UNIVERSITY OF WISCONSIN –MADISON, DEPT. OF BIOMEDICAL ENGINEERING

Ultrasound Probe Holder

Mid-semester Design Report

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Abstract: The application of a probe holder has been identified as a tool for improving the effectiveness of ultrasound vasculature reactivity studies. Such a device would be used to stabilize and consistently position an ultrasound probe on a patient to image the brachial artery. The positioning flexibility of such a probe holder would require three directional degrees of freedom and three rotational degrees of freedom. With this specification in mind, several positioning solutions were identified and analyzed. Ultimately, an articulated arm with movement capabilities similar to that of a human arm was selected. Additional work has been done to identify the means for effectively supporting the probe in the device, and also stabilizing the subject's arm.

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Problem Statement

To aid the use of ultrasound for study of arterial reactivity, a simple, stable, adjustable probe holder is needed. The stabilization provided by such a holder could potentially improve probe imaging quality and diagnostic effectiveness. The device should be able to be finely adjusted with 6 degrees of freedom, and free the hands of the technician for the duration of the study.

Introduction and Motivation

The use of ultrasound for the study of vasculature health has become common practice in medicine. Ultrasound can be used for a variety of diagnostic techniques including arterial imaging and blood flow measurement. This design project focuses specifically on the use of ultrasound in vascular reactivity studies of the brachial artery. Reactivity studies are conducted on patients to monitor the epithelial response of the tissues to pressure changes in the vasculature (Coretti, *et. al.,* 2002). Abnormalities can be early indicators of atherosclerosis (Harrison, *et. al.,* 1987). Thus, improvement of the techniques for obtaining vascular ultrasounds can provide medical staff with a more effective and reliable means of diagnosis.

The reactivity study under specific focus for this project involves the use of ultrasound on the upper arm of a patient. The brachial artery is imaged for more than five minutes at one position. Typically, a sonographer will properly position the probe and then hold it in the desired position for the duration of the study. While the study is conducted and the vasculature is monitored, the blood flow through the artery is restricted with a tourniquet style blood pressure cuff. As pressure builds up in the brachial artery, vascular response is observed, then after a certain time, the cuff is released, again eliciting a reactive response of the artery (Korcarz).

The limitations to this current method are not difficult to recognize. The reliance of a sonographer to stabilize the probe is not only inefficient, but also does not ensure that the same region of the artery is being imaged throughout the study. Furthermore, the practice of the study puts undesirable stress on the sonographer, who often must sustain unhealthy postures that may lead to musculoskeletal injuries, such as Carpal Tunnel Syndrome.

In this report, the specifications of how to stabilize and efficiently position an ultrasound probe have been investigated. Several different methods have been identified and analyzed. The application of a positioning system in to the broader specifications of the device are also addressed, including the task of holding the ultrasound probe and stabilizing the patient's arm to ensure image stability. The positioning device has been established and future work will be directed to integrating all components of the device into a functional and usable prototype.

Specifications

Below is an overview of the considerations for the design. For more detailed and quantitative specifications, see Appendix A for the Design Specifications.

Positioning Freedom

In order to correctly image the artery, the probe must have six degrees of freedom. The two lateral directions, along with the vertical direction, would be used mainly as a rough adjustment to find the artery. These movements would enable the sonographer to move the probe from its resting position to the upper arm of the subject. Once the probe is in position, the three rotational degrees of freedom would be used to obtain the best image possible since the probe must be perpendicular to the artery. The rotational movement will allow differential pressure to be applied to the arm, an important quality for image resolution. Finally, when the stimulus—the pressure applied to the lower arm—is removed, the artery may shift slightly and the probe will have to be readjusted. Finding the correct position again may require all six degrees of freedom as modeled in Figure 1 - Degrees of Freedom needed for proper positioning. Therefore, the probe's ability to move freely in all directions is a vital component of the design.

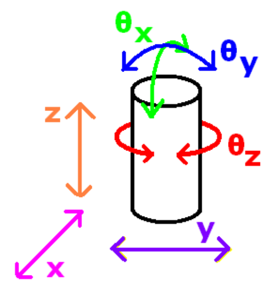

Figure 1 - Degrees of Freedom needed for proper positioning.

Adjustment abilities

The device should be easily adjustable and sensitive to fine tuned movements. When beginning a study, the sonographer will orient the probe with very subtle adjustments in order to obtain the proper cross sectional image of the artery. However, the location of the artery within a patient may be subject to slight shifts throughout a study due to the pressure changes on the arterial walls. The device must allow for quick, fine tuned adjustment of the probe position with as little complexity as possible. Similarly, minimizing the set up time of the exam and the required labor to position the probe is also essential. Simple but accurate adjustability is one of the main requirements of any design option.

Accommodation of Probe Varieties

The final design of the device should be able to accommodate a variety of different ultrasound probes. Although the general dimensions of different probes are within a common range, they can vary in their shape and orientation. Either a universal or modular clamping mechanism must be designed to accommodate the variety of probe shapes. Figure 2 show three examples of common probe designs.

