Final Design Project Report

Redesigning the Medical Ultrasound - Team Ultrasonic (Team 2)

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PART I: ABSTRACTION

The Problem & It's Importance

The growing prevalence of work-related musculoskeletal disorders (WMSDs) among medical ultrasound professionals highlights the critical need for comprehensive approaches to addressing ergonomic issues in equipment design, training, and work-rest schedules. WMSDs, including carpal tunnel syndrome, tendinitis, and back pain, have been reported in up to 90% of ultrasound professionals, with far-reaching implications for their health and wellbeing, productivity, the quality of diagnostic outcomes, and the sustainability of healthcare systems. This paper systematically examines three evidence-based aspects of the ergonomic challenges faced by ultrasound professionals and their potential consequences for healthcare systems:

1. High prevalence of WMSDs: Extensive research indicates that the majority of ultrasound professionals experience symptoms of WMSDs during their careers. Factors such as high workloads, increasing patient body mass index, and inadequate equipment design contribute to these disorders, emphasizing the urgent need for improved ergonomics in ultrasound practice to prevent discomfort, pain, and injury, and to promote occupational health.
2. Impact on healthcare professionals' wellbeing and productivity: WMSDs have been found to decrease the quality of work and productivity of ultrasound professionals, affecting healthcare systems through increased absenteeism, employee turnover, and additional costs for treatment and rehabilitation. By addressing ergonomic issues, the health and wellbeing of these professionals can be significantly improved, leading to increased patient satisfaction, reduced healthcare costs, and a more sustainable healthcare workforce. Adequate ergonomics knowledge, advice, and guidance are crucial for ensuring the health and wellbeing of ultrasound professionals and promoting a culture of safety and prevention.

3. Influence on diagnostic accuracy and patient outcomes: Ergonomically designed ultrasound equipment has been shown to improve image quality and potentially reduce the risk of misdiagnosis. Proper ergonomic practices, such as maintaining optimal posture, using adjustable chairs, and adapting scanning techniques, can enhance diagnostic accuracy and contribute to more effective treatment outcomes, better patient experiences, and improved overall healthcare quality.

This paper underscores the importance of ergonomic considerations in medical ultrasound for enhancing healthcare professionals' wellbeing, productivity, diagnostic accuracy, and the sustainability of healthcare systems. The design of ultrasound equipment must account for user body size, posture, and individual preferences to ensure optimal scanning techniques and high-quality imaging, ultimately contributing to improved patient care and reduced healthcare costs. Future research and policy efforts should focus on developing and implementing evidence-based ergonomic guidelines and interventions, fostering interdisciplinary collaboration, and promoting a culture of safety and prevention in medical ultrasound practice.

Hierarchical Relationships

What is the task

Ultrasound works by emitting high-frequency sound waves into the body and measuring the echoes produced by the interaction of the waves with tissues. The echoes are then processed to form images or provide information about the structure and function of internal organs. The sound waves are generated by a device called a transducer and are usually directed into the body through a medium such as gel. The frequency of the waves determines the level of resolution and depth of penetration, with higher frequencies providing better resolution but less penetration (NCBI, 2014).

Why is the task performed

Ultrasounds are performed for diagnosing and directing treatment. The most common ultrasounds include pelvic, abdominal, and obstetric. It helps diagnose the causes of pain, swelling and infection in the body's internal organs and to examine an unborn child (fetus) in pregnant women. In infants, doctors commonly use ultrasound to evaluate the brain, hips, and spine. It also helps guide biopsies, diagnose heart conditions, and assess damage after a heart attack. Ultrasound is safe, noninvasive, and does not use radiation (RadiologyInfo.org, 2021).

How is the task performed

Medical Ultrasound (Full) Cycle:

1. Prepare the transducer and apply gel
2. Position transducer on the skin
3. Transmit ultrasound waves into the body
4. Receive echoes from the interaction of the waves with tissues
5. Process echoes to form images or gather information
6. Interpret the images or information to make a diagnosis
7. Document and report the results to the patient or referring healthcare provider

Note: in order to focus on specific pain points and effectively design to make improvements, the team is going to focus on ultrasound during pregnancy

Information Flow

In a medical ultrasound, a sonographer uses a transducer to produce images of internal structures. They receive visual feedback in the form of real-time images displayed on a monitor. The indications for the exam can include evaluation of organs, tissues, blood flow, and a fetus during pregnancy. The sonographer may also receive indirect feedback from the patient through information provided to the physician or directly from the patient about their comfort level during the exam.

Sequence & Timing

When and how frequently is the task performed

For the patient, it can vary but there are usually several weeks in between each appointment. On an average day, the majority of sonographers perform 9–11 examinations that can last anywhere between 20–45 minutes. This results in spending an average of 5–7 hours per day actively performing ultrasound examinations (Russo, G., Cipolla, M., & Giandalia, A., 2013).

In What Order is the task performed

The order which this task takes is first setting up software on computer and explaining the procedure (10 min approx.), helping patient lie on the table (5 min approx.), placing gel on the transducer and scan vertically (10 min approx.), placing gel on the transducer and scan horizontally (10 min approx.), and conclude scanning and finalize scans (5 min approx.).

How long does the task take to complete

Setting up for the task is typically fast and simply involves preparing the transducer and software. It takes about 25-40 minutes altogether, including any conversation between the technician and the patient.

Location & Environmental Context

Usually, medical ultrasound cycles are performed in hospital, clinics, medical center, or other healthcare settings. “Diagnostic medical sonographers and cardiovascular technologists and technicians complete most of their work at diagnostic imaging machines in dimly lit rooms.” Social condition are not strictly defined, but patients’ privacy need to be respected. Usually there are only the technicians, patients, and maybe patients’ family in the room (MyPlan.com, n.d.).

