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UW Madison Biomedical Engineering

Ultrasound Transducer Holder

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ABSTRACT

Advancements in ultrasound imaging software have made its use more prevalent in a clinical setting. Echometrix, a Madison-based startup company, recently developed innovative ultrasound video software involved in musculoskeletal diagnostics and rehabilitation. The software, however, requires the use of three hands in order to operate. In this report, a simple and elegant ultrasound transducer holder is proposed. The holder needs to allow the transducer to be maneuvered with six degrees of freedom and to be secured to the surface of most body parts. Multiple designs are presented that allow angular rotation of the transducer. There are also design options presented that allow translation of the transducer perpendicular to the skin. The design alternatives are critiqued with a design matrix and, based on this critique, a final design is established. Plans for fabrication of this design and further modifications are summarized.

INTRODUCTION

ULTRASOUND BACKGROUND

Imaging with the energy created from ultrasound has become a very widely adopted diagnostic practice in a clinical setting. The general idea behind ultrasound imaging involves a transducer transmitting an ultrasound pulse which echoes off of the material that it contacts. Changes in impedance in the material alter the pulse that is echoed back from the material. These changes are recognized by the ultrasound transducer, and software can be used in order to process this data and create an image. When using a gel or gel pad of known acoustic properties to form a complete contact surface between the transducer and a patient's skin, the transmittance and reception of waves can produce an image of a patient's internal tissues such as blood vessels and tendons. An image of this kind provides information about the patient's health that cannot be obtained with external senses. Other imaging techniques such as MRI and CT are also used clinically for this purpose and have been shown to provide a clearer image and more insightful information than ultrasound imaging. However, ultrasound remains relevant in clinical practice due to its portability, safety, and cheap cost [1].

There are numerous factors that influence the amount of information that can be obtained from an ultrasound image. Properties of the transducer such as length and width of pulse transmitted affect the amount of axial and lateral resolution of the image produced [1]. This means that the transducer best suited for a particular situation can be variable. Also, the injection of a contrast agent may increase the clarity of a specific tissue that is the main focus of the image [2]. The skill and experience of the ultrasound technician that is operating the transducer can have an effect on the image quality as well. Of all these factors, the design of the software that is used in order to interpret the information received by the ultrasound transducer is the factor that is of greatest interest to our client. Ultrasound software determines the type of information that can be obtained from the image. Our client, Echometrix, develops software for use with dynamic ultrasound imaging in order to diagnose and track rehabilitation of musculoskeletal conditions. Specifically, the software recognizes tendons and ligaments of interest on the image and then tracks pixels as the tissue of interest is stretched [3].

The current method for using the ultrasound transducer with the Echometrix software is reliant upon three hands. One hand is used to position the transducer on the tendon to be studied. Once the desired image is obtained, the clinician must use his or her remaining hand to apply stretch to the tendon. A third hand is then needed to record the image from the ultrasound machine. During this process,

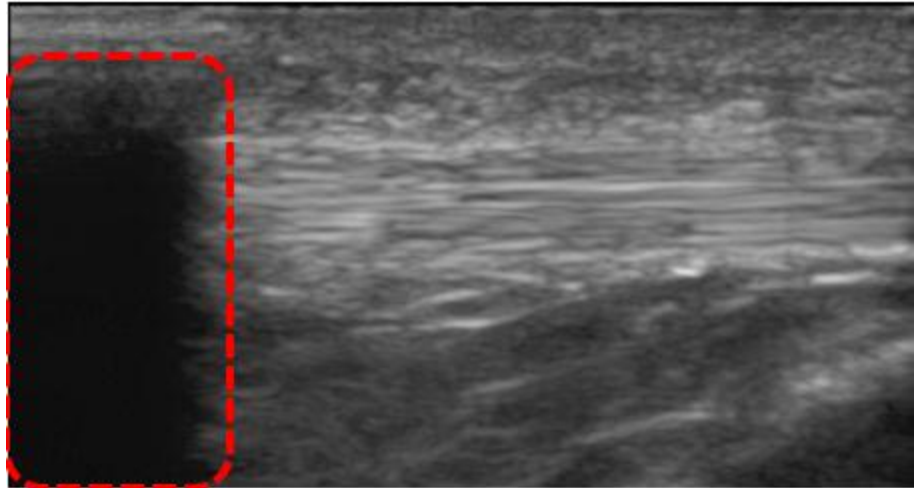


Figure 1: An ultrasound image of a tendon displaying a shadow (highlighted in red) due to detachment of the transducer

