



Digital Traction with Japanese Finger Sleeves

PRELIMINARY REPORT

BME 200/300

Section 303

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Abstract

Hand traction is essential in orthopedic and surgical procedures to maintain wrist alignment and joint stability during surgical procedures and casting. At Idrissa Poye Hospital in Senegal, the loss of their previous traction device left clinicians without a reliable method to stabilize the hand, forcing them to depend on manual traction or improvised setups. These workarounds reduce accuracy, increase clinician workload, and introduce safety risks for patients. Existing hand-traction technologies are often expensive, immobile, or incompatible with low-resource settings, underscoring the need for a durable, adjustable, and sterilizable alternative. This design project developed a traction device designed specifically to address these limitations by providing consistent, comfortable, and easily adjustable traction while minimizing physical strain on both patients and medical staff. The device integrates an adjustable mechanical body, finger sleeves, and materials suitable for repeated sterilization. The traction device's mechanical strength, traction accuracy, and sterilization endurance will be tested, along with the sleeve's ability to securely hold fingers. The results will determine if the device can provide a safe, effective, and sustainable solution for hand stabilization in low-resource clinical environments, with the potential to reduce clinician fatigue, improve surgical precision, and enhance patient outcomes.

Table of Contents

Abstract.....	2
Table of Contents.....	3
Introduction.....	5
Motivation and Global Impact.....	5
Existing Devices and Current Methods.....	6
Current Device.....	9
Problem Statement.....	10
Background.....	11
Biology and Physiology.....	11
Relevant Research.....	12
Client Information.....	12
Product Design Specifications.....	12
Preliminary Designs.....	13
Base Designs.....	13
Design 1 - Wheel or Clamp Base.....	13
Design 2 - Table Attachment.....	13
Design 3 - C-Frame Base.....	14
Traction Designs.....	15
Design 1 - Oscillating Pulley.....	15
Design 2 - Tripod-Folding System.....	15
Design 3 - Pin Locking.....	16
Preliminary Design Evaluation.....	18
Base Design Matrix.....	18
Summary of Design Matrix:.....	18
Safety (25).....	18
Ease of Fabrication (20).....	19
Flexibility/Mobility (15).....	19
Ease of Use (15).....	19
Cost (15).....	19
Footprint (10).....	20
Traction Design Matrix.....	21
Summary of Design Matrix:.....	21
Safety (30).....	21
Ease of Fabrication (25).....	22
Flexibility/Mobility (15).....	22
Ease of Use (15).....	22
Cost (15).....	22
Comfort (5).....	23

Proposed Final Design.....	23
Fabrication.....	25
Testing and Results.....	27
Discussion.....	27
Conclusions.....	29
References.....	30
Appendix.....	33
Appendix A: Product Design Specifications.....	33
Function.....	35
Client requirements.....	35
Design requirements.....	35
1. Physical and Operational Characteristics.....	35
a. Performance requirements.....	35
b. Safety.....	36
c. Accuracy and Reliability.....	36
d. Life in Service.....	36
e. Shelf Life.....	36
f. Operating Environment.....	36
g. Ergonomics.....	36
h. Size.....	37
i. Weight.....	37
j. Materials.....	37
k. Aesthetics, Appearance, and Finish.....	37
2. Production Characteristics.....	37
a. Quantity.....	37
b. Target Product Cost.....	37
3. Miscellaneous.....	38
a. Standards and Specifications.....	38
b. Customer.....	39
c. Patient-related concerns.....	39
d. Competition.....	40
References.....	41
Appendix B: Expenses - Fall 2025.....	44
Appendix C: Preliminary Fabrication Plan - Fall 2026.....	46
Appendix D: Testing Protocol - Static Load Test.....	50
Appendix E: Testing Protocol - Traction Load Accuracy Test.....	52
Appendix F: Testing Protocol - Finger Sleeve Slippage Testing Protocol.....	54
Appendix G: Testing Protocol - Finger Sleeve Slippage Testing Protocol.....	55

Introduction

Motivation and Global Impact

Hand injuries are a significant global health problem because they can affect a person's ability to work, perform daily activities, and maintain a normal hand function. A global analysis found that there were approximately 179 hand and wrist fractures per 100,000 people worldwide, with the burden increasing in some low and middle income regions indicating that many of these areas have limited access to specialized hand-surgery care [1]. Hand injuries affect people across different ages, genders, and geographic regions. They are especially common among working-age populations, with occupational injuries being an important cause. A study of more than 4,000 patients referred to a hand surgery unit found that 70% were male, the median age was 36, and more than half of the patients required surgical management [2]. During wrist surgery, surgeons need to position and stabilize individual fingers while maintaining access to the surgical site as shown in Figure 1. The traction provides a pulling force that separates bones in the hand and wrist to improve visualization and adequate space during surgical procedures [3]. Traditional finger-trap systems can provide traction, but a device that can accommodate different angles and positions may give surgeons greater flexibility during procedures. A full workup of the patient is performed to understand what type of injury occurred. Then during the surgery there must be precise instrument handling that allows for the surgeon to perform delicate repairs. The maintenance of a steady static load on the finger is important to ensure there is no unintended movement during the surgery and/or casting [4].



Figure 1: Image of traction device used in a wrist surgery to stabilize the hand [5]

Our device is based on the concept of Japanese finger traps and is designed to provide controlled finger positioning while allowing the hand to be positioned at multiple angles. This could make the system more adaptable to different surgical procedures and patient anatomies. The broader goal is not simply to meet the needs of one surgeon or client, but to improve the flexibility, usability, and accessibility of surgical positioning equipment for hand procedures. A more adaptable system could potentially improve surgical access and positioning while addressing the wide variety of injuries and patients encountered in hand surgery.

Existing Devices and Current Methods

Several devices and techniques are currently used to position and stabilize the hand and fingers during surgery. Existing methods vary in precision, cost, adjustability, and precision which can be beneficial in certain contexts, however it does not meet the client needs which are to alter traction during surgery, accommodate multiple different angles, and transport easily within surgical/procedure rooms.

The Reison Hand Fixation Device (Reison Medical, Part No. 10-394) provides stabilization of the hand and forearm during surgery using stainless steel and polycarbonate components. The device is adjustable to accommodate different hand sizes and offers strong positional stability during fracture repair or fixation procedures, as shown in Figure 2 [6]. Despite its stability, it is heavy and static, lacking individual finger mobility and ergonomic flexibility. These limitations make it less ideal for longer procedures where patient comfort and clinician control are critical.



