

Bedside Device to Measure the Jugular Venous Pressure

BME 200/300 – Fall 2012

BIOMEDICAL ENGINEERING DESIGN

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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 sensors to measure the absolute distance between the external jugular vein and sternal angle and a protractor-like device to measure the angle of elevation. The angle measuring device will be attached to the bedside near the patient's hip to get an accurate angle measurement. The circumference of the patient's chest will be measured to determine the depth of the right atrium. In the future, the jugular venous pressure may be measured via an iPhone application since it requires less equipment and fewer calculations for the physicians.

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 sensors placed on the body to measure the patient's chest circumference, angle of elevation, 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.

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

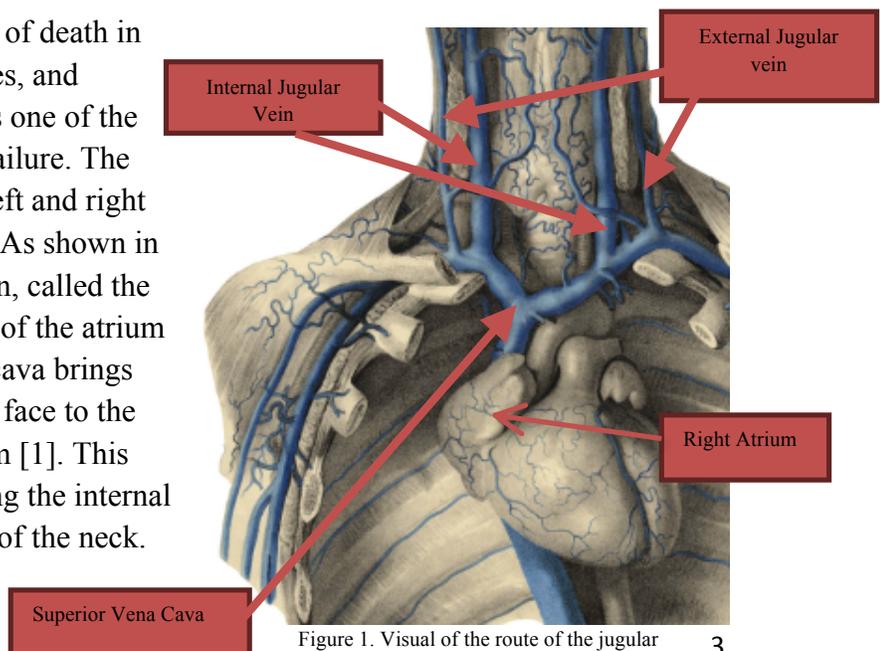
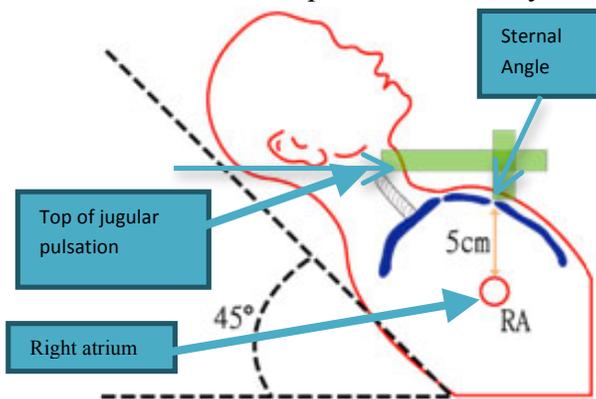


Figure 1. Visual of the route of the jugular veins to the right atrium.
http://www.anatomyexpert.com/structure_detail/8710/1201

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 heart because the blood that flows through them goes directly 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, making it a less ideal candidate for the measure of the jugular venous pressure.

The jugular venous pressure can be evaluated by measuring the vertical distances between critical points on the body. This measurement uses the external jugular vein by



observing the distances on the surface of the skin. These distances, as shown in Figure 2, are from the right atrium to the sternal angle, and from the sternal angle to the top of the jugular pulsation. Adding these two distances together gives the level of the jugular venous pressure. A normal mean JVP is considered to be 6 to 8 cm of water, fewer than 5 cm could mean hypovolemia, and over 9 cm of water could mean impaired cardiac filling [2]. 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 pumps into the brain and out through the jugular veins, so the external jugular venous pressure will be significantly more observable

Figure 2. How to find jugular venous pressure using distances.
<http://renal fellow.blogspot.com/2011/01/jugular-venous-pressure-distention.html>

when the head is lower. So the standard for normal at a lower angle will be higher, because the blood pressure will be naturally higher, then the standard for normal at a higher angle. Even though the external jugular vein is not the ideal candidate, the measurement is still accurate, if done correctly, and provides the necessary information for assessment and diagnosis of heart failure.

