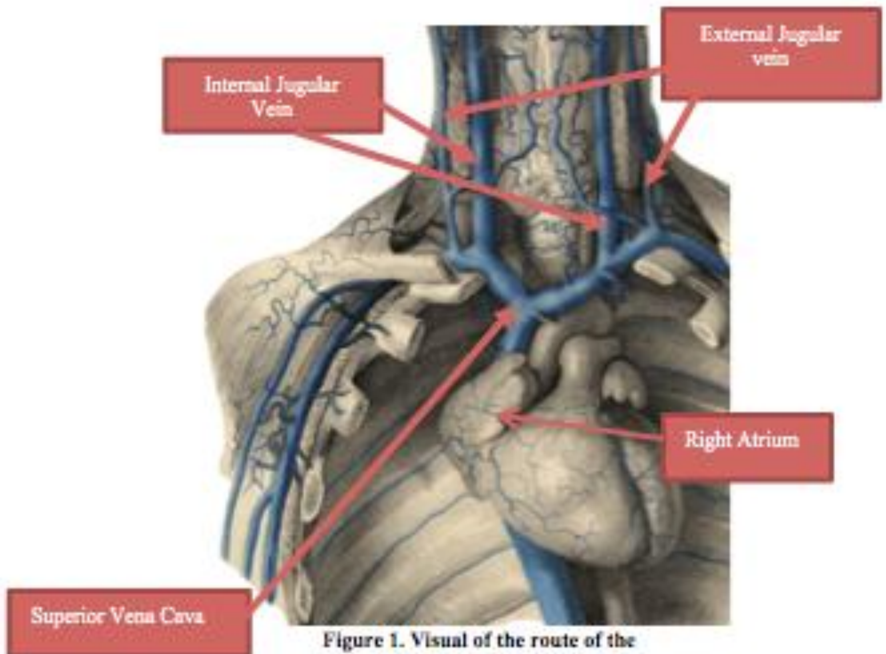

Figure 1. Visual of the route of the jugular veins to the right atrium. http://www.anatomyexpert.com/structure_detail/8710/1201

The jugular venous pressure can be evaluated by measuring the vertical distances between critical points on the body. First in order to make this measurement the top of the pulsation of either the internal or external jugular veins must be located. This is the most difficult part of the measurement and inexperienced physicians struggle to distinguish if the pulsation is from one of the jugular veins or from the carotid artery [2]. As shown in Figure 2, the distances needed to make the measurement, are from the right atrium to the sternal angle, and the vertical distance from the sternal angle to the top of the jugular pulsation. The sternal angle is a distinct bony ridge that can be easily located on the chest. The distance from the right atrium to the sternal angle is an internal distance that cannot be physically measured except through CAT scans. The location of the right atrium will be different from person to person but it is proportional to the patient's chest circumference. Adding these two distances together gives the level of the jugular venous pressure.

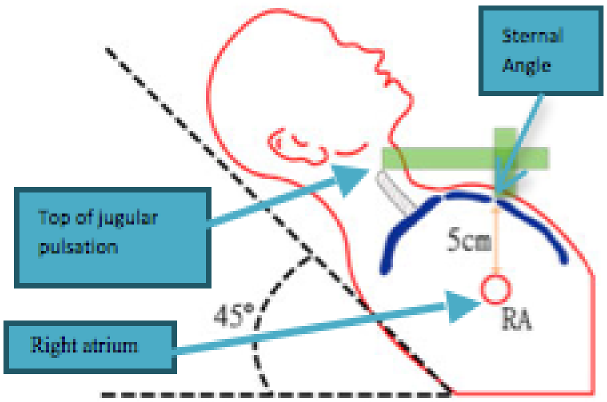

Figure 2. How to find jugular venous pressure using distances. http://renalfellow.blogspot.com/2011/01/jugular-venous-pressuredistention.html

This distance is an accurate measure of the blood pressure in the heart, because the visible pulsation is one of the best indicators of how well the heart is working. In the jugular vein the blood is emptying from the head and into the heart. When the pulsation is visible, the head is returning more blood to the heart than the heart can pump back out [2]. The height of this column of blood that is building up in the vein accurately displays the pressure because it shows the heart's ability to keep up with the circulation of blood throughout the body. These two distances added together give the height of the column of blood, thus giving the heart pressure by providing an accurate measurement of how efficient the heart is pumping. This is the jugular venous pressure, which corresponds to the pressure in the right atrium of the heart.

A normal mean JVP is considered to be between 6 and 8 cm of water; fewer than 5 cm could mean hypovolemia, which is a decrease in blood volume, and over 9 cm of water could mean impaired cardiac filling [3]. This normal mean of jugular pressure depends on the angle of elevation of the patient; what is normal at one angle will not be normal at a different angle. This is because when the head is lowered more blood is pumped into the brain; this is the same effect of being dizzy after doing a handstand because all the blood rushed to the head. This increase of blood in the head empties through the jugular veins causing the jugular venous pressure to be significantly higher and more observable when the head is lower. Therefore what's considered a normal, healthy jugular venous pressure at a lower angle will be higher if the patient were at a higher angle of elevation. Knowing the angle of elevation allows the doctor to evaluate whether the patient's JVP is above or below what is considered healthy. This would allow the doctor to also track the change of the JVP over time [3].

The change in the jugular venous pressure is one of the best indicators of the success of a treatment. If a patient has a higher JVP and it continues to increase after a treatment is administered, then the treatment is not working. The increase in JVP means that the heart is losing its ability to pump out blood as fast as it is being returned to the heart causing an excess amount of blood in the jugular vein that is waiting to move into the heart. This might not be the only reason for an elevated JVP. It could also be a sign of many other medical conditions, most commonly superior vena cava obstruction or fluid overload [4]. If the JVP decreases over time the treatment is indeed working and should be continued until the doctor considers the patient's JVP normal. Since the JVP is such a good measure of the blood pressure in the right atrium, many cardiologists would like to evaluate the JVP as part of a standard physical exam for heart patients [5].

2. d. Project Motivation

Proper analysis of jugular venous pressure is a critical factor in diagnosing and monitoring heart failure patients in a clinical setting. Currently, the procedures taking place today are lacking in feasibility, accuracy, and straightforwardness to impact the vast number of people that could benefit from them. To reach accurate and precise measurements of JVP within a reasonable range, an ultrasound machine, which price in the tens of thousands of dollars, is necessary for correct location of vein. Even if correct measurements are obtained, the repeatability of results between physicians for cross-clinical applications is lacking a common ground. The current, out-of-date method relies on miscalculated data that results in improper diagnosis. It is the culmination of these negative properties of current jugular venous pressure measurement that motivates the team to design a more utilitarian, affordable, simple to use, and transportable pressure measuring device geared specifically towards patients of heart failure. In conclusion, a device that increases affordability to low budget communities, generates more repeatable results between physicians, and creates a more standardized process of jugular venous pressure would revolutionize the field of heart disease.