Figure 2: Reison Hand Traction [6]

The Chinese Finger Trap System is a traditional device for wrist and forearm traction. It suspends the patient's hand using woven finger sleeves, allowing gravity to apply continuous traction. A readily available alternative described by Akhtar et al. (2013) demonstrates how clinicians sometimes substitute tape for the woven traps when the original device is unavailable [7]. Although effective in generating traction, this system depends entirely on gravity, offers limited adjustability, and lacks built-in feedback or

sensing capabilities. Moreover, availability can be inconsistent, particularly in resource-limited or after-hours clinical settings, making it an unreliable option for the client's needs. Figure 3 illustrates a standard finger trap setup.



Figure 3: Chinese finger trap system suspending patient's hand.

The third device analyzed was the Handmade Traction Wrist Tower, also referred to as the Hook and Trumpf Hand Holder [8]. This system consists of a metal base with an S-shaped hook and adjustable rods designed to create controlled traction across the fingers and wrist. Foam padding is used to protect soft tissue at points of contact, but the overall design is large and metal-based. While it provides adjustability, its weight and bulk limit ergonomic efficiency and portability. The device is shown in Figure 4.



Figure 4: Hook-and-Trumpf [3]

The Acumed Arc Wrist Tower (US20050240136A1) is a surgical positioning and traction medical device used to stabilize the forearm and hand during wrist arthroscopy and fracture-reduction procedures [9]. The device as shown in Figure 5 can rotate between a vertical position which can provide traction for wrist arthroscopy and can also move to a horizontal position to treat distal radius, hand, and wrist fractures. It has an ability to swivel 180 degrees around the patient's forearm and elbow to allow for a clear view of the hand or wrist being operated on. This device also has adjustable traction which can enable more extension and flexion throughout the wrist and fingers. The device provides consistent, controlled stabilization of the patient's limb, reducing the need for manual assistance and helping minimize movement-related errors during the procedure. This is a high costing device making it more difficult to access in less wealthy communities and towns [10].



Figure 5: Accumed Arc Wrist Tower [9]

The Digi Grip is a manual traction system intended for use in physical therapy [11]. It features an adjustable-height IV pole with a custom attachable plate to suspend the fingers from as shown in Figure 6. The associated finger sleeves are like finger traps and are connected to the custom plate using chains. The traction in this system is very simple. An arm sleeve is wrapped around the user's bicep, and weights are attached to the bottom so that the elbow is at a ninety-degree angle and pulls vertically on the fingers. This device is very similar to what the client is looking for, but it is lacking in a few areas. While this device has a lot of mobility, the base is unstable and therefore unsuitable for use during procedures. It is also unable to be adjusted horizontally making it ill-suited to the client's needs.

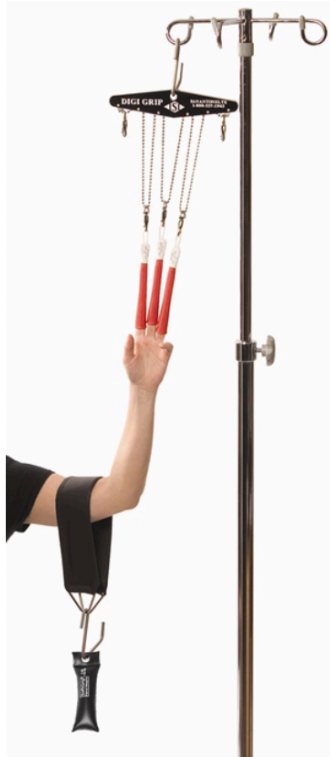


Figure 6: Digi Grip [11]

The designs presented above are all functional and commercially available but lack critical features needed for the client's environment. However, they are high-cost systems that are difficult for the client to procure reliably and lack the portability needed to move easily between treatment areas throughout the hospital. Later sections further discuss how these limitations guided the team's development of an improved, sleeve-based digital traction device capable of improving upon the weaker functionality of the client's current device.

The hospital formerly made use of Japanese finger traps for digital traction; however, these systems were either lost or experienced deterioration due to repeated use. With the limited supply of medical devices in the Dakar region as well as Idrissa Pouye Hospital's restricted budget, digital traction devices are currently not being repurchased by the facility. Instead, the hospital staff use manual traction to stabilize the wrist and forearm during casting, wrist arthroscopies, and other procedures. However, manual traction is suboptimal because it is imprecise for the doctor and often uncomfortable or painful for the patient. This leads to less successful surgeries as well as a longer patient recovery time. Manual traction also requires multiple clinicians to sustain traction and provide treatment, which is an inefficient use of personnel in a hospital that treats 50,000 orthopedic patients per year [12].

Current Device

This project aims to improve on the previous iteration of the design project. The current model's mechanical base design consists of an IV pole with a height adjustable body and aluminum mounting plate as shown in Figure 7. The finger sleeves hang off of the mounting plate. The mechanical base design was deemed

unstable by the client due to it being easily shifted when touched. The current finger sleeve design is mainly composed of ballistic nylon with velcro straps to adjust to different size fingers as shown in Figure 8. Through previous testing, the strength of the ballistic nylon sleeves decreased after being autoclaved, so they did not meet the client's requirement of withstanding multiple sterilization cycles for reusability. Therefore, this semester the client has agreed to purchasing finger sleeves. This semester's aim is to create a traction device with a stable base that can provide traction to the fingers.

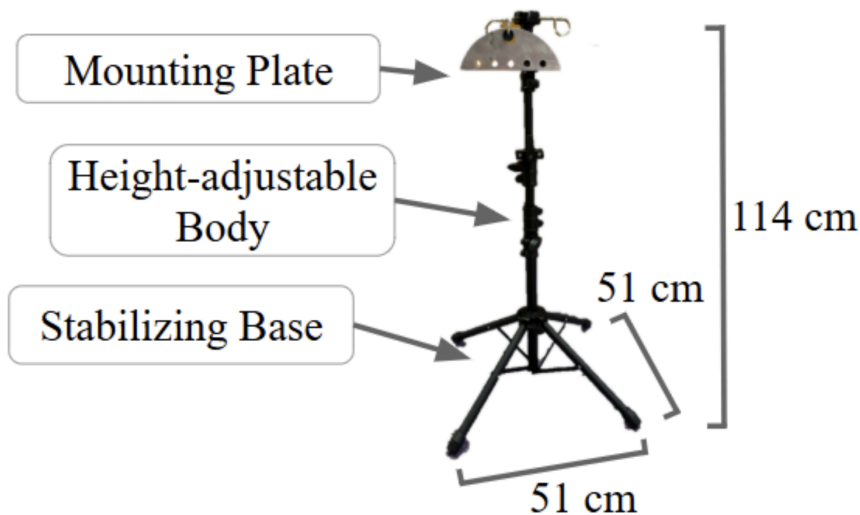


Figure 7: Previous semester's mechanical design final prototype, displaying stand and mounting plate portions of the design.