it is imperative that the transducer remain firmly pressed to the skin in a fixed position. Failure to maintain transducer contact with the skin can cause shadows in the image, as seen in Figure 1. Shadows such as this prevent the software from making accurate measurements.

The software's reliance on the ability to multitask is inefficient and can result in wasted time and resources. A device that would remove the need to hold the ultrasound transducer against the skin would eliminate one of the tasks that the operator is required to perform and allow more attention to be devoted to the other tasks. This will lead to an efficient and effective use of the software. The design of this device must take into account all factors that affect ultrasound image quality, including variable transducer size, site injection of contrast agent, and operator variability. A number of solutions have been proposed to address this problem.

PROBLEM STATEMENT

Ultrasound imaging has become more preferred than other, more insightful imaging techniques such as CT or MRI due to its portability and low price. Echometrix, our client's company, is developing ultrasound video software that would add to the diagnostic and prognostic value of ultrasound imaging techniques. The software adds another complication to the manual manipulation of the ultrasound transducer as the doctor will have a greater workload. Our client would like to develop a simple and elegant ultrasound transducer holder that can be maneuvered easily with six degrees of freedom and can be secured to the surface of most body parts in order to standardize the modern ultrasound technique.

DESIGN SPECIFICATIONS

To record a satisfactory image, the transducer must be positioned directly over the tendon. For this reason, the holder must be attachable anywhere on the arms and legs of the patient. Upon attaching the holder to the appendage, the transducer must be able to translate

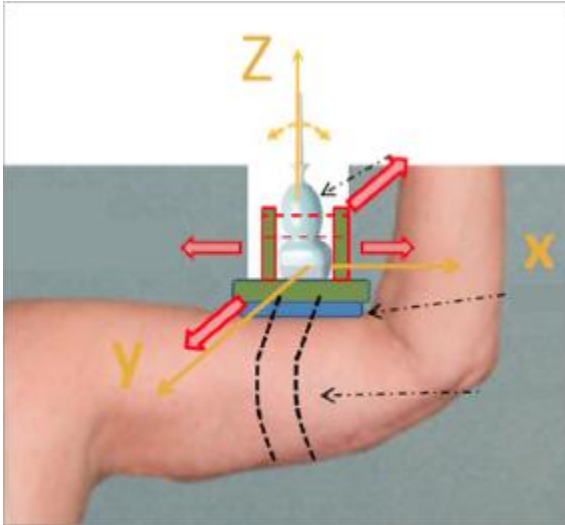


Figure 2: A representation of the reference axes of the transducer movement relative to the skin.

across the plane of the skin to find the tendon. It must then be pressed to the skin. The amount of pressure between the skin and transducer can slightly affect the resulting image, thus z-direction motion (in reference to Figure 2) is important. Rotation of the transducer about the x- and y-axes allows for the transducer to remain perpendicular to the skin in case the base is not flush with the skin once strapped into position. Additionally, rotation about the z-axis allows for longitudinal and cross-sectional views of the tendon to be captured, which allows for versatility of use. This aspect is extremely important since it allows the exact image to be replicated at a later point in time.

Upon positioning the transducer in the desired location, the device must remain in this fixed position. It should be able to withstand slight shifts due to possible patient movement without noticeable deviation from the original orientation. Furthermore, the device must be easily adjustable and able to accommodate fine tuning movements. As the tendon is stretched, the ability to quickly reposition the transducer to enhance quality is desirable. The capacity for simple and stable adjustment of the device is a main requirement for any design considerations.