Observation

Based on videos of various ultrasound procedures and interviews with sonographers, procedures often occur in small exam rooms where ultrasound technologists don’t have room to move the machine around for better ergonomic positioning. In addition, when portable exams need to be performed, the sonographer must move the heavy machine, and may end up in a cramped room or in a poor position where they must awkwardly move in order to scan the patient. It is rare for an ultrasound to be performed in a location where the sonographer has enough space to position their body, the machine, and their patient in a way that delivers minimal stress to their body.

Retrospective & Prospective Task Assessment

The majority of ultrasound technology development up to modern times focused on improving the capabilities of the scanning. The machines got smaller, and the images went from bistable to grayscale to moving. The Doppler ultrasound was invented, which allowed for scanning of blood movement, and soon after came color to ultrasound technology. In the 1970s, the microchip allowed for increased power, faster scanning, and 3D scanning (BMUS, 2007).

More recently, ultrasound has been evolving to help sonographers. Cordless transducers are now available, as well as adjustable monitors and ergonomic chairs specific to ultrasound. Joan Baker, a pioneer of the ultrasound industry, who sits on the boards of many sonography societies and committees, has built a brand around teaching about ergonomics in ultrasound and decreasing WRMSDs, as well as selling specialized products to help reduce risk of injury. Unfortunately, this information is still not taught to enough sonographers, not practical for many who have strenuous case loads, and the products are expensive and scarce. As patients in the US on average present with larger BMI's, it is becoming significantly more difficult on the bodies of sonographers, and the technology to help them maintain their health is not keeping up. There is still much room for improvement (Sound Ergonomics, 2005).

In future, ultrasound technology will likely undergo substantial changes to adapt to the changing bodies that require scanning. For example, transducers may be able to auto detect the propagation speed for a body type and fat content to get better images. There might also be adjustment to the power output needed to address these sizes in patients. Further development may lead to abandoning transducers for large patients and replacing them with a mat or belt that could be laid over where the sonographer needs to operate. This would allow them to choose vantage points to complete a scan without having to apply self-damaging force.

Surveys & Interviews

For this topic, it is incredibly important to receive feedback from sonographers about what procedures create pain, where that pain is, and how they believe it could be fixed or decreased. To do this, surveys and/or interviews can be conducted. Both structured and unstructured questions are important in this step. Structured questions have specific, selectable answers, such as the following:

> I thought the transducer was easy to use (score 1-5, with 1 as strongly disagree and 5 as strongly agree)

> On a scale from 0 to 10, with 0 being none at all, 3 being moderate, 5 being strong, and 10 being maximum, how much physical force does performing an ultrasound take from your body?

Unstructured questions are open to customized answers, such as these examples:

> List 3 things you like about this transducer.
>
> If you could make all the changes you wanted to the ultrasound machine, transducer, or any other aspect of the ultrasound process, what would you change?

The following is a list of questions that were answered by sonographers, as well as a summary of their responses:

1. How long have you been a sonographer, and in what setting?
2. Have you developed any lasting pain related to your work performing ultrasounds? If you have, please describe the location of the pain as well as what type of pain.
3. Are there different ultrasound processes that are harder on your body than others? Which are the easiest and the most difficult? Why?
4. On a scale from 0 to 10, with 0 being none at all, 3 being moderate, 5 being strong, and 10 being maximum, how much physical force does performing an ultrasound take from your body? (If this number changes based on how many ultrasounds have been performed that day, please provide both the low and high rankings for a given day)
5. If you could make all the changes you wanted to the ultrasound machine, transducer, or any other aspect of the ultrasound process, what would you change?

See Appendix 1.1 for interview data.

Data Recording & Quantification

Through literature research, interviews with medical professionals, and our own observation, our team was able to identify and quantify a number of physical exposures.

We primarily measured awkward postures through video analysis. This allowed us to assess maximum joint angles and the amount of time in various awkward postures. We also used subjective assessments via interviews with sonographers, to understand their discomfort and/or pain associated with sustained awkward postures.

For repetition, we also used videos to assess the frequency of exertions. Repetition of motions can vary the most based on the type of scan, therefore it was important to be consistent in the type of ultrasound scan. Interviewing experienced sonographers helped us understand the most repetitive motions during ultrasounds.

While the most difficult to quantify, we plan on measuring force by using subjective assessments via interviews with sonographers to assess perceived level of force and associated discomfort.

See Table 1.2 in the appendix for our full problem list and their relevant unit(s) of measurement.

Note: For the area of cognitive demands of concern, we primarily focused on the intuitiveness of our design alongside alleviating physical exposures.

See Appendix 2.2 for calculations of functional requirements for the design based on anthropometric data.

PART II: CONCEPTUALIZATION

Design Parameters

Our key target parameters we aim to design for include eye height, reach, hand size, pinch grip capacity, and cylindrical power grip capacity. With the exception of eye height, which we plan on accommodating to include the high extreme (tall male sonographers, 95th percentile male), we aim to accommodate for the low extreme for each other parameter (specifically the 5th percentile female). Below are the relevant numbers:

Eye Height (accommodates 95th percentile male - 175.0 cm)
Shoe allowance + 2.5 cm male, 1.5 female (choose male for max)
Max Eye Height to Accommodate: 177.5cm
Reach (accommodates 5th percentile female - 67.7 cm)
Hand size (accommodates 5th percentile female - 7.34 cm breadth, 6.5 cm length)
Pinch Grip Capacity (accommodates 5th percentile female - 0.855 kg)
Cylindrical Power Grip Capacity (accommodates 5th percentile female - 23.7 kg)

Success Criteria

1. Reduce 50% of awkward postures in an exam (measure by count / min). For example, reduce 6 times of awkward postures in a min to 3 times in a min.
2. For unavoidable awkward postures, reduce 30% of repetitive actions in an exam (measure by count)
3. Reduce 30% force from transducer to patient
4. Reduce 50% force from sonographer to transducer
5. Subjectively, reduce 20% muscle fatigue ratings collected from interviews. For example, reduce average muscle fatigue rating of 8 / 10 after completing all exams in one day to 6.5 / 10.