2. e. i. Non-invasive Procedure

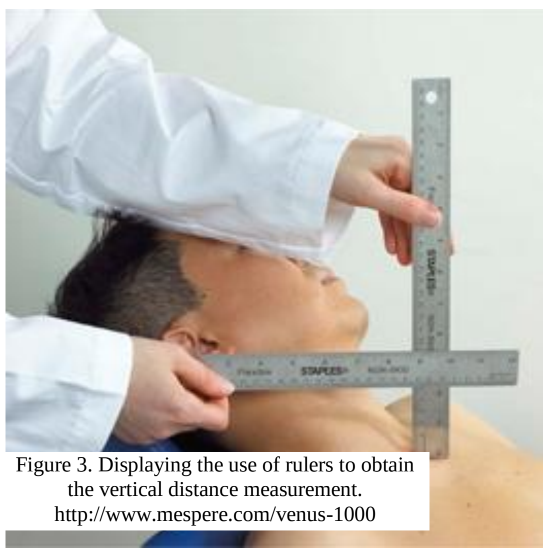

Figure 3. Displaying the use of rulers to obtain the vertical distance measurement. http://www.mespere.com/venus-1000

The more conventional and well-known method of measuring jugular venous pressure is a non-invasive method using metric rulers and the doctor's eyes to determine the vertical distance of the pulsation. To begin this procedure, the patient must be positioned in a manner so the physician is able to locate the position of the pulsation of the internal jugular vein. If a clear internal jugular vein pulsation cannot be seen, the external jugular vein pulsation must be used in its place. The patient must also have their chest bared to permit access to the anterior portion of the sternum. For increased visualization of the pulsation, the patient may need to turn their head 10-20 degrees to their left. The patient is then laid at a 45 degree angle for maximum presentation of the pulsations. Once the pulsations have been identified, a horizontal straight edge is held at this location. Then, the sternal angle, which is a bony ridge approximately 2 inches below the most anterior portion of the sternum, must be located [6]. After a metric ruler is held vertically at this point, the vertical sternal-angle-to-internal jugular-vein-height should be estimated in centimeters. This value is then added to 5 cm, which is an outdated estimate of sternal-angle-to-right-atrium depth. Current evidence of CAT scans suggests the distance varies with the angle of elevation [7]. This method is the most established and common measurement of JVP, but this process lacks in accuracy because the physician is reliant on his ability to recreate absolute vertical and horizontal directions with the measuring utensils. In addition, this procedure is not finite in its steps; physicians worldwide may favor a specific elevation angle, a different sternal-angle-to-right-atrium depth, etc., which immensely complicates the cross-correlation of results between physicians. Benefits of non-invasive measurements include nearly zero medical equipment necessary and an easy approximation of values.

2. e. ii. Invasive Procedure

A less common method of obtaining jugular venous pressure involves a direct measurement using a pressure-monitoring catheter. This procedure is more generally used when a patient is critically ill or experiencing rapid fluid shifts during blood transfusions and surgery. Ultrasound machines provide the preliminary step of determining the location of the internal jugular vein for proper pressure analysis. After induction of general anesthesia prior to the procedure, the IJV is punctured with a syringe needle. A spring wire is guided through the needle into the vein. An intravenous canulla is then threaded over the wire after removal of the needle to avoid excessive bleeding around the puncture location. Finally, a pressure-monitoring catheter is passed through the IJV to directly measure the JVP. This procedure gives more reliable and transferable results between physicians, but incorporates complications with being an invasive procedure including catheter malfunction, thrombosis, infection, haemothorax, pneumothorax, and cardiac tamponade [8]. Also, if the syringe needle misses and punctures an artery or nerve, prominent blood vessel and neuronal damage may endure. Use of ultrasound machines and knowledge of such a procedure make this procedure difficult to be performed by inexperienced healthcare professionals.

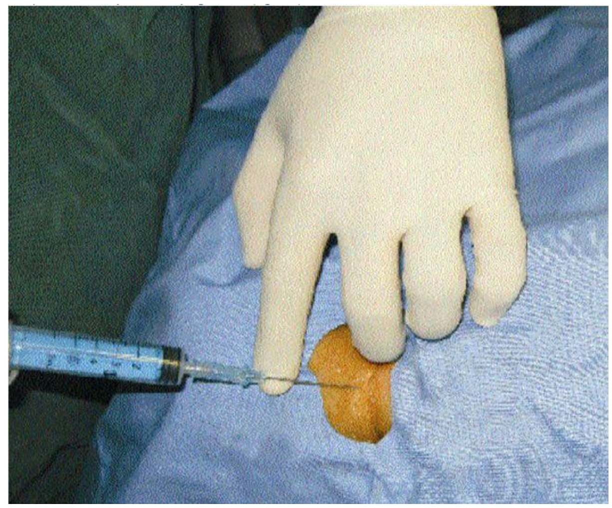

Figure 4. Depicting the insertion of a needle syringe for obtaining the JVP. http://www.jpma.org.pk/full_article_text.php?article_id=3675

2. f. Product Design Specifications

The client has given the team specific requirements in which the team should follow in designing a device to measure jugular venous pressure. The angle of elevation must be adjustable from supine (180 degrees) to upright position (90 degrees). Preferably, the internal jugular vein will be used for measurement, but external jugular vein may be used for ease. A method of non-invasive vertical measurement from the right atrium to the pulsations in the neck is critical to determine pressure. The patient’s chest circumference must also be determined for proper analysis of sternal-angle-to-right-atrium depth. A complete design will incorporate the chest circumference, elevation angle, and sternal-angle-to-pulsation height to ultimately determine jugular venous pressure. The design must be able to measure jugular venous pressure within 1-2 cm of water and angle of elevation within 5 degrees. Lastly, a display on a monitor or cell phone is preferred for function ability and ease of use.

3. a. i. Design 1

The first design to measure the jugular venous pressure uses an ultrasound of the internal jugular vein on the neck. This design is based off a combination of two already practiced ways of determining the JVP. The first design is based off the conventional ultrasound measurement of the inferior vena cava and current invasive method. For this method, doctors are able to accurately predict the pressure in the right atrium, but due to the power necessary for this procedure, the ultrasound is not exceptionally portable and is very expensive [9]. Since there is a similar relationship between the jugular venous pressure through the expansion and contraction of the right atrium compared to the internal jugular vein, it seems the IJV is an easier approach for measuring the JVP. The second device is also based off the current invasive method used to measure the JVP. In this method the doctors use an ultrasound on the neck to locate the internal jugular vein, which they then proceed to insert a catheter into this vein to directly measure the JVP. Given that there is a relationship between the jugular venous pressure and the distention of the external jugular vein, the ultrasound method can be used.

Since the IJV is larger on the right side of the neck than the left side, it will be easier to obtain a clearer picture from the right side. When using the ultrasound, the picture on the monitor should show both the carotid artery and the internal jugular vein. Of the two, the IJV will always appear larger, so it will be easily identifiable. Once the IJV has been located and there is a clear picture, the doctor will take continuous snapshots of the monitor. The doctor will then be able to scroll through these snapshots to find both the largest expansion and the smallest contraction of the internal jugular vein. From these two pictures, the doctor will be able to measure the circumference of the vein. To do this, the doctor will need to treat the vein as an ellipse and measure the vertical and horizontal diameters of the vein using a measuring tape. Once these diameters are determined, the doctor will be able to input these values into a program, which will output the value of the circumference. While this may not be the exact circumference, it will be sufficient for the purpose of creating a more exact JVP measurement in a non-invasive procedure.

Figure 5. Ultrasound that will be used in procedure to produce a similar picture of the internal jugular vein. http://www.nejm.org/doi/full/10.1056/NEJMvcm0810156

In this design, the purpose for measuring the jugular venous pressure is solely for monitoring the patient's progress. This means that it is only necessary to have a semi-quantitative measurement of the JVP in terms of low, medium, high, etc. The doctor treating the patient will determine the range of these values. As long as the doctor stays consistent with these ranges, they will be able to determine the progress of the patient and their necessary treatment. While this doesn't meet all the original requirements, it will still be able to better diagnose heart failure than some current methods.