Additional requisites of the device include the ergonomics of the design. For example, the use of the apparatus must be straightforward and intuitive; it should not require training to use the device. On the other hand, the holder must be comfortable for the patient to wear and cannot be overly heavy or else it will exert a large force on sensitive, damaged tissue. The device must also permit ultrasound guided injection therapy, wherein ultrasound images aid in percutaneous injections. This allows for continuous visualization of the needle and exact delivery of drugs in affected body parts, specifically enabling direct injection into joint spaces and muscle tendon sheets [4].

DESIGN COMPONENTS AND CONSIDERATIONS

In order to determine a design that would maximize the transducer holder effectiveness, several options were discussed and evaluated. In all cases the mechanism that would allow for translation in the directions parallel to the skin was a set of sliding carriages on rails (Figure 3). All cases would also be attached to the appendage via straps that are suspended

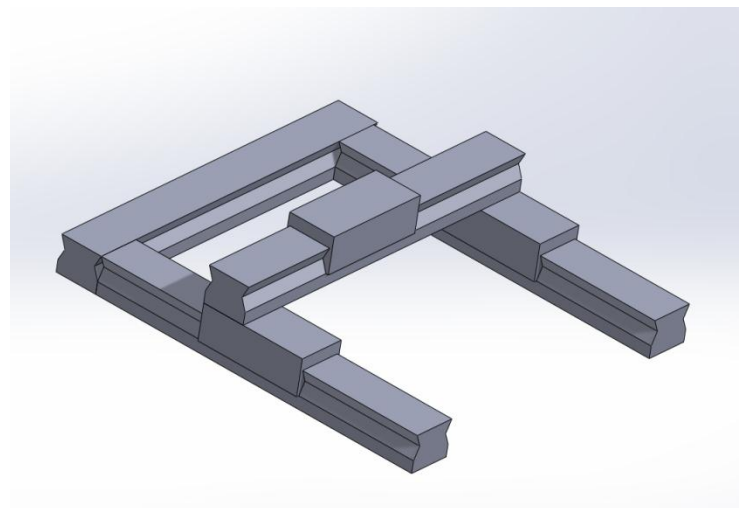


Figure 3: A diagram of the rail system designed for translation parallel to the skin (x-y plane).

from the rails. These straps would be wrapped around the appendage and secured together with Velcro. Two distinct pieces of the project were subjected to an extensive design process: the mechanism that would hold and rotate the transducer and the mechanism that would allow z-direction translation to increase compression on the skin. Multiple design alternatives for these two mechanisms were considered in order to ensure that the concept was thoroughly investigated and that the best design was found. A design matrix was developed in order to compare the design alternatives.

Five main criteria were considered in the design matrix. The criteria included: ease of use, adjustability, ease of fabrication, durability and cost. Ease of use was the most important criteria as dictated by the client. The main purpose of the device was to decrease the work load of the clinician, and a device that is hard to use would not accomplish this purpose. The most valuable asset to a clinician is their time, and so the device needed to be simple to operate and set up. The device also had to be lightweight so that it was comfortable for both the doctor and the patient.

Adjustability of the device was the second most important quality to the design. An ideal design would move easily and smoothly with little resistance, but also remain firmly in its place at the clinician's will. This would permit the clinician to use one hand to capture the image, and one hand to do the stretching exercises needed. Both fine and gross adjustments in the X-Y plane were necessary to gather an ultrasound image in the ideal location. The device also must allow the transducer to rotate 180°. This ensured either a longitudinal or cross sectional image of the desired tendon or tissue to be obtained. Ideally, the transducer would be able to rotate without significantly changing location on the patient's tendon.

Another important criterion was ease of fabrication. Echometrix plans to sell their software to allow economic ultrasound imaging to replace the highly expensive MRI scans. Therefore, the device needed to be easy to fabricate in order to be mass-produced. Additionally, the team needed a design that was feasible to construct. Fabrication was less significant than other aspects of the design because these components would most likely be purchased.