Research on Alternative Designs

An investigation into existing alternative designs and solutions aimed at reducing work-related musculoskeletal disorders (WRMSDs) among sonographers revealed that the primary barrier is not the availability of functional solutions, but rather their cost and lack of adoption by healthcare institutions. The following products and designs were explored:

Sound Ergonomics Products

Sound Ergonomics, founded by Joan Baker, offers a range of ergonomic supplies specifically designed for ultrasound technologists. Their product line includes support cushions, ergonomic chairs, exam tables, educational pamphlets and cards on ergonomics, and posture braces. Although these products have the potential to mitigate WRMSDs, they often come with a high price tag, necessitating individual sonographers to purchase them. Furthermore, these solutions do not address the core issue of modifying the practice of performing ultrasounds to minimize the risk of injury. Instead, they primarily work around the existing limitations (Sound Ergonomics, n.d.).

EagleView Cordless Ultrasound Transducer

EagleView has developed a cordless ultrasound transducer that eliminates the weight and tether of traditional cords, providing sonographers with greater freedom of movement during scans. However, the high cost of this transducer prevents widespread adoption, as hospitals and clinics typically opt for more affordable equipment that can perform the necessary technical functions.

Moreover, the design of EagleView's cordless transducer does not offer substantial ergonomic improvements compared to standard transducers (EagleView, n.d.).

GE Ultrasound Products

GE Healthcare has introduced several ultrasound products designed to reduce stress on sonographers' bodies. Their innovations include transducers with multiple buttons, allowing sonographers to make adjustments without reaching for the keyboard, and portable ultrasound machines that are considerably lighter than other options on the market. The primary barrier to widespread adoption of these products is cost, as healthcare institutions often cannot afford to replace their existing machines with the latest models. Consequently, many sonographers continue to struggle with WRMSDs, with relief contingent on overcoming financial barriers (GE Healthcare, n.d.).

Group Brainstorming and Solution Development Process

Our group initiated the solution development process by conducting extensive research on the ergonomic challenges faced by sonographers and existing solutions in the market. We engaged in a series of brainstorming sessions, utilizing whiteboards and sticky notes to visualize and categorize the problems, barriers, and potential solutions.

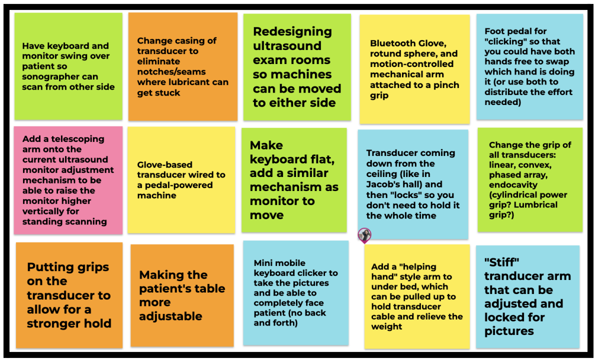
During these sessions, we discussed the limitations of current designs, considering aspects such as cost, accessibility, and adoption by healthcare institutions. We identified the need for affordable, practical, and easily adoptable solutions that can modify the ultrasound practice itself, instead of merely working around the existing limitations. As a result, we generated a list of possible solutions, evaluated their feasibility, and prioritized them based on their potential impact on reducing WRMSDs. We then engaged in further brainstorming sessions to refine and optimize these solutions, focusing on their practicality, ease of implementation, and cost-effectiveness.

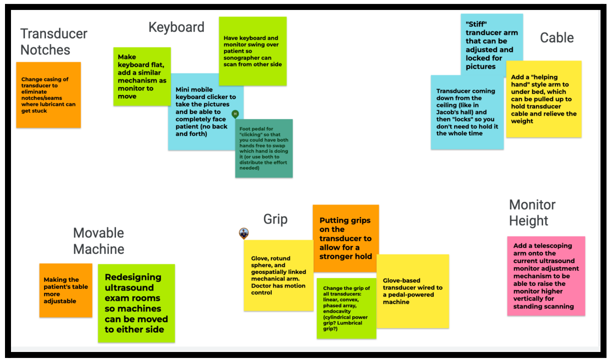
Design Brainstorming Sessions & Iterative Process

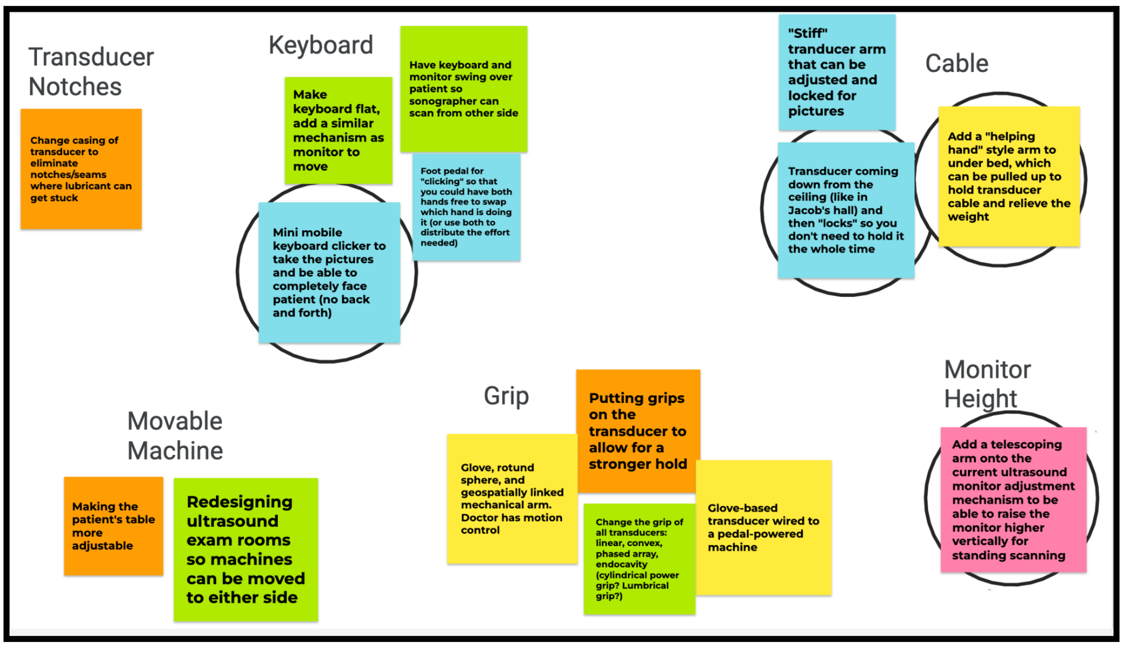
Step #1 : All team members inputted their ideas onto a jamboard.