While this design would give the most accurate readings compared to the other designs, it isn't the most probable. This design would be more accurate because it measures the pressure from the internal jugular vein, which flows directly into the right atrium, rather than measuring the external jugular vein which has branching valves before reaching the heart, which affects the pressure. Only licensed professionals would be able to perform this measurement because of the training required to accurately use an ultrasound machine. The key to this design would be consistently obtaining a clear picture, which can be difficult, even for a professional. Also, the costs of even the most basic ultrasounds machines are extremely expensive and can range from $12,000-$40,000.

3. a. ii. Design 2

The second design is the most simplistic and least expensive way to measure the jugular venous pressure. It entails using two tools, a protractor and a measuring tape. The protractor will be used to measure the angle of elevation of the patient, while the measuring tape will be used to measure distances on the body. Similar to the current non-invasive method of measuring the JVP, the doctor will need to determine the distances from the right atrium to the sternal angle, and the sternal angle to the pulsation of the internal jugular vein in the neck, as well as the angle of elevation. To find this elevation angle, the doctor will place the protractor by the hip of the patient and measure the angle from the patient's back to the bed they are lying on. Since the patient will be lying on a bed, this angle being measured will be indicative of the angle of elevation.

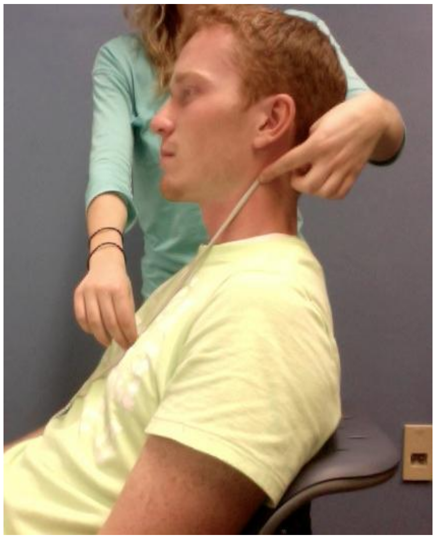

Figure 6. Measuring the distance from the sternal angle to the pulsation of the internal jugular vein in the neck.

Before the distance from the right atrium to the sternal angle can be determined, the doctor needs to locate the atrium. To do this, the doctor will measure above the breast line using measure tape to find the circumference of the chest. The circumference should be measured above the breast line because it is close to the sternal angle, and because it will provide a more consistent number among men and women of the same size. With this value, the doctor can find the distance from the right atrium to the sternal angle using the relationship between the circumference of the chest and the depth of the right atrium (see Design 3). Next, the doctor will measure the distance from the sternal angle to the pulsation in the neck of the internal jugular vein. Since only the vertical distance of the measurement is needed, the doctor will use geometric calculations in relation to the previously determined angle of the patient. Once these two measurements have been determined, the doctor will add them together, which will give the jugular venous pressure.

This design is similar to the most common non-invasive method of measuring the JVP, but is slightly more accurate. Where there is guesswork from both measuring the vertical distance from the sternal angle to the pulsation in the neck with rulers and locating the right atrium, this new method has a more error free method for finding the vertical distance and a more accurate location of the right atrium. Even with this improvement, this design will not produce the most accurate data, but it will still provide sufficient results. Due to the basic tools necessary for this procedure, the JVP measurement will be both inexpensive and simple.

3. a. iii. Design 3

The third and final design focuses on the use of sensors to measure the absolute distance and a protractor-like device to measure the angle of elevation of the patient. A device will be manufactured similar to a protractor to measure the angle of elevation. The device will be attached at the bedside and directly lined up with the patient's hip to determine the angle most accurately. The physician will arbitrarily place the patient at an angle based on previous medical history and past treatments. A greater angle of elevation signifies a high jugular venous pressure and the patient might even need to be in a sitting position for the physician to see the internal jugular vein in the neck. Similarly, a smaller angle of elevation demonstrates a low jugular venous pressure and in order for the doctor to see the internal jugular vein pulsate, the patient might need to be lying flat on the bed [10].

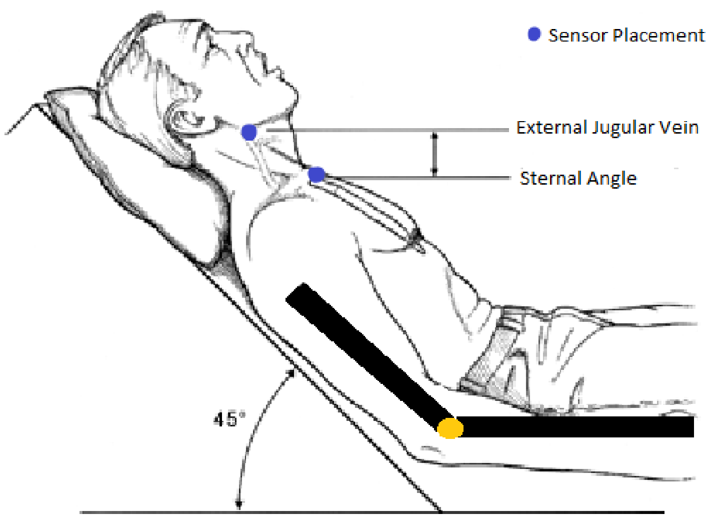

Figure 7. Process for Design 3 using sensors to measure distance between internal jugular vein and sternal angle. http://emsbasics.com/2011/10/17/what-it-looks-like-jugular-vein-distention/

The circumference of the patient's chest is directly related to the depth of the right atrium below the sternal angle. The measurement will be made when the patient checks into the hospital or clinic with measuring tape along with other necessary vitals. For a patient with a chest circumference of 78 cm, the right atrium is 10 cm below the sternal angle. Using the equation for circumference, $C=2\pi r$, for every 4 cm increase in the chest circumference, 0.25 cm needs to be added to the initial depth of 10 cm. Likewise, for every 4 cm decrease in chest circumference of the patient, 0.25 cm needs to be subtracted from the initial 10 cm depth of the right atrium [10]. The chest circumference does not need to be measured often unless there is a significant weight loss or gain of the patient.

The displacement sensors will be used to measure the absolute distance between the location where the physician can see the internal jugular vein pulsating and the sternal angle. The sensor will be linked to a computer via an arduino and will not require electricity or batteries. The sensors will be much more accurate than manual measurement because it will take out the guessing used in estimated the vertical distance between the internal jugular vein and sternal angle. One sensor will be placed on the neck at the internal jugular vein on the right side because the veins on the right side of the neck are larger [10]. The other sensor will be placed on the sternal angle so the absolute distance between the two points can be measured. The angle will then be factored in to determine the vertical distance between the two points using geometrical relationships such as sine, cosine and triangles in reference to the measured angle.

A program will determine the jugular venous pressure based on the three inputs of angle of elevation, depth of the right atrium and absolute distance from the internal jugular vein to the sternal angle. The absolute distance between the sternal angle and internal jugular vein will be transferred directly to the program via an arduino. The jugular venous pressure will be displayed in cm of water on an easy-to-read screen so it can be hand-held and small. The sensors will be sterilized after each use to ensure there are no bacteria transferred from patient to patient.

Category	Weight	Design 1 – Ultrasound	Design 2 – Manual Measurement	Design 3 - Sensors
Ease of Use	0.40	1	4	5
Cost	0.10	1	5	4
Accuracy	0.15	4	1	3
Precision	0.25	3	1	4
Size	0.10	2	5	4
Total	**1**	**2.05**	**3.00**	**4.25**

Table 1. Design matrix for 3 design alternatives

3. b. Design Matrix

The design matrix as shown in Table 1, displays the three possible designs along with respective weights. The group decided that ease of use is the most important aspect to the design since there are current methods available for physicians to measure jugular venous pressure but they are very inconsistent and difficult to perform. Precision is also very important regarding treatment of patients that have been diagnosed with heart failure because physicians need to measure consistent values for JVP and how the measurements are changing over time. These values determine if new treatments are necessary or if current treatments seem to be improving the patient's condition. Accuracy is the next highest weight because it is extremely important for physicians to diagnose healthy patients and treat heart failure. In order to do that, it is necessary to have a correct value for the JVP to determine if the patient's pressure levels are elevated, low or normal. Cost and size are equally important because the client did not give a strict budget to maintain and the size just needs to be reasonable when considering the hospital and clinic setting that the device will be used and stored in.