Durability was another important aspect of the design. Due to the fact that this design would be used in hospitals, it had to be able to be cleaned with 70% alcohol, a health care standard. The device also had to be strong enough to counteract the resistance force supplied by the skin. A successful product would have a functional life of several years without loss of effectiveness or strength.

The final criterion considered was cost. As with all medical devices, a product marketed with a lower price has a greater chance of widespread use. This was especially important because ultrasound imaging is being presented as a low cost alternative for MRI, so the holder must also be economical. Our client, Dr. Hirohito Kobayashi, was fiscally responsible for the materials associated with the project. Materials were to be purchased and an expense report was to be filed at the end of the term for reimbursement. A budget of \$500 was established, with additional funding possible if needed.

DESIGN EVALUATION

ROTATION

The first complex aspect of the design was the mechanism that would allow the transducer to be rotated. This problem could be approached from several ways, so after discussing many options, the three top performers were evaluated.



Figure 4: An example of a rotating base system [5].

safe, making this a viable option. This device stood out due to its adjustability, covering all the degrees of freedom needed. However, turning the device would significantly change the placement of the transducer, making the process of going from a lateral image to a cross sectional image a chore.

Concept 2 - Hinge Joint

The second design that was considered was a lockable hinge joint. What allows this joint to lock is a spring loaded pin that may be physically extracted, allowing a free range of motion. Once the pin is aligned with a slot, the spring snaps the pin back into the secured position, locking the joint at the desired angle. This joint is adjustable from 0 to 220°, locking in 10° increments. This concept is illustrated in Figure 5. These increments would limit the adjustability of the device. Although the mechanism may be durable and strong, it requires two hands to adjust. Therefore the device is not the most

Concept 1 - Rotating Base

The first option for allowing rotation was to use a bracket that would simply hold the transducer in place while the base itself would rotate. Similar to a dash mount cell phone holder, the point of attachment stays stationary and a base above the point of attachment rotates, while the arm that holds the device protrudes outwards. This design allows rotation in any direction and would likely be available as a prefabricated unit. These units also allow the tilt to be adjusted to some degree. Such units are typically composed of materials that are biologically



Figure 5: An example of a commercially available locking hinge joint [6].

ergonomic. This joint also fails to rotate, but could be coupled with the rotating base to allow for the desired degrees of freedom.

Concept 3 - Ball and Socket

The final option considered was a simple ball and socket type joint, as seen in Figure 6. The joint would be tight enough that once positioned, friction alone would maintain the desired position. It was determined that the most logical place to put the joint was below the bracket that would hold the transducer, similar to a joystick. This would allow for the most natural motion, mimicking the original movement by the MD using the transducer without a supporting device. Therefore this device would be extremely easy to use. This joint would allow for both rotational movement as well as allowing for the transducer to be tilted. It was determined to project the joint slightly off of the base carriage to ensure that no binding between the bracket, transducer, and rails would occur. Due to the slight offset, a minimal amount of displacement of the picture window may be present, but it could be easily compensated for since the radius of projection is sufficiently small. This option would allow for an ideal joint due to the high amount of adjustability.



Figure 6: An example of a commercially available ball and socket joint [7].

Table 1: The design matrix for the three attachment options.

	Max	Rotating Base	Hinge Joint	Ball and Socket
Ease of Use	40	25	30	35
Adjustability	30	25	15	30
Durability	15	5	15	10
Fabrication	5	5	5	5
Cost	10	10	5	5
Total	100	70	70	85

Each of the 6 design options were evaluated over a general scale of effectiveness. Categories that were weighed heaviest included ease of use (40%) and adjustability (30%). Other categories included durability (15%), fabrication (5%) and cost effectiveness (10%). A higher score indicated a more satisfactory completion of the criteria. The scores were then

compiled, giving a clear cut picture that the ball and socket joint was the best selection. All design options were tested independently of the sliding rails, since these rails would ultimately be incorporated into whichever design proved most applicable.