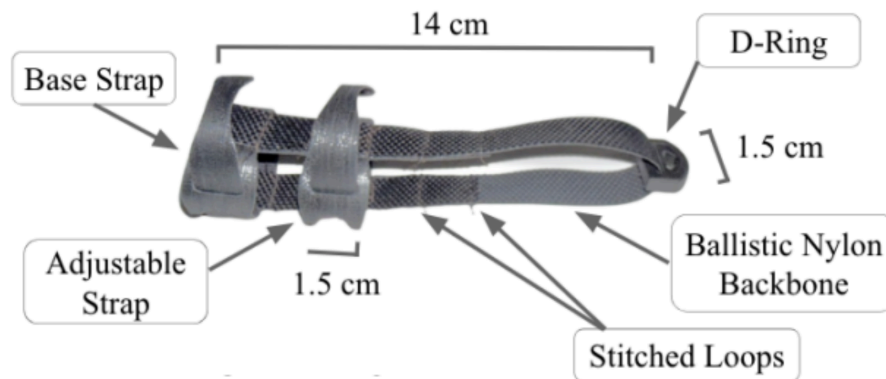


Figure 8: Previous semester's final finger sleeve design.

Problem Statement

The objective of this project is to create a digital traction device using finger traps that precisely pulls the patient's hand, wrist, and forearm into a comfortable, neutral position while holding a stable static load 1/10th of the patient's weight ($\pm 7\%$). To be feasible for Idrissa Pouye Hospital, the device must be portable and usable in both the plaster casting room and the operating room. This requires a compact device that can be transported easily between spaces and provides unobstructed access to the forearm for casting and arthroscopy. It must tolerate 50 sterilization cycles without degradation and maintain its mechanical material properties. In

addition, the design must be simple enough to fabricate, assemble, and repair using materials and processes available in or near Dakar so that the hospital can maintain a reliable inventory even as individual devices are lost or damaged over time.

Background

Biology and Physiology

Together, the wrist and forearm work together as an intricate system in the human body. To understand why digital traction systems are utilized during various surgeries, it is key to understand the anatomy and physiology of the treatment area. As a whole, the wrist and forearm provide mobility and support for the upper limb, which allows for successful use of the hand. These bones provide this support through movements of pronation and supination. The distal end of the radius connects to the carpal bones through the radiocarpal joint, a common site for distal radial fractures [13]. The carpus is the collection of 8 small bones held together by stabilizing ligaments. Due to their small size, they are often prone to fractures when subjected to heavy loads and rotational movements. Along with that, the carpal tunnel captures many tendons and the median nerve. The compact and intricate alignment of these bones, ligaments, nerves, and tendons make it necessary to be exact during operation of these body parts [14], [15]. This means that the digital traction device with Japanese finger sleeves must keep finger compression force under 5N [16] using hypoallergenic, latex-free materials [17]. This allows for minimal discomfort, prevention of nerve damage or loss of blood circulation, and effective realignment by reducing stressors and protecting soft tissues.

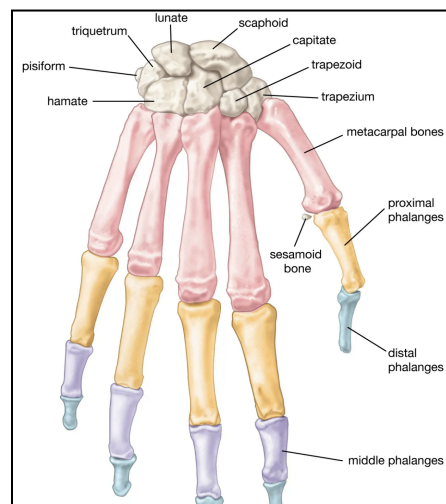


Figure 9: Anatomical figure of the hand and wrist [18]

As mentioned earlier, distal radius fractures are frequent in a hospital setting [19]. In these procedures, commonly wrist arthroscopies, digital traction can serve as a diagnostic and therapeutic tool, as it can align small bone fragments and prevent neuromuscular degradation, leading to favorable results [8]. Maintaining consistent traction with neutral wrist and forearm positioning is necessary to achieve a good prognosis and recovery.

Relevant Research

Creating a digital traction system that is both locally reproducible and versatile for surgical procedures and casting applications requires expertise across multiple disciplines. Key considerations include logistical factors, regulatory compliance, and biological requirements. Biomechanical research into the specific forces exerted on the wrist during traction plays a crucial role in establishing safe operating boundaries and developing techniques to maintain neutral joint positioning over extended periods of time. Previous literature on traction methodologies covers broad clinical applications across diverse global healthcare settings. Additionally, anatomical and physiological research is necessary to pinpoint structures and ensure alignment of the wrist and forearm during treatment.

Material selection for this device demands careful evaluation. Because the device has skin-to-device contact with the patient, all materials must be medical-grade, non-allergenic, and completely sterilizable without any compromise on structural integrity over repeated usage [7]. Furthermore, compliance and research with regulatory standards for medical devices is essential. The team reviewed relevant international standards, including ISO 13485:2016 for quality management systems, ISO 10993-1:2025 and ISO 10993-10:2021 for biocompatibility and skin sensitization assessment, ISO 14971:2019 for risk management, ISO 17664-1:2024 for healthcare product processing, and more [17], [20], [21], [22], [23]. Additionally, further research in U.S. FDA regulations, such as 21 CFR 888.5850 for nonpowered orthopedic traction apparatuses and 21 CFR 888.5890 for noninvasive traction components, was also analyzed to ensure the design satisfies global safety and performance criteria [24], [25] (See Appendix A for more details on standards).

Client Information

The client, Mr. Pape Samb, is a Sun Prairie-based community producer, board member at the Sun Prairie Media Center, and the founder and executive director of the non-profit organization Jamarek. Collaborating on the clinical side is Dr. Mohamed Soumah, a physician practicing at a hospital in Dakar, Senegal, that performs a high volume of hand and wrist procedures.

Product Design Specifications

The product design specifications outline the functional, biological, structural, and performance criteria for the digital traction device using Japanese finger sleeves. The main objective is to deliver precise and accurate mechanical finger traction to stabilize the arm and digits during hand and wrist orthopedic procedures, such as distal radial fracture reduction and wrist arthroscopies, improving clinical effectiveness and eliminating risks associated with manual holding. The system must reliably support the patient's forearm and hand at angles between 90° and 180° for at least 50 minutes per procedure. Operationally, the device is engineered to maintain a target pull traction load designated by the client in Equation 1, with an absolute total load ceiling at 60 N across all sleeves to avoid excessive joint loading or tendon damage.

$$\text{Traction Force [N]} = \text{Body Mass [kg]} \times \text{gravity [m/s}^2] \times 0.1$$

Equation 1: The Traction force applied to the hand during surgeries performed by the client

The specifications outlined in the PDS are the quantitative performance metrics and qualitative requirements necessary for prototype testing. For additional information, the full Product Design Specification, including supporting references and regulatory standards, is provided in Appendix A.