The design using the ultrasound technology scored lowest in the design matrix for many reasons. It is very accurate and precise because it would directly measure the pressure of the internal jugular vein which flows directly to the right atrium without any valve interruptions by using the wand directly on the patient's neck. This design would be very expensive since the cost of ultrasound machines range from $12,000-$40,000 and it would be bulky since the entire ultrasound system would be used. The design is not very easy to use because not all physicians are correctly trained to use ultrasound technology and consistently get a clear picture and not all clinics have the technology available at all times.

Using manual measurements to measure the jugular venous pressure is extremely inaccurate because of the human error involved when using measuring tape. The design would be extremely cheap and easy to use since there are only two basic tools required to perform the necessary measurements and no training is essential. With this design, size would not be an issue since storage space would be small.

The design incorporating sensors received the highest marks for various reasons. It is very easy to use because the sensors measure the absolute distance for the physician. The sensors are reasonably priced ($50-$200 each) and the size is within reason for hospital and clinic standards. This design is both accurate and precise because it takes into account different body types when determining the circumference of the chest and relating that to the depth of the right atrium. It also utilizes geometry and mathematical equations to determine the vertical distance from the sternal angle to the internal jugular vein instead of estimating using imaginary horizontal lines.

Accuracy and precision in theory are the most important in the design matrix because they can be proved using statistical analysis of data that is collected from testing. True accuracy can only be determined by comparing the data from a sensor with data from the invasive procedure performed on patients with heart failure. This could be very difficult since patient consent would be necessary to use their information and access to heart failure patients would be required. It would be necessary to gather data from a large enough sample group to correctly analyze the data using statistics. Precision could more easily be measured by taking multiple measurements at every angle. It is important that this process is repeatable among different people measuring whether they are surgeons, clinicians or students.

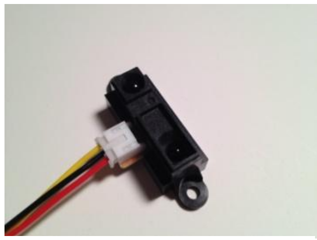

Figure 8: The Sharp GP2Y0A21YK IR proximity sensor used in the design [13].

3. c. Final Design

The device created involves the sensor communicating with a PC through an arduino, a USB connection, medical tape, measuring tape, a hand-held mirror, and a computer program written in MATLAB.

3. c. i. Hardware

Figure 9: The Arduino Leonardo used in the design [14].

The final design of the bedside jugular venous pressure device is based mainly off design 3. It incorporates a number of materials including an infrared proximity sensor, and arduino, and USB cable, a laptop, and an iPhone. The specific sensor used was the GP2Y0A21YK developed by Sharp. This sensor detects and measures the distance to any IR reflective object. For the group's purposes, a hand-held mirror is placed at the observed location of the jugular venous pulsations while the sensor gets its reading. The sensor is then wired to an arduino, specifically the Arduino Leonardo. The sensor reading is converted to a digital signal, and then transmitted to the computer through the USB cord. The computer receives the arduino output in the COM ports, where it can be utilized by a computer program. To relay the angle of elevation, a free iPhone app, AccelMeter, is placed on the incline of the bed and outputs a visual feedback.

3. c. ii. Software

To interpret the sensor, an open source project code provided by Google Project Hosting was used to program the arduino. To complete a final calculation of jugular venous pressure, a MATLAB code was used to read the inputs of chest circumference, angle of elevation, and sensor value to output a final jugular venous pressure. The code first inquires an entry of the angle of elevation and chest circumference in the Command Window. It then uses data from an interpolation of the 5 right-atrium-to-sternal-angle depths based on a 5th degree polynomial to give the patient's depth for their specific angle of elevation. The known depths are 5.3, 8.0, 9.7, 9.8, and 8.3 cm for angles of 0, 30, 45, 60, and 90 degrees, respectively [11]. The code also relates the chest circumference to an average anterior-posterior chest diameter by increasing the right-atrium-to-sternal-angle depth for person's having a diameter of greater than 25 cm, and vice versa. Finally, the program determines the vertical distance of the sensor reading by using geometric calculations, adds that value to the right-atrium-to-sternal-angle depth, and gives a final readout of jugular venous pressure. Both codes can be found in the appendix.

Figure 10: Display of AccelMeter for angle measurement.

3. c. iii. Budget

The materials needed for the design project included a computer, computer programming software, an Arduino Leonardo, Sharp IR proximity sensor, USB cable, medical tape, measuring tape, wiring, and a handheld mirror. The arduino costs $24.95 and the sensor costs $13.95. A jumper wire for the sensor was also purchased for $1.50. The USB cable, medical tape, measuring tape, and computer were previously available to the design team, and we assume the user can obtain these items with ease. If MATLAB and the assumed items are available then the budget runs around $40. If a license to MATLAB is required that increases the price of the system at least $500.00 [12].

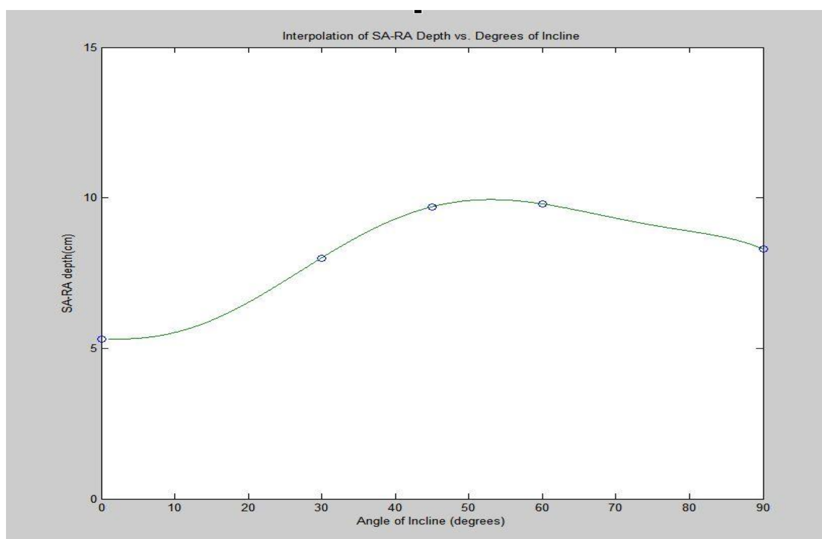

Figure 11: The interpolation curve for the relationship between angle of elevation and initial depth of right atrium

4. Experimental Testing

Dr. Steven Yale, the client, wants to be able to use the product to both diagnose and treat heart failure. This means the procedure must be both accurate, to be able to diagnose heart failure within 2 cm of water, and precise, in order to tack the treatments progress. The procedure must produce an accurate result over and over again, whether an experienced doctor or a resident is performing the procedure.