Step #2 : Our team collectively decided on a set of groups that we would then proceed to classify the ideas.

Step #3 : We went through each group thoroughly, discussing the potential and implications of each idea. We used our constraints and parameters to determine the feasibility and usefulness of an idea, and **after making changes based on our discussion**, decided on four main ideas that we would consider in later stages (circled below)

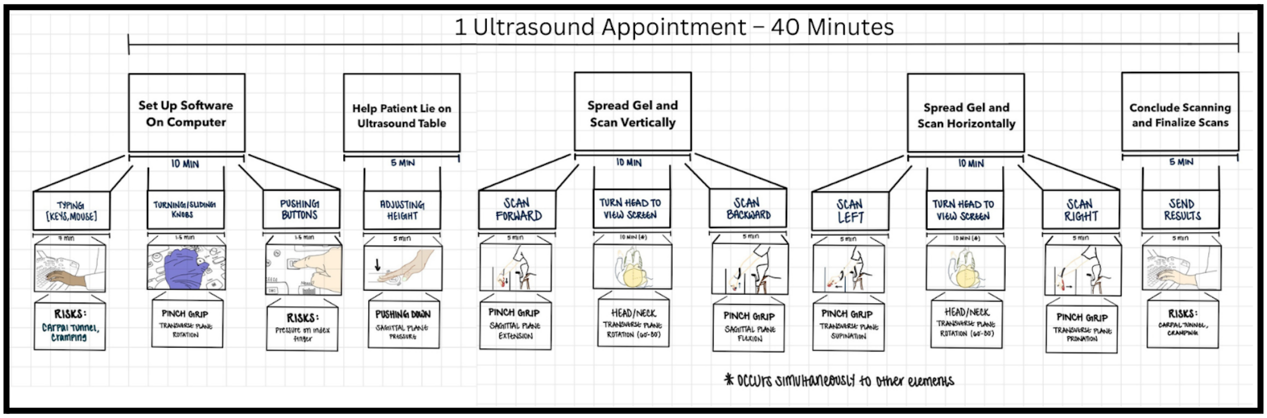




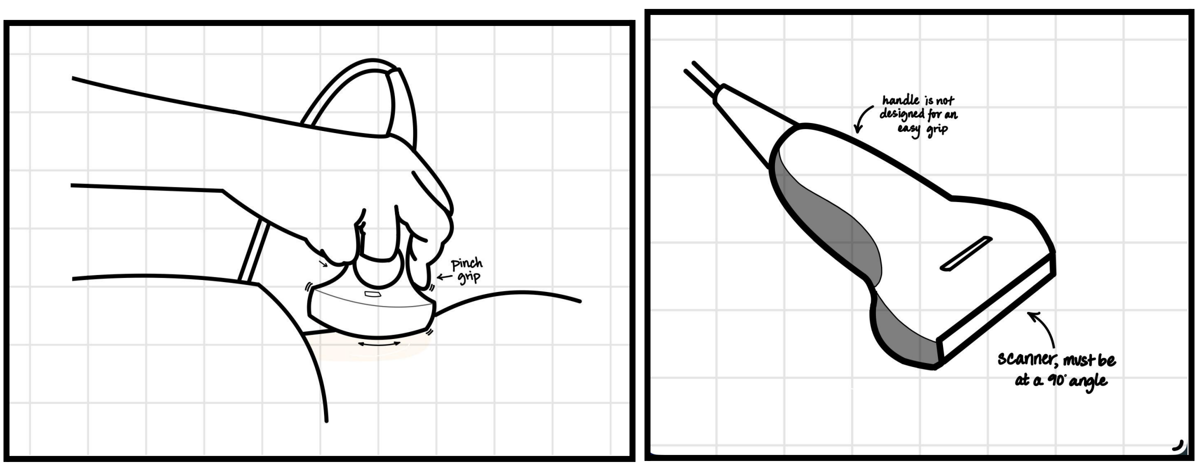


Design Descriptions & Sketches

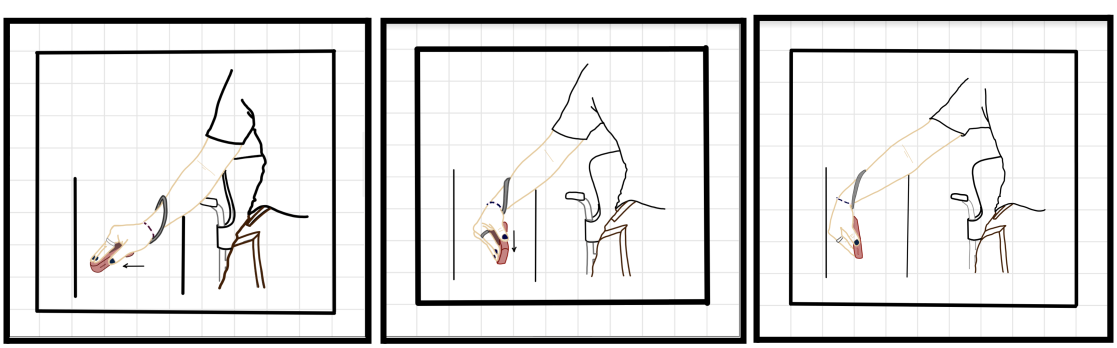
Workflow Diagram :



Previous Concept Sketches :



Movement Diagrams :



These iterations of design helped us thoroughly understand the issues within the process, and allowed us to ideate potential solutions that were mindful of the constraints and current state of the ultrasound transducer and setup.