Preliminary Designs

Base Designs

Design 1 - Wheel or Clamp Base

The Wheel or Clamp Base design features a main rod that can be inserted into two different bases. One base is a C-clamp base that can clamp onto the procedure table or the patient's bed. The other base is a wheel base that has four wheels with a locking mechanism. The main rod also features a ball-and-socket joint that can rotate 360 degrees and bend 90 degrees. This will support procedures where the elbow is flexed at different angles and enable rotation of the wrist. The traction mechanism of the device would attach to the main rod.

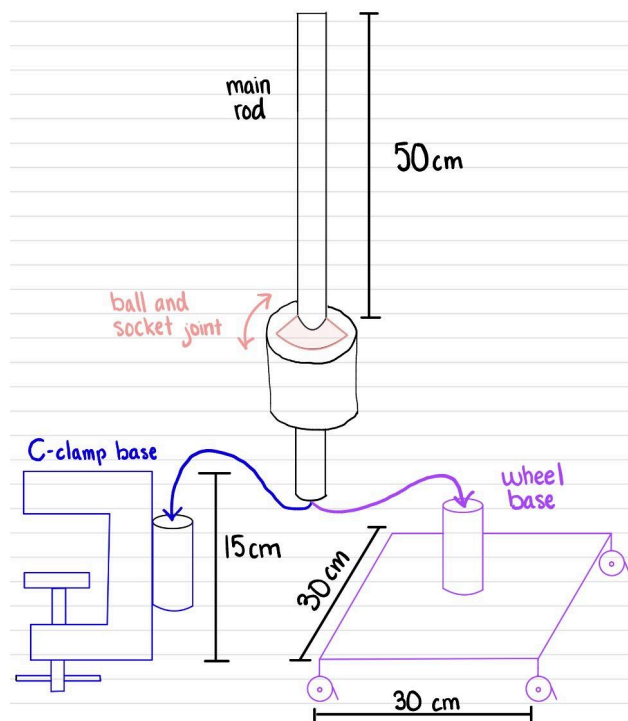


Figure 10: Wheel or Clamp Base Design Drawing

Design 2 - Table Attachment

The Table Attachment design is based on the idea of clamping the device to a surgical bedside or casting table. The device is made up of one main block, which is the base of the product, where there is a space in the top of the block to insert the traction device. It will latch onto the inside with a screw-in system. Then, on the side of the base, there is a gap that is used to place the base on the edge of the table. The device will sit parallel

to the table. Then, with a screw-in system, it will lock the base in place on the side of the surgical bedside or casting table.

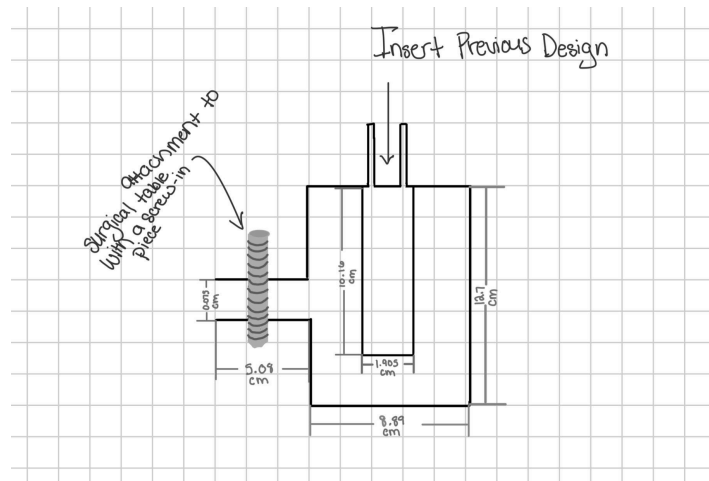


Figure 11: Table Attachment Base Design Drawing

Design 3 - C-Frame Base

The C-Frame design is based on the idea of creating a portable frame that can provide overhead traction for the patient's hand. The device is made up of one main C-shaped frame, which consists of a vertical support connected to a horizontal arm at the top and a base at the bottom. The horizontal arm contains the attachment point for the finger trap device, allowing the individual finger cables to extend downward toward the patient's hand. The vertical support can be adjusted to change the height of the traction system. The base is designed to sit beside or underneath the surgical bedside or casting table, allowing the device to remain stable without permanently attaching to the table. The frame can be made from lightweight aluminum tubing and can be disassembled or folded for easier transportation and storage.

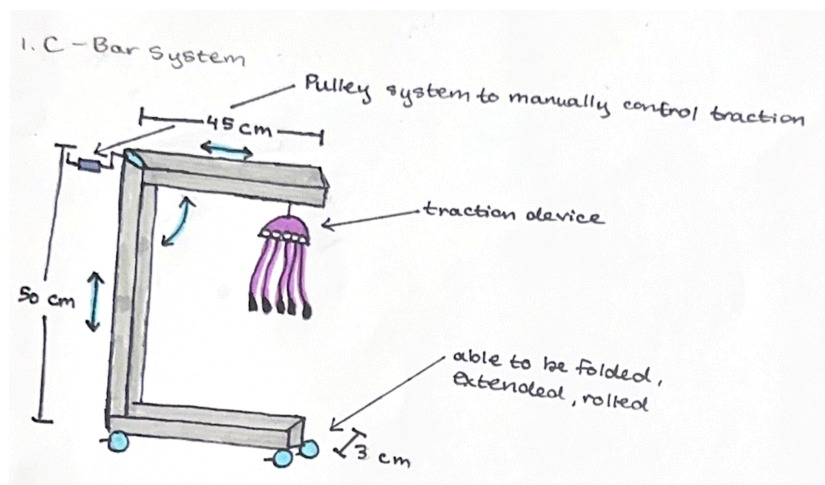


Figure 12: C-Bar Base Design Drawing

Traction Designs

Design 1 - Oscillating Pulley

The Guillotine Pulley design features a frame that allows for rotation so that traction can be applied vertically or horizontally. The traction is applied using a reel connected to a manual crank or motor, depending on use. The base is a frame containing an elbow pad and traction crank, and connects to the rotating frame containing the pulley system and finger plate. The rotating frame rotates using two quarter-circle plates that keep stability and allow for locking at specific angles. The crank shaft on the base frame has a holed plate that allows locking of the crank shaft with the holes in the base frame.