Figure 2 - Variety of probes to be accommodated in design. All of similar sizes, but contours vary significantly

Ergonomics

The usability of this device is key to its success in improving ultrasound studies. The ultimate goal of the probe holder is to simplify the ultrasound procedure and improve its consistency. Therefore, considerable attention was given to the ease of use of the device, which is to allow the most freedom and control with the least amount of adjustments. The device must be able to integrate into the workflow without hampering or impairing the flexibility of the sonographer. A device which does not require much training to operate will be the most desirable.

Figure 3 - Image of ultrasound workspace layout. Sonographer (left) will be required to hold the probe in the shown position for 5+minutes. The wrist is in a radially deviated posture.

There is a significant element of occupational ergonomics to this device as well. A well designed device will reduce or eliminate the occupational stress on the sonographer associated with poor wrist postures (Figure 3). A sonographer holding the probe in the position shown has a radial deviation of the wrist which, over time, can put unhealthy pressure on the Carpal Tunnel and lead to musculoskeletal disorders (Keir, *et. al.,*1997). In the laboratory where this device is to be implemented, OSHA limits a sonographer to one study per hour due to the stress that the procedure can induce on the test administrator (OSHA). The implementation of this design could potentially relieve some of the stresses associated with conducting these studies, and allow a sonographer to complete more studies in less time.

Design Considerations

Positioning Mechanism Options

Design Rating Criteria

Five main characteristics were taken into consideration when choosing a design for this project: ease of use, reliability, durability, complexity, and cost. These criteria and their associated importance were determined by the client's requirements.

The most important aspect of this device is that it improves the ultrasound procedure. However, it must not impede the workflow and efficacy of the sonographer. Ease of use is paramount to the integration of this device into a healthcare setting. The device should be quickly adjustable and require minimal training to use. Additionally, shorter setup times will allow for greater productivity.

The second most important criterion for this device is reliability. The device must ensure that the probe only moves as desired. Ideally, the final product would be reliable enough that the sonographer can set the probe in place and then do other things while the procedure is being conducted.

There is a need for the device to last for many years. A durable device is much more valuable, and less expensive, than having many devices with unknown life spans.

The complexity of construction was the fourth category considered for this project.   A device with a few modular sections is much easier to fix than a product that needs to be wholly replaced if one part breaks.   It is advantageous to design something which requires less machined parts or unique tools to assemble. This would reduce the time to fix the device in the event of a malfunction.

Lastly, the cost must be considered. A vascular ultrasonic machine may cost between $10,000 and $20,000, so a budget a few hundred dollars or more is not unreasonable. The primary focus of this project is on quality and functionality rather than cost. Even though minimizing the cost is always a goal, it is not a main goal for this project.

Option 1 – Snake

Figure 4 - Illustration of snake positioning concept. From McMaster-Carr.

The main component of this design was the snake like positioning arm (Figure 4). The arm itself is essentially many ball and socket joints linked together with a spring running through the middle. Each ball has limited rotation abilities, but the collection of all the joints allows the snake to have a wide range of motion. The spring acts as a locking mechanism. It pulls all the links together so the friction between them doesn't allow them to move freely. With this design, the probe can be repositioned and adjusted easily. This design is very easy to use, cheap and relatively easy to replace in the event of a malfunction. It has no buttons or knobs so it requires minimal training to operate. However, the springs within the snakes tend to lose their rigidity over time and the snake becomes unreliable. If a stronger spring were to be used to offset the spring degradation, it would require much more force to overcome that spring when the probe had to be repositioned. It may be hard to make fine adjustments once the probe is set in place.

Option 2 – Post Holder

Figure 5 - Post Holder Design. The horizontal bar is free to move up, down and rotationally along the vertical post. From Noga Engineering.

This design has a vertical pole with a horizontal bar that has a knob which will allow it to slide up and down the pole (Figure 5). Additionally, the horizontal bar can swing laterally 360 degrees on the pole, increasing its range of motion. Other knobs will enable the user to change the angle of the horizontal bar. While the device is very secure and able to hold its position accurately for long periods of time, it is difficult to change the position quickly and has a limited range of motion.

Figure 6 - Several Articulated Arm models. One knob at the corner joint tightens all three joints, allowing size degrees of freedom with one adjustment. From Noga Engineering.

Option 3 – Articulated Arm

The articulated arm functions just like a human arm (Figure 6). There are two ball and socket joints and a hinge joint that provide 7 degrees of freedom. The entire device is controlled by one knob, which makes it easier to use and adjust. Fine tuning adjustments can be made at the end of the device. The fine tuning will be beneficial if the artery shifts slightly as a result of the reduction in pressure. While this device is the most costly, it provides the greatest range of motion. The device can hold its shape and the necessary pressure for long periods of time. It is easy to use, reliable and capable of supporting forces much greater than needed.