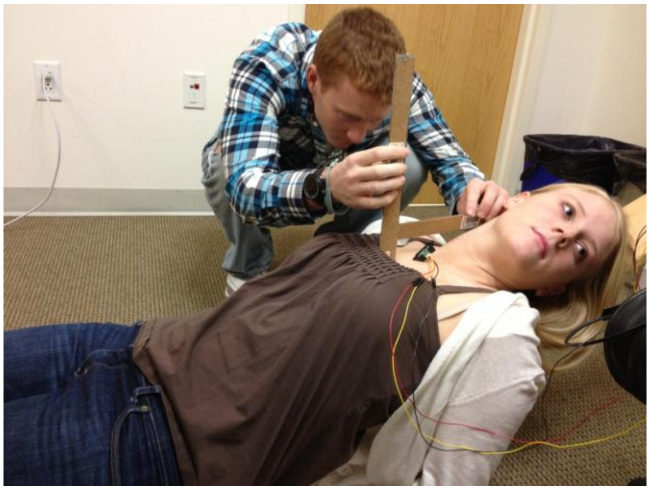

Figure 12: Testing the JVP using the standard ruler method at various angles.

In order to test accuracy, the original experimental plan was performing the measurements by the untrained group members with the sensor and comparing that data to the results of an experienced doctor, Dr. Kao at the UW hospital. This would prove that the sensor results were at least to the same degree of accuracy when compared to an experienced doctor who performs this measurement on a daily basis. After talking with Dr. Kao about this experimental plan, it was decided that a different experimental plan was necessary. Dr. Kao said comparing untrained users measurements to his measurements would be like comparing one wrong answer to another wrong answer. When he measures the JVP, he uses his eyes to estimate the distance, and he doesn't know if his estimate is that accurate either. Dr. Kao also does not include the depth from the right atrium to the sternal angle which is proof of the lack of standardization of the process among doctors. This would make the sensor value, which does include this depth, much different then Dr. Kao's estimate. Dr. Kao did perform a few measurements on two team members though which is displayed in the appendix.

After meeting with Dr. Kao, a new experimental plan was devised. This new plan was to measure two team members at angles of 15 degrees, starting at 0 degrees to 60 degrees. Every team member would perform the procedure four times on each person at each angle; two times using the standard ruler method and two times using the sensor method. This gives enough data points to perform analysis, to prove precision of the device. With these tests it can be determined if the jugular vein pulsation were at a certain location on a patients neck, with a certain chest circumference, the sensor method outputs JVP measurements close to the values from the standard ruler measurement which can be seen in the charts in the appendix.

Unfortunately, the device can no longer be tested for accuracy since the only way to really test accuracy is to perform the invasive on a patient after the sensor procedure was performed. This is the only way to get the exact JVP, but limitations of time made this impossible. Testing for accuracy was also hard since the team members are not experienced doctors and cannot find the top of the jugular vein pulsation in the neck. This makes distance measurement difficult since there is no way to estimate the location of the internal jugular vein pulsation, making the vertical distance impossible to find.

5. Statistical Data Analysis

The data collected in Table 2 shows that the overall variance from the ruler method is smaller than the variance from the sensor method; this does not support the null hypothesis that the sensor method is more precise than the ruler method. To statistically analyze the data, a modified paired data test assuming nonequivalent variances was performed. It shows that overall the ruler method has less of an error than the sensor method. These variances for this calculation were taken at angles 0°, 15°, 30°, 45°, and 60° on two group members during testing. Specifically, the mean variance from the ruler method was lower, with a value of 0.22961, and the mean variance from the sensor method was higher, with a value of 0.3008. The results of this test are shown in full in the Appendix.

Patient 1

Angle (Degrees)	Ruler Variance (cm)	Sensor Variance (cm)	Difference (R-S) (cm)
0	0.1156	0.529	0.0627
15	0.5929	0.0064	0.5865
30	0.0529	0.1156	-0.0627
45	0.2116	0.9409	-0.7293
60	0.25	0.3844	-0.1344
Mean	0.2446	0.39526	-0.05544

Patient 2

Angle (Degrees)	Ruler Variance (cm)	Sensor Variance (cm)	Difference (R-S) (cm)
0	0.1369	0.0441	0.0928
15	0.5929	0.0016	0.5913
30	0.2209	0.1296	0.0913
45	0.0324	0.4356	-0.4032
60	0.09	0.4096	-0.3196
Mean	0.21462	0.2041	0.01052

Overall Results

Ruler Variance (cm)	0.22961
Sensor Variance (cm)	0.3008

Table 2: Variance for sensor and ruler method from the data set including two team members measured multiple times at many angles

Ideally, the best way to analyze the sensor would be to test its accuracy and its precision, but because it was not possible to obtain exact JVP measurements, via an invasive method, a test for accuracy of the sensor design could not be performed. To test the precision of the sensor, the variances were calculated and showed that the precision was sufficient. When comparing this precision with that of the ruler method, it was found that the ruler method was more precise. Determining whether the sensor method is better than the ruler method is not accurately portrayed from our testing because the ruler method was performed much more precisely than it is in the clinical setting. From speaking with Dr. Kao, it was concluded that many doctors don't actually use rulers when determining the JVP, but rather, make an educated guess about the distance. During the actual testing of the ruler method, two rulers were used, which made the results much more precise than they actually would be. Also, during testing, the exact elevation angle was measured via a Smartphone application, where as doctors do not measure the angle device, but once again make an educated guess of the angle. These two factors played a key role in making the ruler method so accurate.

6. Future Work

It is important for the MATLAB program to be converted to Java or a program that is free for all users. Not all companies and hospitals have access to MATLAB since it requires a membership fee. The code was written in MATLAB because the group is not familiar with any other type of computer programming so it would be necessary to learn how to write code in Java or utilize a resource that could help the group convert the program.

Also, the device needs to be tested for accuracy by testing on heart failure patients. The only true accurate method to test the Jugular Venous Pressure is to invasively measure the pressure of the heart by sticking a needle into the internal jugular vein. Obviously, to acquire this type of data, patient consent would be necessary. Also, it would be necessary to ensure patient comfort, confidentiality and safety. The invasive method would have to be compared and contrasted to the sensor method created by the group this semester. The data would need to prove that the sensor method is within 5% accuracy of the invasive procedure in order for this device to be considered a complete success. The patient sample size would have to be large and vary by age, condition and sex to ensure a variety of data.

In the future, the client Dr. Steven Yale would like to perform the jugular venous pressure measurement solely using a Smartphone application because it would be more convenient for doctors. It would also require less equipment and fewer calculations for the doctors to measure the jugular venous pressure. This method would also be faster which is important regarding heart failure patients. Dr. Yale also wants to incorporate measuring the jugular venous pressure into every physical and check-up, whether the patient has heart failure or not to hopefully prevent deaths directly related to heart failure.

7. Discussion

As a whole, the group expected the sensor method to be more reliable than the current ruler method since it takes out the human error in guessing the vertical distance between the sternal angle and internal jugular vein. One of the main goals of this project was to standardize the procedure to measure the jugular venous pressure and the sensor device definitely contributed to the standardization since the two key points are relatively easy for a trained eye to locate and the sensor does all the difficult measuring. The only room for human error is in the measurement of the chest circumference and placement of the reflective object on the pulsation of the internal jugular vein.

Overall the data analysis was unsuccessful since the precision is based on the variance of the data. The data for the ruler method actually had a smaller variance than that of the sensor method. So according to the data and statistical analysis, the ruler method had less error which is exactly opposite that which the group wanted to prove.

The largest obstacle regarding testing turned out to be the lack of medical knowledge of the average person. The success of this device to give both accurate and precise data depends on the ability to locate the pulsation on the right side of the neck of the internal jugular vein. Since there are so many veins and arteries in the neck, the untrained eye would not be able to locate the correct pulsation. The average person may mistake the carotid artery throbbing as the internal jugular vein because it is in fact more noticeable. In order to reduce the error due to inaccurate placement of the pulsation of the internal jugular vein, it would be necessary for trained physicians or surgeons to perform the analysis with the sensor method. If the absolute distance is measured from the sternal angle to the incorrect pulsation, obviously the JVP calculated by the computer program will be inaccurate.