The change in the jugular venous pressure is one of the best indicators of the success of a treatment. If the JVP increases over time, then the treatment is not working and something else should be tried. A raised JVP can also be a sign of other medical conditions like superior vena cava obstruction, fluid overload, and many others [3]. If the JVP decreases over time the treatment is working and it should be continued. Since the JVP is such a good measure of the pressure many cardiologists evaluate the JVP as part of a standard physical exam for heart patients [4]. The difficulty with taking the JVP is the two current methods are not very practical.

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

The more conventional and well-known method of measuring jugular venous pressure is a non-invasive method. To begin this procedure, the patient must be positioned in a manner so the physician is able to locate the position 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 be 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 away in the opposite direction. Lying the patient at a 45 degree angle is standard for maximum presentation of 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 [5]. After a metric ruler is held vertically at this point, the vertical “sternal angle to top of jugular pulsations” distance should be estimated in centimeters. This value is then added to 5 cm, which is an outdated estimate of “sternal angle to right atrium” distance. Current evidence of CT scans suggests the distance varies with angle of elevation [6]. This method is the most established and common measurement of JVP, but this process lacks in accuracy because the physician is reliant

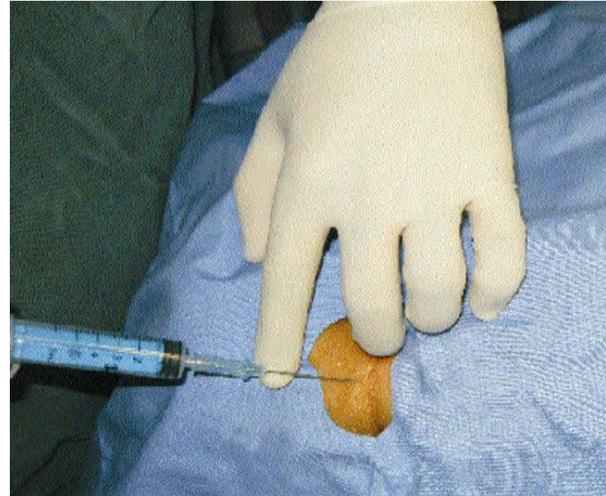


Figure 3. Displaying the use of rulers to obtain the vertical distance measurement.
<http://www.mespere.com/venus-1000>

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 incline angle, a different “sternal angle to right atrium” distance, etc., which immensely complicated 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 and conventional 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 which results in accurate pressure. 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 [7]. Also, if the syringe needle misses and punctures an artery or nerve, prominent blood vessel and neuronal damage may endure. Use of expensive ultrasound machines and knowledge of such a procedure make this procedure difficult to be performed by inexperienced and low budgeted healthcare individuals.



2. f. Product Design Specifications

The client has given the team specific requirements that he wants the team to follow in designing a device to measure jugular venous pressure. The angle of inclination 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” distance. A complete design will incorporate the chest circumference, inclination angle, and “sternal angle to top of jugular pulsations”

distance to ultimately determine jugular venous pressure. 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 [8]. 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 had 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.



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/NEJMvem0810156>

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 design would give the most accurate readings compared to the other designs, it isn't the most probable. 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 external 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.



Figure 6. Measuring the distance from the sternal angle to the pulsation of the external 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. Next, the doctor will measure the distance from the sternal angle to the pulsation in the neck of the external 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, and that 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.