After our brainstorming session, we decided on four ideas that we sketched out in an ultrasound environment to help show the positioning and ways that they could work together.

Ideathon Sketches – Testing Out Different Solutions :

See appendix 2.1 for sketch of final list of solutions.

<ins>Idea #1:</ins> A telescoping arm that would allow for the screen to be raised and lowered as needed. This was an extremely important issue that was brought up during our user research, with many ultrasound technologists complaining about the inconvenience and strain that is caused by the positioning of the screen. By using a telescoping arm, we expand the range of the arm, catering to a much larger variety of heights.

<ins>Idea #2:</ins> A pulley system installed in the ceiling of the ultrasound room will hold the transducer's cable. This will alleviate the strain and frustration that is caused by having to lift and maneuver the cord when trying to scan the patient's body. When gently pulled down, the cable will click downwards, allowing more of the cable to be released. When sharply pulled down upon and released, the cable will retract into the pulley and will shorten the length of the cable. This will allow for extension as needed, without the cable getting in the way.

<ins>Idea #3:</ins> An arm will be located on one edge of the bed that will prop up the cable, keeping it out of the way for the ultrasound technologist. This is an alternative solution to Idea #2, and we decided to include both depending on whether the hospital or clinical practice would be willing to install something into the ceiling or not. This arm can be very easily attached and secured, and can extend and rotate as desired.

<ins>Idea #4:</ins> Many ultrasound technologists voiced that they would greatly benefit from the screen being directly in front of rather than to the side of them as they are performing the ultrasound. This reduces strain in the neck and allows them to see what they are doing both physically and on the screen at the same time. Due to the screen and attached keyboard being on the opposite side of the bed, we proposed a remote that sends infrared rays to the ultrasound machine in order

to freeze the frame, move back and forth by a few seconds, and take a snapshot of the screen (an ultrasound image). This can easily be done with the opposing hand of the ultrasound, allowing for a more accurate image to be taken without stopping the ultrasound. The buttons (power, freeze frame, and snapshot) are all based on the keyboard of the ultrasound machine, and ideally would be designed in conjunction with the machine itself.

Design Selection Process

Through our brainstorming session, we were left with many valid and useful ideas for both redesigns and new products that would help to reduce the risk of WRMSDs. For a full scale redesign of the ultrasound process, we would have liked to pursue multiple of these ideas in order to provide the best possible working environment for sonographers. However, due to out limited resources and time constraints, we decided to narrow our options down to a single prototype which could be designed and displayed.

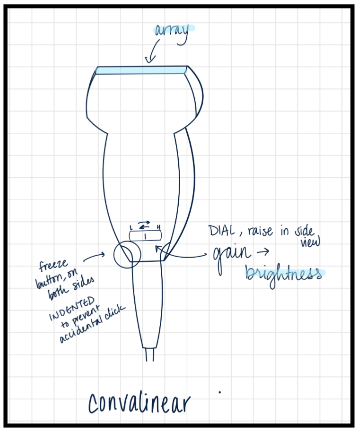
Our first idea, the telescoping arm for the monitor, was a solid improvement to the machinery already installed, but was also limited in it's ability to help protect sonographers. It only had an effect when sonographers decided to stand, and while switching between standing and sitting is helpful, it is also more difficult to ensure the behavior is constantly performed. For this reason, we decided to pursue a different idea.

The second idea, a pulley system to remove the weight of the transducer cable, would be directly solving a problem that many of the sonographers we interviewed reported having. However, it would require changing the design of sonography rooms, is not portable, and does not solve any major cause of the WRMSDs that are occurring, so we moved on.

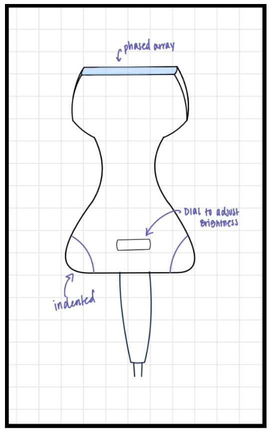
Our third idea, an arm attached to the exam bed to hold up the transducer cable and reduce the weight on the sonographer's wrist, was more realistic and transportable than our second idea. However, it also does not solve any major cause of the WRMSDs that are occurring, so like our second idea, we chose a different design.

Based on our decisions against these ideas, we knew we wanted to design a solution that was transportable, easy to implement into current systems, and severely diminished a major cause of WRMSDs. We went back to our brainstorming board and selected changing the grip of the transducer. We wanted to avoid this selection, as we knew it was the most common change made by groups assigned this problem. However, it held the greatest potential of making a real change in the lives and longevity of sonographers.