Z-DIRECTION MOTION

The second complex aspect of the design was the mechanism that would allow translation in the Z direction. An ideal design would require only one hand to achieve Z axis movement. It should also be able to lock in place, and be finely adjustable.

Concept 1 – Pen

The pen design resembled the mechanical component of a simple click pen. When a pen is clicked, a spring is compressed and a series of concentric shafts slide and shift a pin, allowing retraction of the pen point. The design would parallel this mechanism. This device was ideal because of its simplicity for the user; it would be able to be operated with one hand. However, this device would be difficult to fabricate and would quickly become bulky in order to gain the rigidity required to apply the necessary tension.

Concept 2 – Crutch

The crutch design utilized two cylinders to achieve Z direction movement. In the design, an outer shaft with holes contained an inner shaft with two spring-loaded buttons. When the buttons were compressed, the shaft was able to slide. A spring provided the lift for the inner shaft, as seen in Figure 7. The crutch was an appealing system because it was very simple, and would

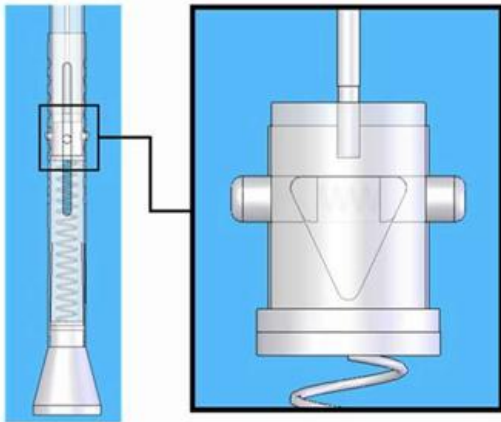


Figure 7: Representation of how a crutch exhibits translation [8].

accomplish the task well. It would also be easy to disassemble in order to clean. Unfortunately, the 3 mm movement needed would mean the button would have a very small distance to travel. This would limit the strength of the device, and would necessitate the use of two hands.

Concept 3 – Screw

The screw design drew on several fundamental concepts. In the design, the lower cylinder was threaded so that the screw could rotate within. A spring supported the upper cylinder. The upper cylinder was smooth, and had a slightly larger diameter than the screw. This allowed the upper cylinder to slide on the screw's shaft. The screw head was tangent to the upper cylinder. When the screw head would be turned, the spring is compressed and the transducer, which is connected to the upper cylinder, is translated downward in the Z direction. This design was ideal because it could be operated easily with one hand. Additionally, the Z direction movement was adaptable. The clinician could get more or less translation based on the number of turns they

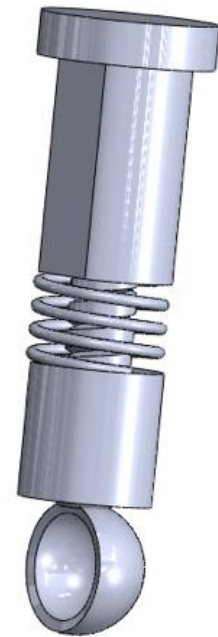


Figure 8: SolidWorks drawing of screw design for z-axis translation.

applied to the handle. The device would lock in place due to the force put on the screw by the spring. However, this device required some lathe machining which increased the time required to fabricate.

Table 2: Design Matrix for Z Movement Designs

	Maximum	Pen	Crutch	Screw
Ease of Use	40	40	30	35
Adjustability	30	15	15	30
Fabrication	15	5	5	10
Durability	10	5	10	5
Cost	5	5	5	5
Total	100	70	65	80

The three designs were entered into a design matrix (Table 2) and analyzed using the following criteria: ease of use, adjustability, ease of fabrication, durability and cost. The categories were given weights according to their importance as follows: ease of use (40%), adjustability (30%), ease of fabrication (15%), durability (10%), and cost (5%). A higher score indicated a more satisfactory completion of the criteria. Based on the design matrix, the screw design was determined to be the optimal final design component.