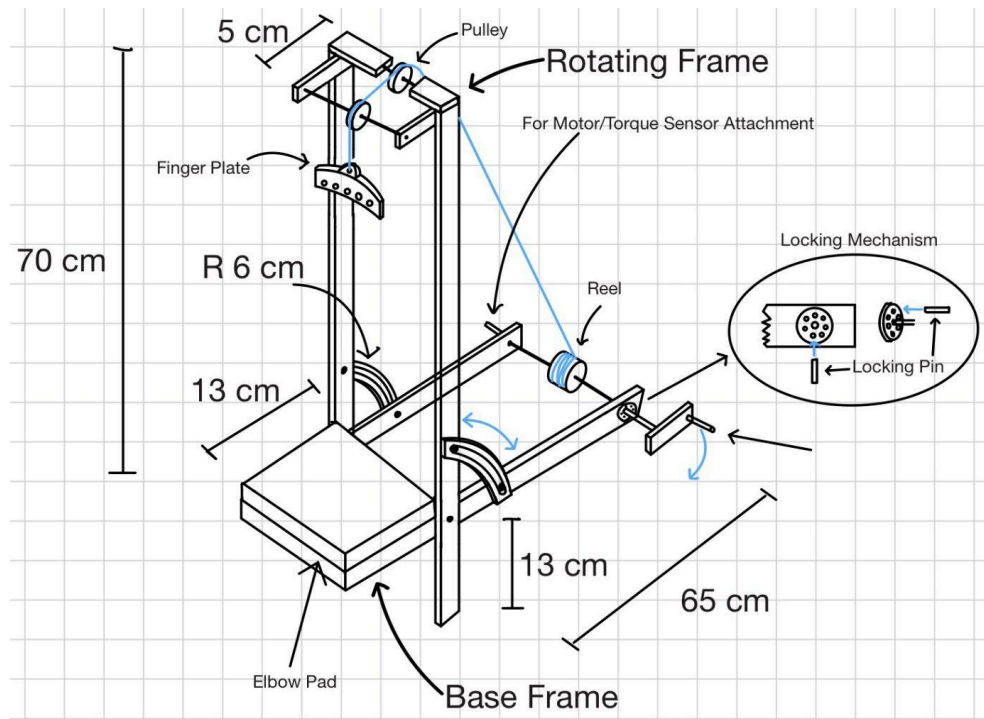


Figure 13: Guillotine Pulley Traction Design Drawing

Design 2 - Tripod-Folding System

The Tripod traction design features five pulleys that apply traction to the fingers on a hand individually. The strings from each finger go through their own pulley, which are then grouped together and run through a pulley system to one crank shaft. This design does not use a hand plate, instead having the crank apply traction to all five strings that connect to the finger traps on the hand simultaneously. By turning the crank, traction would be applied equally to all five fingers.

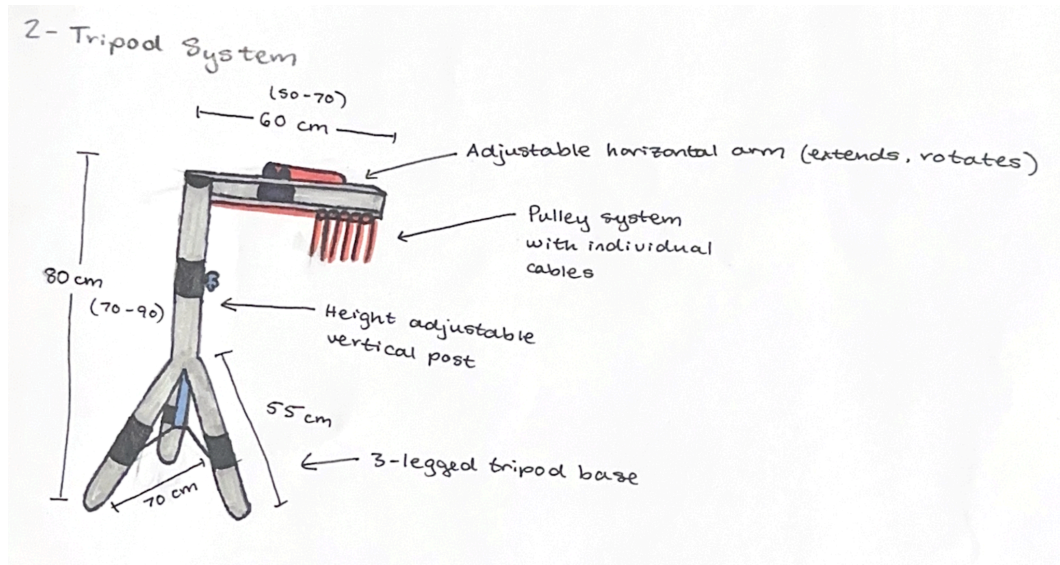


Figure 14: Entire Tripod System Design Drawing

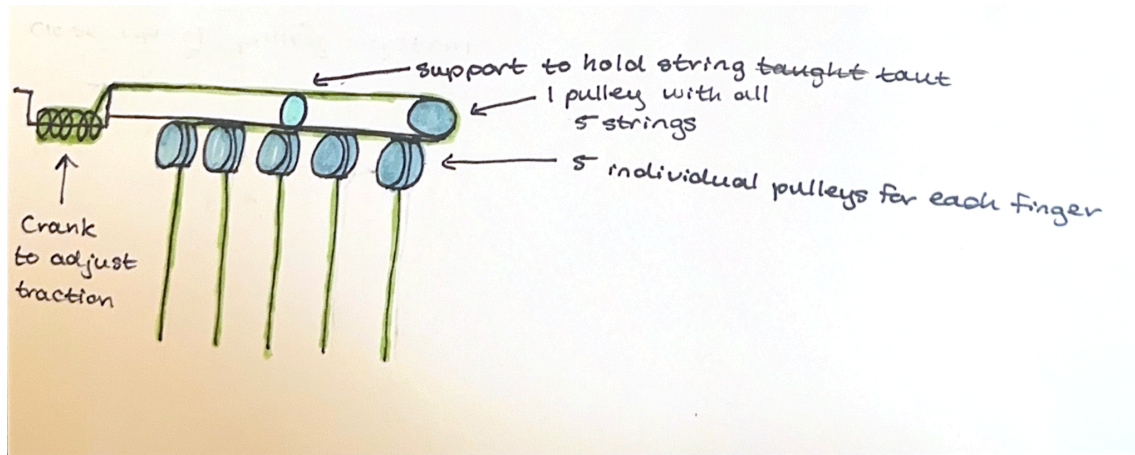


Figure 15: Tripod Design Drawing for Traction System

Design 3 - Pin Locking

The pin locking design features a strain gauge that is attached to the mounting plate to measure the amount of traction. The strain gauge is connected to a hollow outer rod with multiple holes drilled through it. This hollow outer rod goes over an inner rod with one hole drilled through it. To connect the two rods, the holes between the two rods are aligned, and the locking pin is pushed all the way through both rods. To increase traction, the locking pin is removed, and the outer rod is lifted until the next hole below it is aligned with the inner rod's hole, and then the pin is pushed through.