8. Conclusion

Table 3. Group timeline for semester

Tasks	September				October				November				December			
	7	14	21	28	5	12	19	26	2	9	16	23	7	14	21	23
Research	X	X	X	X												
Brainstorming Design Ideas			X	X	X											
Design Selection				X	X	X										
Project Design Specification	X	X														
Mid-semester Report						X	X									
Mid-semester Presentation						X	X									
Fabrication							X	X	X	X						
Testing								X	X	X	X					
Modifications									X	X	X	X				
Final Presentations											X	X				
Final Paper												X	X			

For the most part, the group has stayed within the time allotments for this semester and the design process. The initial research took much longer than expected because none of the group members were well versed on the anatomy or physiology of the heart and it was unclear of the actual problem. It took a long time to figure out how the jugular venous pressure is currently measured non-invasively because it was confusing that measuring distances would give a reading for pressure in the right atrium. Once contact was made with Dr. Kao, who is a cardiac specialist at the University of Wisconsin-Madison hospital, it seemed to run smoother since he gave a small demonstration of the current process and gave insight on the anatomy and how the cardiovascular system functions. He also provided information regarding ultrasound technology so the first couple design options took off rapidly. The last design took longer to brainstorm because the group was thinking too complex but after meeting with Professor Amit Nimunkar, who steered the group towards thinking in a more simplistic manner, the last design using manual measurements was formed.

The group was really focusing on constructing and moving forward with the design including ultrasound technology until meeting with the client, Dr. Steven Yale. He was very intrigued with the design incorporating ultrasound machines but he stated that not all clinics have the necessary technology or physicians who can produce a clear picture on an ultrasound display screen. He convinced the group that the focus should instead be on the sensor idea since that would also be cheaper and require less human interaction. After this meeting, the group had to switch research gears and get in contact with a different group of professors and physicians. Once the sensor and arduino was ordered, the design process seemed to progress smoothly. The group had to perform two complete sets of data after rejecting the first set of data because it was irrelevant and did not prove accuracy or precision. Once the testing process was modified to prove precision, the experimental stage moved quickly. The small data set from Dr. Kao was also rejected because after the group conversed with him, he brought it to the attention of the group that comparing his measurement of JVP and the group member's measurement of JVP would be comparing a wrong answer to an even worse representation of the answer.

9. Acknowledgements

The team firmly thanks the client Dr. Steven Yale for presenting a design problem to the University for the Biomedical Engineering Department. He was very supportive of the work done this semester and traveling to Madison for team meetings. Also, the team would like to thank the advisor for this project, Professor Chris Brace who has provided guidance throughout the semester and helped the team with contacts and references. Thanks to Dr. Walter Kao, a cardiac specialist at the University of Wisconsin Hospital for helping the team further understand the current methods for measuring jugular venous pressure and cardiovascular anatomy. Further, he gave information regarding ultrasound technology for the first design and offered the hospital equipment for testing. Professor Amit Nimunkar deserves thanks for helping the team find displacement and distance sensor information and keeping the designs simplistic. Thanks to Matthew Bollom for helping with the arduino code and calibration. For help with writing the jugular venous pressure code in MATLAB thanks goes out to Deb Deppler. The team would like to thank both Devin Harris and Bret Lotzer for assisting with the MATLAB and computer programming necessary for this project. Both Gustav from Karlsson Robotics and Jeroen Doggen deserve thanks for helping the team choose the correct sensor regarding distance measurements and compatibility with the human body. Caroline Price deserves appreciation from the team for helping with the statistical analysis and for recommending different tests and ways to evaluate the data to prove precision. Finally the team thanks the University of Wisconsin-Madison Biomedical Engineering Department for their support in the team's academic endeavors.

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11. Appendix

11. a. MATLAB Code

```
%Matlab Program to Determine JVP

%By Tony Schmitz, Taylor Moehling, Kelsie Harris, Dani Horn

%BME Design 300/200 Fall 2012

clear all


%Input for angle of incline

InclineAngleinDegrees = input('What is the Angle of Incline? (Enter angle in degrees)');


%Calculation of RA to SA distance

ChestCircumference = input('What is the chest circumference? (Enter distance in cm)')';


%Code to determine RA-SA depth

degrees = [ 0 30 45 60 90 ];

depth = [ 5.3 8.0 9.7 9.8 8.3 ];

xx = 1 : 0.01 : 100;

c4 = polyfit(degrees, depth, 6);

yy4 = polyval(c4,xx);

plot(degrees,depth,'o',xx,yy4);

AXIS([0 90 0 15])

TITLE('Interpolation of SA-RA Depth vs. Degrees of Incline')

xlabel('Angle of Incline (degrees)')

ylabel('SA-RA depth(cm)')

SternalAngletoRAdistance = polyval(c4,InclineAngleinDegrees);

Diameter = ChestCircumference/pi;
```

```
Difference = (0.2*Diameter)-5;

SternalAngletoRAdistancewithdifference = SternalAngletoRAdistance +
Difference;

%Code used to read the Com port, select correct COM port, can be found in

%Device Manager under Ports

s = serial('COM8');

set(s,'BaudRate',9600);

fopen(s);

fprintf(s,'*IDN?')

DistancefromSternalAngletoPulsation = fscanf(s)

%.2disp(['71 = [' DistancefromSternalAngletoPulsation(1:2) ']']);

DistancefromSternalAngletoPulsation =
str2num(DistancefromSternalAngletoPulsation);

fclose(s)

delete(s)

clear s

%DistancefromSternalAngletoPulsation =input('What is the distance? (Enter
angle in degrees)');

%Calculations to find vertical distance

InclineAngleinRadians = InclineAngleinDegrees*pi/180;

InclineAngleinRadianswithchangeofangle = InclineAngleinRadians -
0.2070396825;

SAtoPulsationVerticalDistance =
DistancefromSternalAngletoPulsation*sin(InclineAngleinRadianswithchangeofangl
e);




%Final Calculation of JVP

Jugular_Venous_Pressure = SAtoPulsationVerticalDistance +
SternalAngletoRAdistancewithdifference
```

11. b. Arduino Code

A. Arduino Code

```
/*
  distanceTest: test program for "Tony" (Anthony Schmitz): testing distance sensor code on Arduino Leonardo
 */


// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}


// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = getDistanceCentimeter();
  // print out the value you read:
  Serial.println(sensorValue);
  delay(1000);
}



/// getDistanceCentimeter(): Returns the distance in centimeters
int getDistanceCentimeter()
```

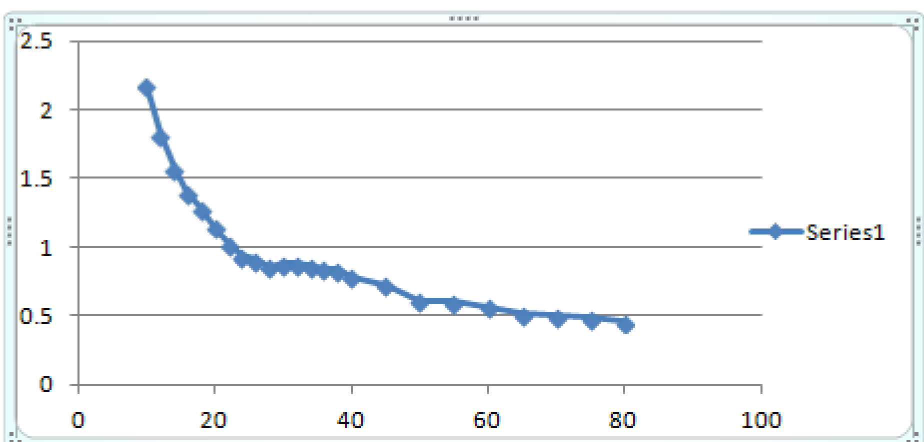
```
{
  int adcValue=analogRead(A0);
  if (adcValue > 600)                          // lower boundary: 4 cm (3 cm means under the boundary)
  {
    return (3);
  }

  if (adcValue < 80 )                          //upper boundary: 36 cm (returning 37 means over the boundary)
  {
    return (37);
  }

  else
  {
    return (1 / (0.0002391473 * adcValue - 0.0100251467));
  }
}
```