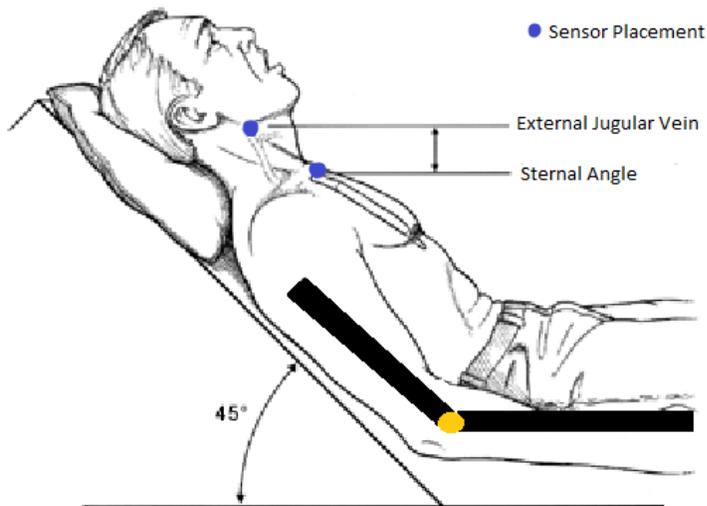


Figure 7. Process for Design 3 using sensors to measure distance between external jugular vein and sternal angle.

<http://emsbasics.com/2011/10/17/what-it-looks-like-jugular-vein-distention/>

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 [9]. 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 external jugular vein pulsating and the sternal angle. One sensor will be placed on the neck at the external jugular vein on the right side because the veins on the right side of the neck are larger [9]. The other sensor will be placed in 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.

A program will need to be written to determine the jugular venous pressure based on the three inputs of angle of elevation, depth of the right atrium and absolute distance from the

accurately. The physician will arbitrarily place the patient at an incline 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 external 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 external jugular vein pulsate, the patient might need to be lying flat on the bed [9].

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

external jugular vein to the sternal angle. The jugular venous pressure will be displayed in cm of water on an easy-to-read screen such as an iTouch 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 and the string would be thrown away after each use.

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 equations to determine the vertical distance from the sternal angle to the external jugular vein instead of estimating using imaginary horizontal lines.

4. Future Work

It is vital that the sensors be ordered in the near future in order to run simulations at the University of Wisconsin-Madison School of Medicine. The protractor-like device shown in Figure 8 will be drawn in SolidWorks and manufactured in the machine shop. A program needs to be written to incorporate the three inputs of: angle of elevation, depth of the right atrium below the sternal angle and absolute distance from the external jugular vein to the sternal angle to display an output of the jugular venous pressure. Using geometrical relationships, the vertical distance from the sternal angle to the external jugular vein needs to be determined using the angle of elevation and absolute distance.



Figure 8. Protractor similar to device that will be manufactured to measure elevation angle
<http://emsbasics.com>

In the future, the client Dr. Steven Yale would like to perform the jugular venous pressure measurement using an iPhone 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.

5. Experimental Testing

Upon purchasing the sensors, the device will need to be tested for accurate and precise data collection. The jugular venous pressure will be compared and contrasted to the current non-invasive method results to determine if the values are in close proximity. It is also important to ensure that the device outputs the same pressure readings for the same angle of elevation to ensure precision for treatment of previously diagnosed heart failure patients. The shelf life of the sensors needs to be evaluated and tested so the hospitals are aware of how long sensors will last before replacement.

6. Conclusion

Table 2. Group timeline for semester

Tasks	September				October				November				December			
	7	14	21	28	5	12	19	26	2	9	16	23	7	14	21	28
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																
Testing																
Modifications																
Final Presentations																
Final Paper																

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.

The client gave a budget of around \$500 for the semester design project but he didn't seem too concerned if it was necessary to spend slightly more. So far based on the research regarding prices of sensors, staying under budget seems fairly reasonable, assuming no major setbacks arrive.

7. Acknowledgements

The team firmly thanks the client Dr. Steven Yale for presenting a design problem to the University for the Biomedical Engineering Department. He is very supportive of the work done thus far 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. 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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9. a. Product Design Specifications

Product Design Specifications- October 23, 2012
Electronic Bedside Device to Measure Jugular Venous Pressure

Team Members

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Problem Statement

A device is needed to measure the jugular venous pressure using sensors placed on the body to measure the patient's chest circumference, incline 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.

Client requirements

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

Design Requirements

1. Physical and Operational Characteristics

- 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.
- Safety*: The device must be able to be safely applied to the body and cause no harm to the patient.
- Accuracy and Reliability*: The device needs to accurately determine the circumference within 1 cm for each different body type. The inclination 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 individual.

- 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, processing center, and a visual display on a computer or phone.
- 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.