FINAL DESIGN

The final design will consist of two separate rail systems for translational motion parallel to the skin, a ball and socket joint to accommodate rotation, and a screw mechanism to provide necessary pressure perpendicular to the skin (Figure 9). The entire design will be attached to the body with several straps. This design will allow the transducer to move small increments in any direction to ensure the best ultrasound signal at the desired location.

The base of this design will be an incomplete, three-sided square made of metal, with each side being approximately 4 in (10.16 cm) in length. The base has only three sides so that the doctor can access the skin below the transducer for any necessary injection treatment. The bottom surface of the metal will be covered with a cleanable padding made of rubber so that it is more comfortable for the patient to wear, as well as being sanitary. On the outside of the base there will be wide holes for straps to attach to. These straps will be standard Velcro bands to connect the transducer holder to the body, similar to a knee brace. There will be six attachment points for the straps: in the center of parallel rails and one in each corner. Varying attachment positions will allow for more versatility of the device. This versatility is enhanced by the translational components of the design.

One direction of translation will be accomplished by using two parallel rails. These rails will allow a specially-fitted carriage to slide across them. The parallel rails will be connected with a metal bar at one end for stability. These three pieces will be attached with a stationary joint at each corner. The carriages will be connected to each other with a third rail, ensuring that they translate in sync. The connecting rail between the two carriages allows for another direction of translation. This lone rail has another carriage on it, enabling sliding along this axis. The combination of these two rail-and-carriage systems allows the transducer to move to any location within the confines of the base.

In addition to moving horizontally within the base, the transducer must be able to rotate in all directions and translate vertically. A ball-and-socket joint is attached to the central carriage to allow for all rotation. Attached to the other side of the ball-and-socket joint is the screw mechanism to increase the downward pressure of the transducer on the skin. As the top part of the screw is rotated, the loosely attached upper shaft compresses the spring, allowing the upper shaft to move downward. This upper shaft is connected to the transducer, so when the upper shaft moves downwards the transducer does as well.

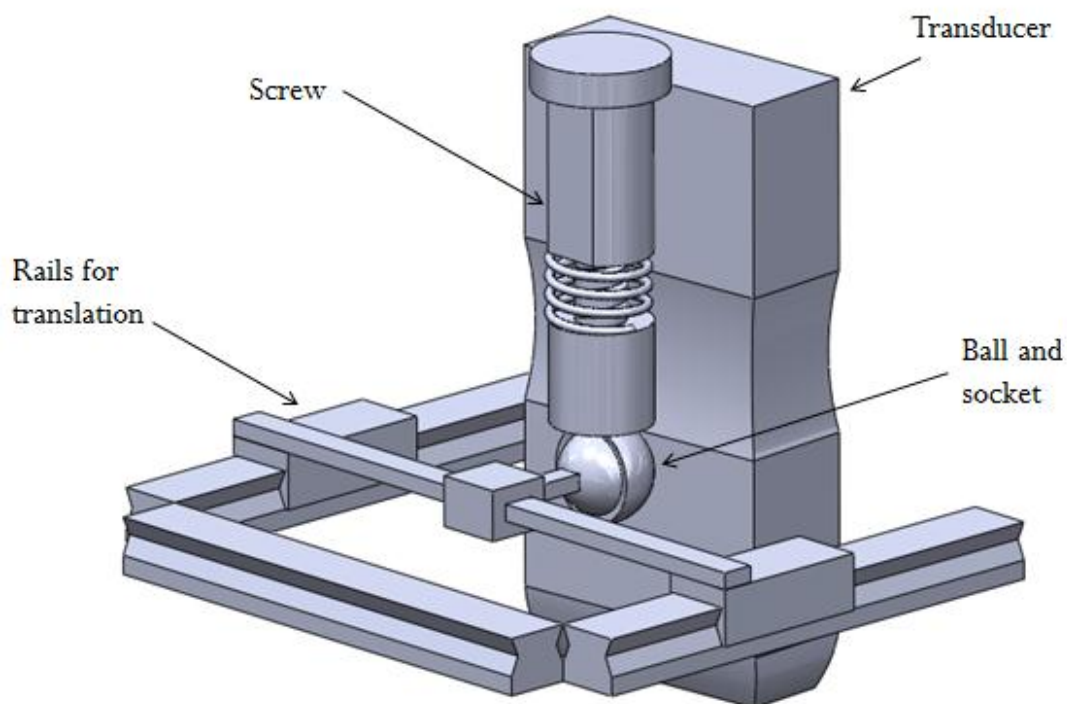


Figure 9. SolidWorks drawing of the final design of the ultrasound transducer holder.