Application	Protractor
0°	0°
5.1°	5°
8.1°	8°
11.2°	11°
15.4°	15°
20.3°	20°
29.5°	29.5°
35.8°	36°
44.4°	44°
50.9°	51°
55.2°	55°
60.5°	60.1°
66.9°	67°
69.9°	70°
73.5°	74°
84.9°	85°
90°	90°

Figure 1: Data from iPhone application AccelMeter vs. a protractor testing for accuracy

Distance (cm)	Voltage (V)
10	2.175
12	1.825
14	1.575
16	1.4
18	1.2875
20	1.15
22	1.025
24	0.9375
26	0.906
28	0.86
30	0.881
32	0.881
34	0.862
36	0.843
38	0.837
40	0.787
45	0.725
50	0.6125
55	0.602
60	0.568
65	0.5125
70	0.5
75	0.487
80	0.456

Figure 2 and 3: Calibration curve and data table for arduino according to the manual



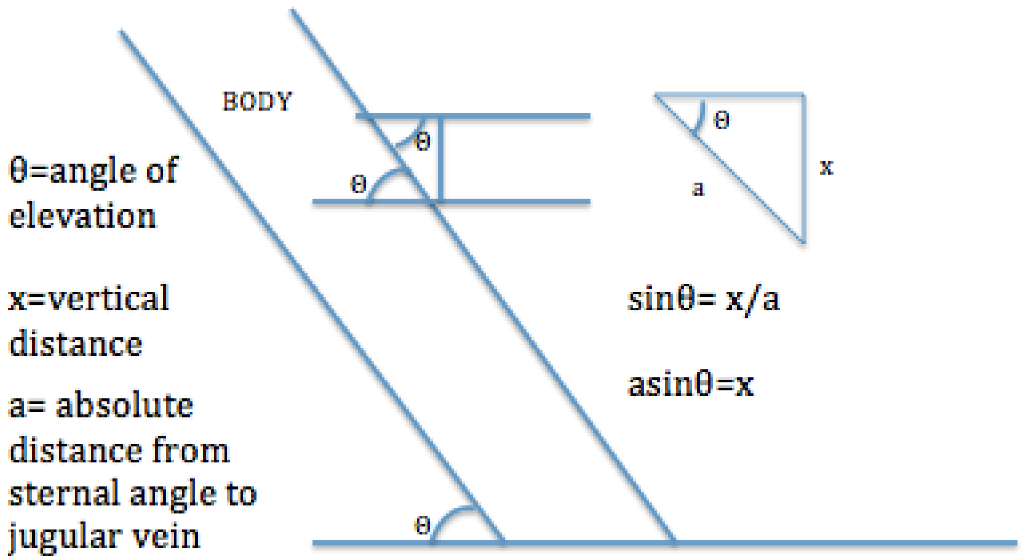
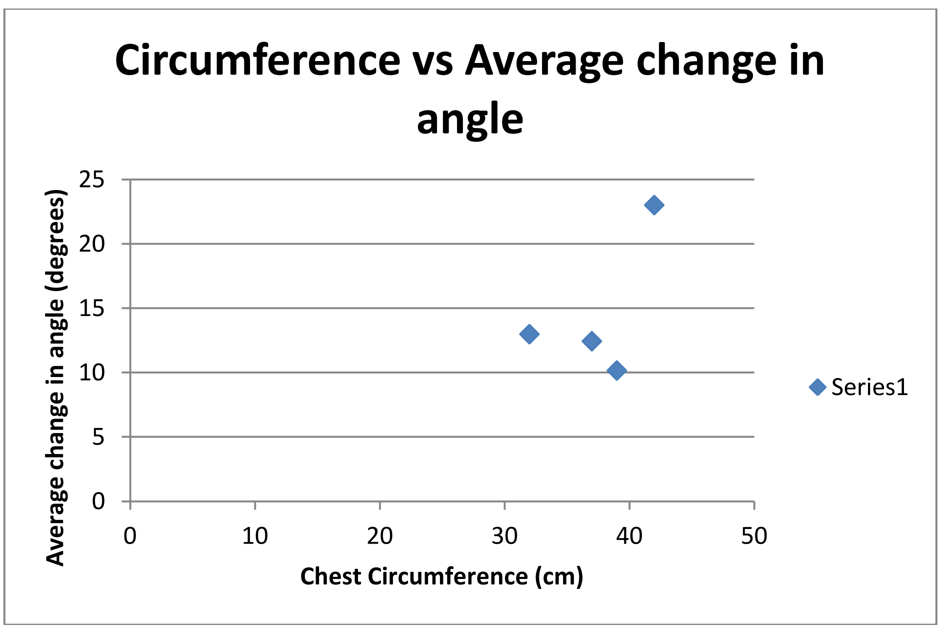


Figure 4: Geometric representation of how the angle of elevation given by the iPhone application outputs a vertical distance from the internal jugular vein to the sternal angle

Overall average change in angle	14.65
Overall average change in angle without Taylor	11.8625
SD will all	5.707543
SD without Taylor	1.497707

Figure 5 and 6: Data and graph comparing average change in angle from pulsation to sternal angle directly measured on the chest



	Kelsie	**Kelsie**
Chest Circumference	37 cm	37 cm
Angle	47.3	34
Dr. Kao's JVP (cm above stern angle)	5-6 cm	7 cm
Absolute distance	14 cm	12 cm
Sensor's JVP	20.73	15.5

Figure 7 and 8: Dr. Kao's measurements of JVP on Kelsie and Dani using both the sensor method and the standard ruler method

	Dani	**Dani**
Chest Circumference	32 cm	32 cm
Angle	48	34
Dr. Kao's JVP (cm above stern angle)	3 cm	4 cm
Absolute distance	10 cm	14 cm
Sensor's JVP	17.1	15.25