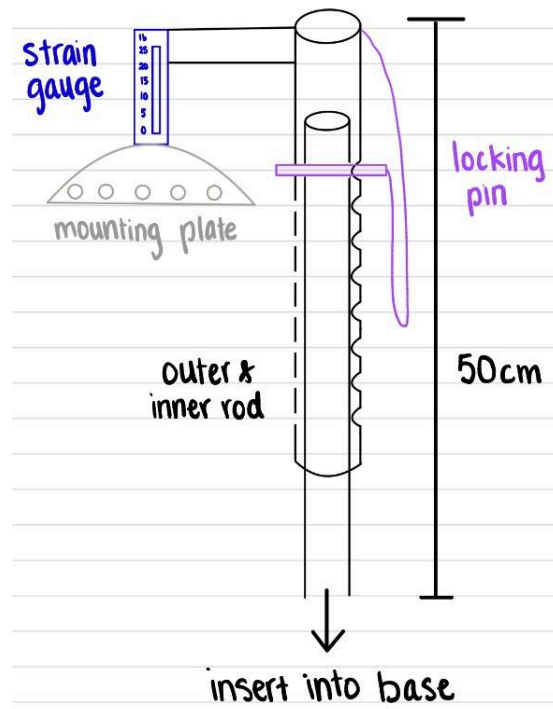


Figure 16: Pin Locking Traction Design Drawing

Preliminary Design Evaluation

Base Design Matrix

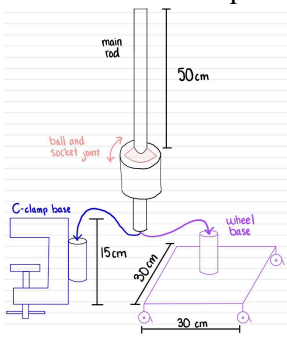
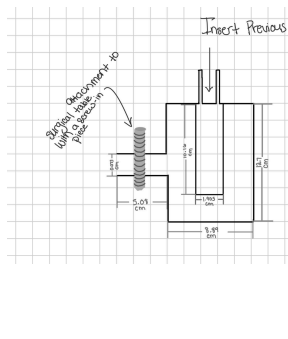
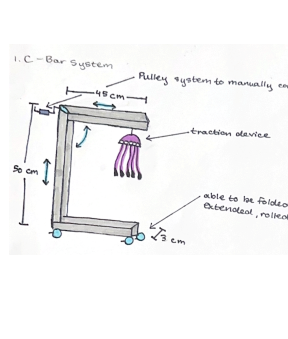
Base Design	#1 - Wheel or Clamp Base		#2 - Table Attachment		#3 - C-bar	
						
Criteria (Weight)	Score (Out of five)	Weight	Score (Out of five)	Weight	Score (Out of five)	Weight
Safety (25)	3	15	4	20	4	20
Ease of Fabrication (20)	2	8	4	16	5	20
Mobility (15)	5	15	3	9	4	12
Ease of Use (15)	3	9	4	12	5	15
Cost (15)	2	6	5	15	4	12
Footprint (10)	4	8	5	10	3	6
Total (100)	61		82		85	

Table 1: Base Design Matrix

Summary of Design Matrix:

Safety (25)

This category evaluates the safety of the design during operation. This category is weighted the highest because the device will be used with patients who are injured and in need of orthopedic procedures. The stability of the base design is important because it will be used to support the traction device that will be connected to the patients' fingers. The Wheel and Clamp Base design received a 3/5 because its design incorporates a ball and socket joint that will allow rotation, but it could be hard to precisely control the amount of rotation and then lock the orientation into place. The "Table Attachment" received a 4/5 because it can securely clamp onto the table, but it will have to support the full weight of the traction device on its own. The

“C-bar” design received a 4/5 because it is one fully connected part, but it is at risk of tipping over because of its tall height and unequal distribution of weight.

Ease of Fabrication (20)

This category evaluates how feasible this design is for the team to manufacture, differentiating very simple and very complex designs for fabrication. This category is weighted at 20 because the more complex the design, the more parts that need to be made per unit or the more time it takes per part. Scores are based on the complexity of the individual parts along with the number of parts. The “Wheel or Clamp Base” design received a 2/5 because, of all the designs, it is the hardest to fabricate due to the two parts of the base and the ball and socket joint. The “Table Attachment” design received a 4/5 because it is made from one solid piece, but the geometry would be complex to machine out. The “C-bar” design received a 5/5 because it is just a big hollow bar in a C shape, which would be very simple to manufacture.

Flexibility/Mobility (15)

This category evaluates how easy it is for the design to adapt to different clinical environments through repositioning and movement by healthcare providers. The device should accommodate the different sizes of each surgical/casting bedside. Its attachment point should provide flexibility in how the base is positioned while maintaining a secure connection to the surgical table or support structure. It is weighted at 15 because it is important that the base can be easily transported and support different procedures. The Wheel or Base Clamp was rated a 5/5 because it is easily able to move to different locations. It is also able to clamp/attach to multiple locations such as surgical beds and tables. The Table Attachment was rated a 3/5 because it is just one piece that attaches to the side of a surgical bed or table but it takes more effort to remove and attach it to different surfaces. The C-Bar was rated a 4/5 because it is easily transportable due to the wheels on the bottom, which allows for adjustments to be made as needed.

Ease of Use (15)

This category evaluates how easily the doctors can use this system. This category is weighted at 20 because the device aims to minimize the effort needed by hospital staff. Scores will be based on how straightforward the device is to use. The Wheel or Clamp Base was rated a 3/5 due to it having multiple pieces that could be used while also incorporating a similar, potentially tricky clamp design. The Table Attachment was rated a 4/5 because while it is a single part, the screw method to clamp it to the bed could cause difficulty. The C-bar was rated a 5/5 because it is a simple design that lacks multiple parts, making it easy to set up by wheeling it to the bed.

Cost (15)

This category evaluates how much it costs to produce this design once the product is done with testing. This is weighted at 15 because we need to consider that this device will be placed in a low-resource area, which means that production resources and funds will be limited. Scores will be based on materials, complexities of parts, and fabrication constraints. The Wheel or Clamp design received a 2/5 due to the two modular base parts that would make it more cost-heavy compared to the other designs along with the ball and socket joint. The Table Attachment design received a 4/5 due to its small size, which would require less material, but need for

mechanical fasteners. The C-bar design received a 4/5 because although it is simple, it is a large device that would require more material.