FUTURE WORK

The next step in this project is to begin fabrication of the design proposed in this paper. The rails, carriages, and ball-and-socket joint must be purchased, while the screw mechanism must be fabricated. The exact attachment method of ultrasound to holder and holder to body must be determined and designed in modeling software. The attachment mechanism for the transducer should be able to hold various different transducers. This initial prototype must

then be tested by ultrasound technicians to ensure that it meets the client's needs. The transducer holder must increase the speed and ease of taking a video ultrasound. Feedback will then be taken from the client and the ultrasound technicians to rework and improve the initial prototype.

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APPENDIX:

Product Design Specifications

Medical Ultrasound Transducer Holder

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Function

Ultrasound imaging, being portable and inexpensive, has become increasingly more preferable than other imaging techniques such as CT or MRI. However, high user dependency along with inexperienced and unskilled use of the ultrasound transducer has prevented it from widespread adoption. Our client is developing ultrasound video techniques that would create another element to the manual manipulation of the ultrasound transducer. Our client would like to develop a simple and elegant ultrasound transducer holder that can be maneuvered easily with 6 degrees of freedom and can be secured to the surface of most body parts in order to standardize the modern ultrasound technique.

Client Requirements

- Securely straps on to the surface of most body parts.
- Holds most of the commonly used transducers at any arbitrary angle to body surface.
- Allows transducer to slide in two orthogonal directions.
- Allows transducer to rotate 90 degrees about the z-axis without any action such as removing and re-setting.
- Holder requires minimal or no ultrasound gel.
- Holder must have a disposable soft-pad (sit between skin and transducer) with known acoustic material property.
- Holder has to be created with material that can be cleaned with 70% alcohol used at hospital
- Allows transducer to change angle with the x-y plane to get desired image

Design Requirements

1. Physical and Operational Characteristics

a. Performance requirements: Device should be able to withstand repeated use, withstand the pressure needed to keep device secured to the skin without movement. Transducer

needs to be able to rotate and translate freely and then be lockable when maneuvered to desired position. Transducer should be able to be moved to a position that is out of the way that allows space for a needle to inject dye into patient.

b. *Safety*: Should have padding between device and skin to prevent bruising. Moving parts should not pinch user.

c. *Accuracy and Reliability*: Device should remain stationary on skin and keep transducer stationary when locked into desired position. Movement of parts should require a consistent amount of force.

d. *Life in Service*: Device should remain operational for 5 years.

e. *Shelf Life*: Safe to store at room temperatures.

f. *Operating Environment*: Will be exposed to the clean conditions of a hospital. Will have contact with skin. Should have numerous users and patients. Device will be under enough pressure to attach securely to the patient.

g. *Ergonomics*: Should be user friendly and decrease the ultrasound technician's workload. Device functions should be intuitive and easy to learn. Device should be comfortable for the patient.

h. *Size*: Approximately 4 inches squared.

i. *Weight*: Device needs to be light enough to avoid discomfort. Less than a pound and a half.

j. *Materials*: Materials should be able to withstand cleaning with 70% alcohol. Materials should be strong enough to withstand the stresses involved in securing the device.

k. *Aesthetics, Appearance, and Finish*: Should look professional and not scare patient.

2. Production Characteristics

a. *Quantity*: 1 product will be needed.

b. *Target Product Cost*: Proposed budget: \$500

3. Miscellaneous

a. *Patient-related concerns*: Device needs to be sterilized in between each use.

b. *Competition*: There is a table top holder, but nothing that is held to the skin.