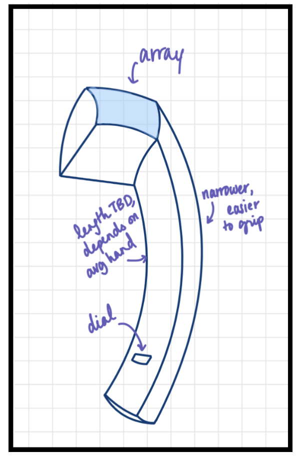
Iterations of Grip Design:



Iteration #1



Iteration #2



Iteration #3

Our first iteration consisted of a base that largely focused on determining whether to focus on a linear or curvilinear transducer, or possibly a phased array. We began with rough physical sketches, and then moved on to digital sketches to better understand the placement and structure. In the first iteration, a more curved grip surface was thought to be the solution, but after testing it out, we realized that it made it more difficult to get a proper grip.

In our second iteration, we decided that the gripped section would be narrower, but thought to keep the wider section towards the end so that the hand remains in a centralized position. We also increased the size of the indented freeze buttons to allow for easier access. However, after creating a physical mockup of this prototype, we realized that larger hand sizes would be unable to comfortably use this transducer. Moreover, the gripping distance that the ultrasound technician chooses varies based on personal preference, so an extended narrow section would be necessary.

This discussion and research led to our third and final iteration. This transducer has a consistently narrow body and has a curvilinear array, unlike the previous two iterations. The final position of the dial was decided after 3D printing various options, and this iteration turned out to be surprisingly comfortable to hold.

PART III: REALIZATION

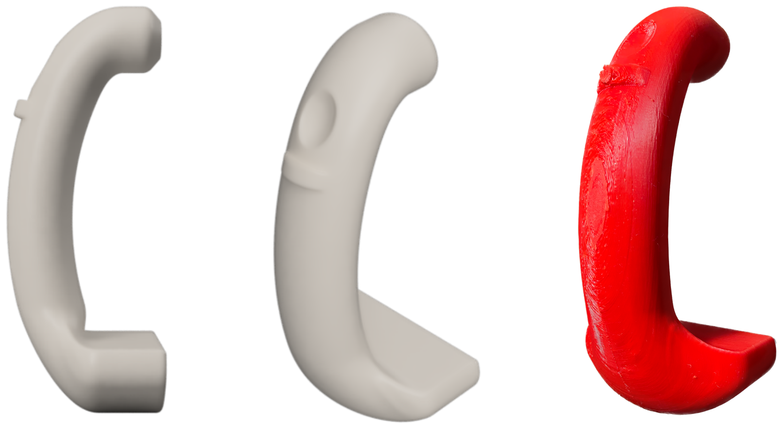
Production Process

Design 1: A good start, but the surface near the base where the palm rests was not flat enough, and when 3D printed, the curve was a bit too severe and uncomfortable to hold.

Design 2: The flatness of the palm rest was solved, but the freeze button located at the top of the grip was too far away from the neutral position of the thumb, requiring it to be uncomfortably craned.

Design 3: The purpose of this design was to move the freeze button closer to the neutral position of the thumb, however, it was not moved far enough. In addition, the unwanted ability of a user to grab the transducer too far above the palm rest was discovered.

Design 4: The freeze button was moved as close to the neutral thumb position as possible, but still was uncomfortable to reach and press. A rethinking of it's position was required. The gain dial was accidentally moved too low, it's position needed to be returned to that in previous designs. The additional bend at the top of the grip was successful in preventing the transducer from being gripped too high.



Final Design: The gain dial was replaced in its original location. The freeze button was moved above the gain dial, and became far more comfortable to use. While further development could be made with this design, it was functional and we were happy with it.

Evaluation Approach

Our success criteria includes evaluation of the whole ultrasound cycle, with some specific ones focusing on the transducer, which we had a new design for. We included metrics like the counts of awkward postures, force exerted on to the transducer, also ratings of muscle fatigue after performing the tasks. See below for examples of measurements pre and post our design to evaluate cognitive and physical demands.

<u>Objective measurements</u>

- How long does it take to first feel a sore back / wrist? Answer unit in sec/min/hour
- Force exerted on transducer, a force measuring tool may be used to measure
- How many times bending body over / head lowered during an exam cycle

<u>Subjective questions (SUS from lecture)</u>

Please rate the following statements from 1 to 5. 1 as strongly disagree and 5 as strongly agree

- I thought the system was easy to use
- I would imagine that most people would learn to use this system very quickly

- I am confident that most clinics would be willing to implement this new system/design
- I feel like the new design is necessary. In other words, it is worthwhile to change normal behavior.

Open-ended questions

- List 3 things you like about this design
- List things you think are unnecessary

While physical demands can be met by reducing the counts of awkward postures or repetitive actions performed, we aim to meet the cognitive demands by lowering the ratings of fatigue or measure the sonographers' cognitive comfort based on options like easy to use, neutral, or hard to use.

Currently, we designed our prototype to accommodate the 95th percentile male for eye heights, and 5th percentile females for other parameters (all from data collected in the United States). While this range already cover the majority of sonographers in the United States, if we would like to assess the design on a larger scale, we could present our prototype to sonographers in other countries too. By doing that, the values of parameters we are accommodating to might be slightly different. If this design actually got spread to the world and more adjustments are needed, further design could also include more flexibilities by for example, making the transducer's length adjustable so that we can accommodate a bigger range of hand size.

Outcomes

Based on our final design at the semester's end, we expect the following outcomes:

➔ Reduced physical strain on ultrasound technologists during the scanning process.
➔ Enhanced ergonomics leading to improved job satisfaction and reduced risk of WRMSDs.
➔ Increased efficiency and accuracy in ultrasound examinations.

Successes of Our Design:

The telescoping arm improves the screen's accessibility and adjustability for users of different heights, addressing the ergonomic concerns raised by ultrasound technologists during user research.

The pulley system and the alternative cable-supporting arm both effectively minimize the inconvenience and strain caused by the transducer cable, offering healthcare institutions the flexibility to choose the most suitable option for their setup.

The remote control with infrared technology allows for seamless control of the ultrasound machine, reducing neck strain and improving the technologist's ability to focus on both the physical examination and the screen simultaneously.