Design Matrix

The three design options were analyzed using the following criteria: ease of use, reliability, durability, cost, and complexity. Based on the client's requirements, each category was given the following weights: ease of use – 40%, reliability – 30%, durability – 15%, cost – 5%, and complexity – 10%. The design matrix shown below in Figure 7 was used to choose the articulated arm as the final design.

	Snake Design	Post Holder	Arm Design
Ease of Use (40%)	9	5	7
Reliability (30%)	5	10	10
Durability (15%)	4	9	9
Cost (5%)	10	7	6
Complexity (10%)	10	7	6
Total (Out of 10)	7.2	7.4	8.05

Figure 7 - Design matrix of positioning options. Based on weighted rankings of each option, the final score of the Arm design was selected as the best choice.

Probe Clamping Options

Option 1 - Three Prong Clamp

A three prong clamp may be used to hold the probe (Figure 8). The prongs on the clamp are able to fit around each size of probe and they can be tightened to ensure that the probe is not moved during the procedure. The prongs have a rubber casing around each tip to ensure that they do not damage the probe and are able to firmly hold different sizes. The prongs are adjusted by the screws. The rod can easily be attached to the mechanical arm.

Figure 8. A three prong clamp that could be used to hold the probes in position. The two screws are used to tighten the clamp when it is in the correct position.

Option 2 - Plate System

The plate system is composed of two parallel plates that sandwich the probe that can be tightened to fit around each different sized probes. The inner surface will have foam or rubber that will cushion the probe when it is locked into place by the plates. Several adjustable screws will connect the two plates at different points and be able to be tightened to fit each probe.

Arm Cradle

In order to ensure that the probe position on the arm remains constant, a cradle should be designed to hold the patient's arm in position. An arm cradle will provide the support for the arm so that the patient does not tire and move around. A possible

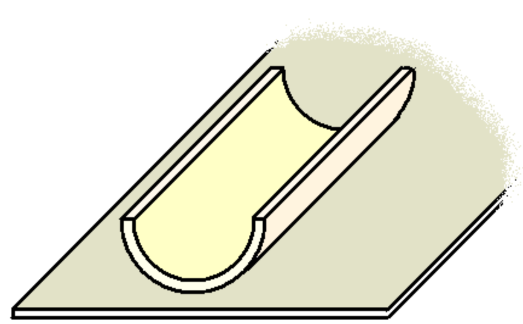

Figure 9 - Basic concept of cradle for stabilizing the forearm

design is to cut a hollow cylinder in half and pad it (Figure 9). Additionally, if a handle was placed at one end, the subject would be able to grip it in their hand and further minimize movement. Eventually the arm cradle should be attached to the subject's bed.

Future Work

The next step is to refine the design of the probe clamp and arm cradle. A first generation prototype will be produced and tested in the clinic. The functionality of this device will be assessed to identify weaknesses in the design. A functional prototype will be constructed before the conclusion of this semester.

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Appendix A

Project Design Specification—Ultrasound Probe Holder (Group 44)

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Function:

A simple, stable, adjustable ultrasound probe holder to aid in the ultrasonography of arterial reactivity. The holder would stabilize the ultrasound probe to improve image quality and reduce noise for better diagnostic effectiveness

Client Requirements:

- Stable, won't fall over or move probe
- Adjustable for small changes
- Cost efficient
- Ergonomic

Design Requirements:

1) Physical and Operational Characteristics
   a) *Performance requirements* – Easily adjustable without interfering with the ultrasound, able to make small adjustments quickly, able to securely hold the probe, able to hold the patients arm while in use
   b) *Safety* – The materials should not be hazardous and should not interfere with the ultrasound
   c) *Accuracy and Reliability* – The device should be able to make small changes quickly and hold its position without changing. It should have 6 degrees of freedom motion
   d) *Life in Service* – The device should last at least five years
   e) *Shelf Life* – The device should be able to be stored indefinitely without compromising its integrity, must be able to be stable for 5 to 10 minute periods
   f) *Operating Environment* – The probe holder will be used in typical laboratory and clinical settings
   g) *Ergonomics* – The device should be able to accommodate a large range of users without interfering with the ultrasound procedure
   h) *Size* – The device should be small and compact, should be able to fit for different sized probes
   i) *Weight* – The probe should be as lightweight as possible while proving a stable support
   j) *Materials* – The materials should be cost efficient and should not interfere with the ultrasound procedure

    k) *Aesthetics* – The device should be aesthetically pleasing

2) Production Characteristics
    a) *Quantity* – Only one product is currently needed, but it should be designed with the intention of mass production
    b) *Target Product Cost* – The device should less than $1000
3) Miscellaneous
    a) *Standards and Specifications* – The device should follow all required standards in regards to ultrasonography
    b) *Customer* – The device will be used by medical personnel in a laboratory or clinical setting
    c) *Patient related concerns* – The device should not harm the patient
    d) *Competition* – There are currently some ultrasound probe holders being patented, but none are available commercially. Additionally, most of the current competition must be mounted to the wall.