Footprint (10)

This category evaluates how much physical space the device occupies when it is being used. A smaller footprint is important because the device will be used in either an operating or casting room, where space is limited and medical staff need enough room to work around the patient. This is weighted at 10 because minimizing the device's footprint is important for maintaining accessibility and mobility in the clinical environment. The Wheel or Clamp Base received a 4/5 due to taking up minimal space while in use as well as not being used and can also be clamped to a table to lower footprint. The Table Attachment received a 5/5 due to being a smaller piece than the others, as it is only being used to attach to the side of the bed; there is no reliance on the floor for stability, which leads to a minimal footprint. The C-Bar received a 3/5 due to the sheer bulkiness of the device. Even though it does have folding/shortening mechanisms built into it when it is not being used, the C-Bar is quite large when it is in use, which takes up more space

Traction Design Matrix

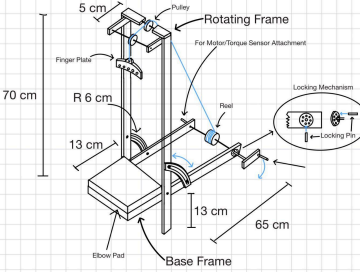
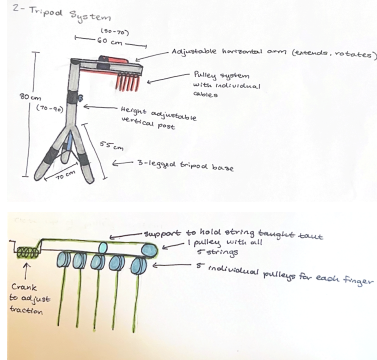
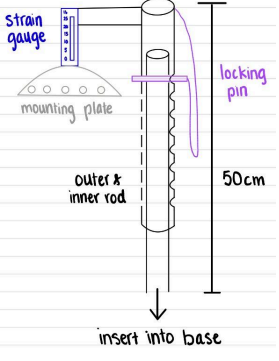
Traction Design	#1 - Guillotine Pulley		#2 - Tripod		#3 - Pin Locking	
						
Criteria (Weight)	Score (Out of five)	Weight	Score (Out of five)	Weight	Score (Out of five)	Weight
Safety (30)	5	30	4	24	3	18
Ease of Fabrication (25)	4	20	2	10	5	25
Ease of Use (15)	4	12	3	9	3	9
Cost (15)	3	9	3	9	5	15
Flexibility/Mobility (15)	5	15	2	6	2	6
Comfort (5)	5	5	3	3	3	3
Total (100)	91		61		76	

Table 2: Traction Device Design Matrix**Summary of Design Matrix:****Safety (30)**

This category evaluates the safety of the design during operation. This category is weighted the highest because the device will be used with patients who are injured and in need of orthopedic procedures. The device must accurately provide traction without excessive finger compression and safely support different orientations of the arm and wrist during the procedure. The Guillotine Pulley received a 5/5 because it can safely change the traction load with a simple pulley system and locking pin mechanism. The Tripod received a 4/5 because its pulley system contains five separate pulley lines that could potentially get tangled and apply an improper

amount of force to the fingers. The Pin Locking received a 3/5 because the user could potentially lose their grip on the outer rod when lifting it to change the traction load, which would cause the patient's limb to fall.

Ease of Fabrication (25)

This category evaluates how feasible this design is for the team to manufacture, differentiating very simple and very complex designs for fabrication. This category is weighted at 25 because the more complex the design, the more parts that need to be made per unit, increasing fabrication time and room for error. The scores are based on both the complexity of the individual parts and the number of parts. The Guillotine pulley received a 4/5 because, while it looks complex, everything except for the pulley and crank shaft can be made from a thick sheet of metal. The Tri-pod design received a 2/5 because there are five different pulleys and strings. This will require a lot of small parts to assemble the device. The Pin-Locking Design received the highest score, a 5/5, because it is the simplest. It is a tube with locking holes drilled out and a bar extending out where the strain gauge and hand plate can attach to, making manufacturing very easy.

Flexibility/Mobility (15)

This category evaluates how the mobility of the device should accommodate different traction positions while keeping the device stable during use. It should allow the fingers to move and be repositioned during procedures to accommodate the different hand positions surgeons must utilize to have an effective surgical experience. It was weighted at 10 because the ability to move the hand during surgery and casting is important. Scores are based on the adjustability of the device. The Guillotine Pulley was rated a 5/5 due to being able to move into numerous possible positions, including moving hand positions and the angle of the hand. The Tripod was ranked a 2/5 because it is difficult to manipulate different hand positions as well as fit inside the MRI machine. The Pin Locking system was rated 2/5 because it is difficult to fit within an MRI machine, and the device has limited positions the arm can be placed in.

Ease of Use (15)

This category evaluates how easily the client can use this system. This category is weighted at 15 because the device aims to minimize the effort needed by hospital staff. Scores will be based on how straightforward the device is to use. The Guillotine Pulley was rated a 4/5 due to it maintaining traction with a pulley system, which minimizes effort needed by hospital staff, but the design also has many parts, which can make it overwhelming to learn how to use. The Tripod received a 3/5 due to it having 5 separate pulleys for finger traps that would all have to be set up and could potentially lead to tangling. The Pin Locking system was rated a 3/5 due to the traction being applied in discrete amounts through different weights, making it hard to adjust the traction for in-between values.

Cost (15)

This category evaluates how much it costs to produce this design once the product is done with testing, which will depend on materials, complexities of parts, and fabrication constraints. This is weighted at 15 because we need to consider that this device will be placed in a low-resource area, which means that production resources and funds will be limited. Scores will be based on how much each device will cost. The Guillotine Pulley design received a 3/5 because even with simple flat pieces, there are various intricacies within the design, making it more expensive. The Tripod Design received a 3/5 as well because it contains intricate parts

in the top, with 5 strings attaching to each finger, which will increase production costs. The Pin Locking design received a 5/5 due to its extremely simple design that is also very small, leading to cheap production costs.

Comfort (5)

This category evaluates the comfort level of the patient while wearing the device. Wrist arthroscopies and hand casting can require long periods of device use, so it is important to minimize the patient's discomfort. This is weighted at 10 due to the fact that this would be temporary, as the device would be taken off post-surgery. The Guillotine received a 5/5 due to padding available on the device itself, allowing a soft surface that the patient's arm/hand can rest on. The Tripod received a 3/5 due to no padding available on the device, which can lead to patients feeling uncomfortable. The Pin Locking also received a 3/5 due to no padding being shown on the device's design, which can cause discomfort for the patient and leave them with pain post-operation.