Potential Limitations and Unintended Consequences:

The implementation of the pulley system may require significant modifications to existing ultrasound rooms, posing challenges for hospitals and clinics with limited resources or restricted infrastructure.

The remote control's reliance on infrared technology necessitates a direct line of sight between the remote and the ultrasound machine, potentially causing disruptions in the workflow if obstructed.

Our design solutions may require additional training for ultrasound technologists to effectively utilize the new features, which could temporarily impact productivity.

Next Design Iteration:

For our next design iteration, we would address the following:

Explore alternative methods for installing the pulley system to minimize the need for extensive modifications to existing ultrasound rooms.

Investigate wireless communication technology for the remote control to eliminate the line-of-sight requirement and enhance its reliability.

Develop comprehensive training materials and resources to facilitate the adoption of our design solutions and ensure ultrasound technologists can efficiently integrate them into their daily workflow.

By continually refining and improving our design based on user feedback, research, and technological advancements, we aim to develop an ergonomic solution that effectively minimizes the risk of WRMSDs for ultrasound technologists while enhancing their overall efficiency and job satisfaction.

PART IV: REFLECTION

Reflection

During the design process, our team was able to overcome a number of challenges. One challenge we faced was collecting and using anthropometric data. In previous design experiences, many of us were used to going straight to designing before taking the time to understand the users' limitations and the measurable impacts on the user. While finding and incorporating this data was new to our team, it allowed us to strategically target our efforts to thoughtfully develop a redesign.

Another learning curve we faced stemmed from our lack of medical background. In order to understand this design challenge, our group spent a lot of time researching the process of conducting an ultrasound, including networking and talking with medical professionals. Developing this background allowed us to understand the limitations of what our design could be beyond the basic knowledge we began the semester with.

Additionally, our lack of access to a sample transducer made it difficult to understand the design challenge first-hand. To address this we 3D printed a traditional transducer, which allowed us to simulate sonographers' typical postures, and compare the traditional transducer to our redesign.

Alongside overcoming these challenges, our team shared a number of rewarding takeaways from this design experience. For example, conducting interviews and hearing from sonographers gave our project meaning, as it helped us empathize with the users and rationalize the need for redesign. From using Kinovea to risk assessment tools, we also enjoyed learning and applying new analytical methods and ways of looking at the problem. Finally, we were also grateful for the chance to work in a well-rounded, disciplined team on a design challenge we were all interested in. We’re glad we were able to take on roles that leaned into our strengths and complemented each other on the team.

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APPENDICES

1.1

Gender	Experience	Location	Injury Complaint	(specific)	(specific)
10 F	8-40 years	5 Hospital	Shoulder - 5	Scapula - 3	Clavicle
2 M		3 Outpatient	Neck - 5	Trapezius	
		4 Both	Wrist - 5		
			Hand/Fingers - 4		
			Back - 3		
			Hip - 2		
			EDS		
			Elbow		
			Worry		

Hardest Procedure	(specific)	(specific)	Force Level
Obese - 6	Reach - 3		Low (avg) 3.15
Vascular - 3	DVT - 5		High (avg) 8.23
Transvaginal - 5			Avg 5.69
Echo - 2	Fetal Echo	Apical Echo	
Pediatric			
Thyroid			
Breast			
Pelvic			
Cardiac			

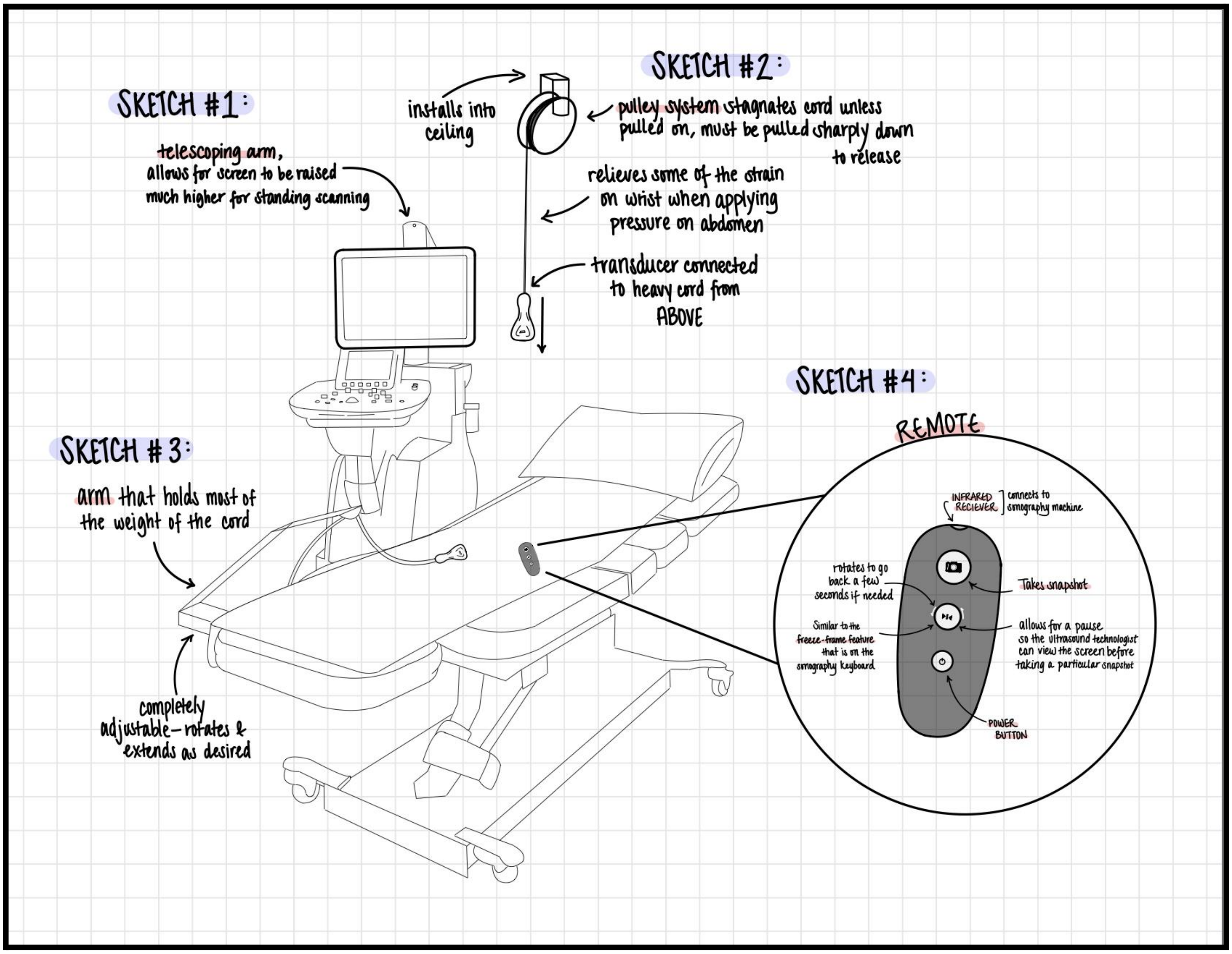
Wanted Solutions	(specific)	(specific)
Cordless - 6		
Movable machine - 2	Closer to tech	Ability to switch sides
Union - 3		
Lighter transducer - 3		
Better portable - 2	Phone connection	
Height - 2		
Chairs - 2		
Touchscreen - 2		
Grip	Fix vascular transducer shape	
Flexible keyboard	Flat keyboard	
No notches		
Mat/Belt		
Lighter cord		
Arm to hold cable		
Education		
Voice control		
Bolsters to prop up extremities		