Kelsie								
Chest Circumference	37	37	37	37	37	37	37	37
Angle of Inclination	2.3	10.9	19.8	29.7	39.8	50	59.8	90.2
Angle Difference	-10	-2	6.7	15.7	27.5	39.3	49.4	76.4
Distance from Sensor	16	16	16	16	16	16	16	16
Distance from Ruler	16	16	16	16	16	16	16	16
JVP from code	5.0455	6.9016						
Manual measurement	-0.8	1.45	2.7	4.6	5.72	10.3	12.1	17.1
JVP from rulers	4.2	6.45	7.7	9.6	10.72	15.3	17.1	22.1
Dani								
Chest Circumference	32	32	32	32	32	32	32	32
Angle of Inclination	0.5	9.8	19.9	29.8	39.8	49.7	60.5	90.2
Angle Difference	-9.9	-2.2	5.4	14.4	25.3	35.1	48.8	79.4
Distance from Sensor	15	15	15	15	15	15	15	15
Distance from Ruler	15	15	15	15	15	15	15	15
JVP from code								
Manual measurement	-0.2	0.8	1.2	2.1	6.05	8.35	10.9	16.6
JVP from rulers	4.8	5.8	6.2	7.1	11.05	13.35	15.9	21.6
Taylor								
Chest Circumference	42	42	42	42	42	42	42	42
Angle of Inclination	1.6	9.9	20	29.9	39.6	49.5	59.7	90.6
Angle Difference	-15.5	-9.3	-1.7	6.1	15.6	22.2	37	62.3
Distance from Sensor	15	15	15	15	15	15	15	15
Distance from Ruler	15	15	15	15	15	15	15	15
JVP from code	6.0288	8.4021	12.0411	16.0296	19.6343	22.4562	24.3296	26.3431
Manual measurement	-4	-3.1	0.9	2.5	5.2	7.6	9.1	16.4
JVP from rulers	1	1.9	5.9	7.5	10.2	12.6	14.1	21.4
Tony								
Chest Circumference	39	39	39	39	39	39	39	39
Angle of Inclination	1.2	10.1	20	29.9	40.5	50	58.7	90.1
Angle Difference	-7.2	2.5	5.1	20.3	29.9	37.8	50.6	80.2
Distance from Sensor	15	15	15	15	15	15	15	15
Distance from Ruler	15	15	15	15	15	15	15	15
JVP from code	5.3252	7.8662	11.4411	15.4296	19.3318	21.9715	23.5862	25.7741
Manual measurement	-1.1	0.2	2	4.2	7.3	8.2	11.4	18.9
JVP from rulers	3.9	5.2	7	9.2	12.3	13.2	16.4	23.9

Figure 9: Entire team data from testing JVP using the standard ruler method and sensor method, only one measurement per angle

Patient 1	Trial 1	Trail 2	Trail 3	Trial 4	Trail 5	Trail 6	Average	Standard Dev
Angle	60.2	60.2	60.2	60.2	60.2	60.2		
JVP: Ruler Method	9	9	8.5	9	9.3	10	9.13	0.50
JVP: Sensor	15.37	15.37	16.1	15.36	15.36	16.84	15.73	0.62
Angle	45.2	45.2	45.2	45.2	45.2	45.2		
JVP: Ruler Method	7	5.6	6.1	6.2	6.3	6.5	6.28	0.46
JVP: Sensor	13.1	12.01	12	14.1	12.56	14.16	12.99	0.97
Angle	30	30	30	30	30	30		
JVP: Ruler Method	3	3	3.1	3.1	2.5	2.9	2.93	0.23
JVP: Sensor	8.78	8.77	8.77	8.47	9.4	8.46	8.78	0.34
Angle	15	15	15	15	15	15		
JVP: Ruler Method	0.2	0	0.4	1	1	2.1	0.78	0.77
JVP: Sensor	3.93	3.83	3.77	3.83	3.88	3.72	3.83	0.08
Angle	0.2	0.2	0.2	0.2	0.2	0.2		
JVP: Ruler Method	-2.2	-3	-2.7	-2.7	-2.5	-2.1	-2.53	0.34
JVP: Sensor	0.8	0.81	0.6	0.394	0.28	0.81	0.62	0.23

Figure 10 and 11 (next page): Individual data for Kelsie and Dani measuring JVP using sensor and ruler method with multiple measurements per angle

Patient 2	Trial 1	Trail 2	Trail 3	Trial 4	Trail 5	Trail 6	Average	Standard Dev.
Angle	60.2	60.2	60.2	60.2	60.2	60.2		
JVP: Ruler Method	8	7.9	8	7.5	7.3	7.5	7.70	0.30
JVP: Sensor	15.04	15.04	15.04	13.55	14.3	14	14.50	0.64
Angle	45.2	45.2	45.2	45.2	45.2	45.2		
JVP: Ruler Method	4.5	4.3	4.2	4.3	4.5	4.7	4.42	0.18
JVP: Sensor	13.3	12.25	13.34	12.25	12.25	11.69	12.51	0.66
Angle	30	30	30	30	30	30		
JVP: Ruler Method	1.9	1.8	1.5	2	1	0.9	1.52	0.47
JVP: Sensor	8.77	8.77	8.77	8.47	7.88	8.77	8.57	0.36
Angle	15	15	15	15	15	15		
JVP: Ruler Method	1	1.2	-0.5	0	1.5	1	0.70	0.77
JVP: Sensor	3.5	3.507	3.51	3.56	3.45	3.56	3.51	0.04
Angle	0.2	0.2	0.2	0.2	0.2	0.2		
JVP: Ruler Method	-5.5	-5.3	-5	-4.5	-4.7	-4.9	-4.98	0.37
JVP: Sensor	0.11	-0.29	-0.09	-0.09	0.3157	-0.0886	-0.02	0.21

11. j. Product Design Specifications

Product Design Specifications- December 11, 2012
Electronic Bedside Device to Measure Jugular Venous Pressure

<u>Team Members</u>

Tony Schmitz - Team Leader
Taylor Moehling - Communicator
Kelsie Harris - BWIG
Dani Horn – BSAC

<u>Problem Statement</u>

A device is needed to measure the jugular venous pressure using sensors placed on the body to measure the patient's chest circumference, elevation angle, and distance from the right atrium to the pulsation on the jugular vein. A digital feedback will display these measurements via a phone or computer monitor.

<u>Client requirements</u>

- Non-invasive device to more accurately measure JVP.
- Hands-free device for measurement display.
- Must calculate chest circumference, angle of elevation, and distance from the right atrium to the pulsation on the jugular vein.

<u>Design Requirements</u>

1. Physical and Operational Characteristics

a. *Performance requirements*: The device will be used daily at a clinic and must be able to withstand normal wear and tear. The feedback must be easily understandable by the user.
b. *Safety*: The device must be able to be safely applied to the body and cause no harm to the patient.
c. *Accuracy and Reliability*: The device needs to accurately determine the circumference within 1 cm for each different body type. The elevation angle needs to be determined accurately within 5 degrees. The distance from the top of the jugular pulsation to the right atrium needs to be within 1-2 cm for each measurement.
d. *Life in Service*: The device must run up to 5 minutes daily for clinical patients for however long the administrator decides is necessary.
e. *Shelf Life*: The device will be stored inside in a hospital or clinic environment.
f. *Operating Environment*: The typical environment for this product will be in a clinic or hospital. The device will be stored until needed where upon use by only certified administrators.

g. *Ergonomics*: The device must be able to accommodate all genders, ages, body shapes and sizes.
h. *Size*: This device must be able to fit reasonably on a clinic or hospital shelf. Ideally, this product should be able to fit in the palm of the hand.
i. *Weight*: For portability reasons, this device should be no more than 5 lbs.
j. *Materials*: The device will include sensors, wiring, arduino, MATLAB program and a visual display on a computer.
k. *Aesthetics, Appearance, and Finish*: The display will be easy to read and interpret. The device does not need to have a specific color, shape, form or texture but it does need to look professional.

2. Production Characteristics

a. *Quantity*: The client only needs one sample device but possibly more for future use in clinics and hospitals.
b. *Target Product Cost*: The target cost of this product is under $500.

3. Miscellaneous

a. *Standards and Specifications*: For this device to be used in clinics and hospitals, patient consent will be necessary before the pressure is measured.
b. *Customer*: The customer must feel comfortable during the procedure. It is important to withhold patient dignity and ensure that there are no negative side effects.
c. *Patient-related concerns*: The data should be protected under the patient-doctor confidentiality agreement. Standard cleaning techniques may be necessary after each use to ensure sterile products. The device must be comfortable and easily administered.
d. *Competition*: There is a very basic device to measure the jugular venous pressure but is very inaccurate because it is a standard measurement for each patient. The method is unreliable because each doctor performs the measurements slightly different.