1.2

Physical Exposures		Relevant Measurement(s)	Summary Average Measurements from Kinovea Video Analysis
Awkward Postures	**Trunk flexion** (bending forward at the waist)	degrees (°) % of max % time (duty cycle)	23.4° 33.4% of max 100% of time
	Shoulder complex abduction (raising and holding arm out to position transducer)	degrees (°) % of max % time (duty cycle)	47.8° 26.6% of max 100% of time
	Neck/cervical spine flexion (forward bending of the neck for visual of patient)	degrees (°) % of max % time (duty cycle)	17.1° 20.1% of max 50% of time
	Neck/cervical spine rotation (twisting of back to better reach patient)	degrees (°) % of max % time (duty cycle)	62.0° 72.9% of max 50% of time
	Wrist extension (bending of wrist up to complete a scan)	degrees (°) % of max % time (duty cycle)	46.3° 61.7% of max 35% of time
	Wrist flexion (bending of wrist down to complete a scan)	degrees (°) % of max % time (duty cycle)	42.9° 57.2% of max 28% of time

	Wrist ulnar deviation (bending of wrist towards pinky finger to complete a scan)	degrees (°) % of max % time (duty cycle)	30.4° 100%+ of max 88% of time
Repetition	**Repetitive wrist extension**	Reps/cycle time	5 times/cycle
	Repetitive wrist flexion	Reps/cycle time	4 times/cycle
	Repetitive wrist ulnar deviation	Reps/cycle time	8 times/cycle
	Repetitive neck/cervical spine rotation	Reps/cycle time	8 times/cycle
Force	**Applied force, transducer-to-patient** (forceful pushing of transducer into patient)	N % time (duty cycle)	**N, not assessed w/Kinovea Research Study Estimate: 6.5N (Koyama, Ushioda, & Kondo, 2016) 100% of time
	Pinch grip force, sonographer-to-transducer (forceful gripping of the transducer)	N % time (duty cycle)	**N, not assessed w/Kinovea Research Study Estimate: 15.2N (Koyama, Ushioda, & Kondo, 2016) 100% of time

2.1



SKETCH #1:
telescoping arm, allows for screen to be raised much higher for standing scanning
installs into ceiling
SKETCH #2:
pulley system stagnates cord unless pulled on, must be pulled sharply down to release
relieves some of the strain on wrist when applying pressure on abdomen
transducer connected to heavy cord from ABOVE
SKETCH #3:
arm that holds most of the weight of the cord
completely adjustable–rotates & extends as desired
SKETCH #4:
REMOTE
INFRARED RECIEVER
connects to sonography machine
rotates to go back a few seconds if needed
Takes snapshot
Similar to the freeze-frame feature that is on the sonography keyboard
allows for a pause so the ultrasound technologist can view the screen before taking a particular snapshot
POWER BUTTON

2.2

cylindrical, 40cm diameter

elliptical shape, width → length 1:1.25

minimum length 100-125 mm

avg hand breadth → M 87mm F 78mm

95% F – ... –5% F

hand length - 180.3mm

breadth 62.8mm

grip breath width - 41.2 mm 32.2 23.2 mm

length - 35.7mm 25.7 15.7mm

taiwanese

16,17,18

91.4% Women in the US

	5th	95th	50% male	
length	$\boxed{165\text{mm}}$	196.9mm	$\boxed{193.3}$	around grip
breadth	$\boxed{73.4}$	$\boxed{85.6\text{mm}}$	$\boxed{90.3}$	length of grip

	5th	95th	
elbow-finger tip →	399mm	475mm	
elbow-grip →	287mm	345mm	
palm length →	$\boxed{97\text{mm}}$	117mm	117mm

95% male
96mm

5 95 around grip

thumb length → 53.9 70.7

grip diameter = 33mm

111°

70mm length
28mm width

base of hand to freeze button must be < 73.4+53.9=127.3

$\frac{(1.33)}{1.25}$

20°

33mm