Proposed Final Design

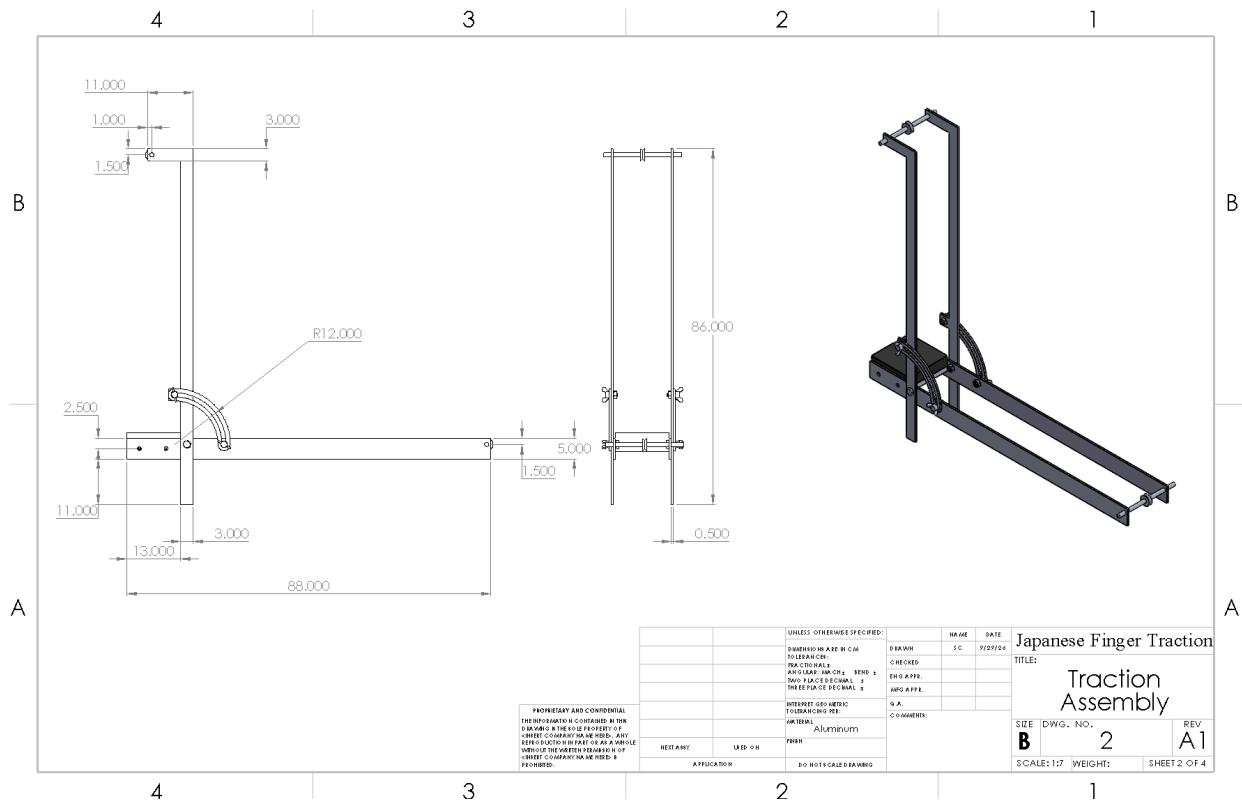


Figure 17: Guillotine Pulley - Traction system designed to use pulleys and a crankshaft to apply traction to a hand using finger traps

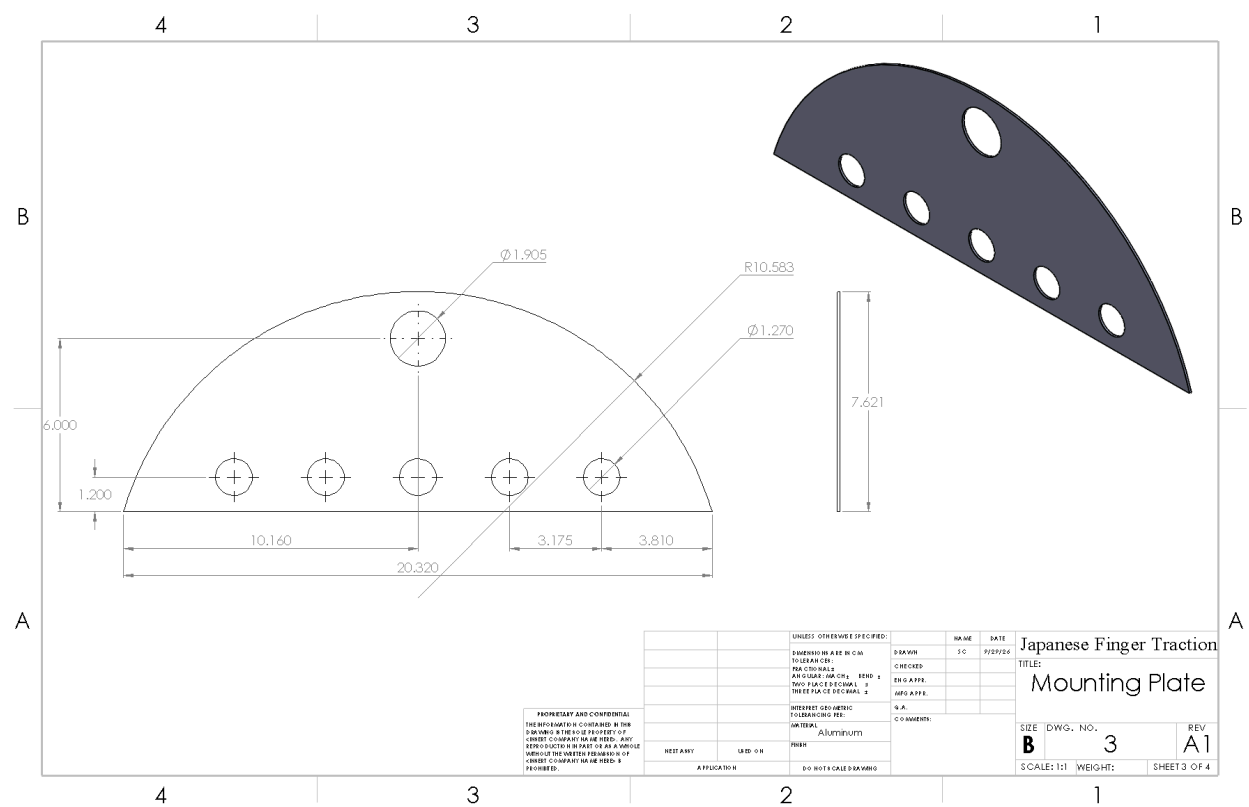


Figure 18: Mounting Plate - A plate to connect the pulley system of the traction device to the finger sleeves on the patient's hand

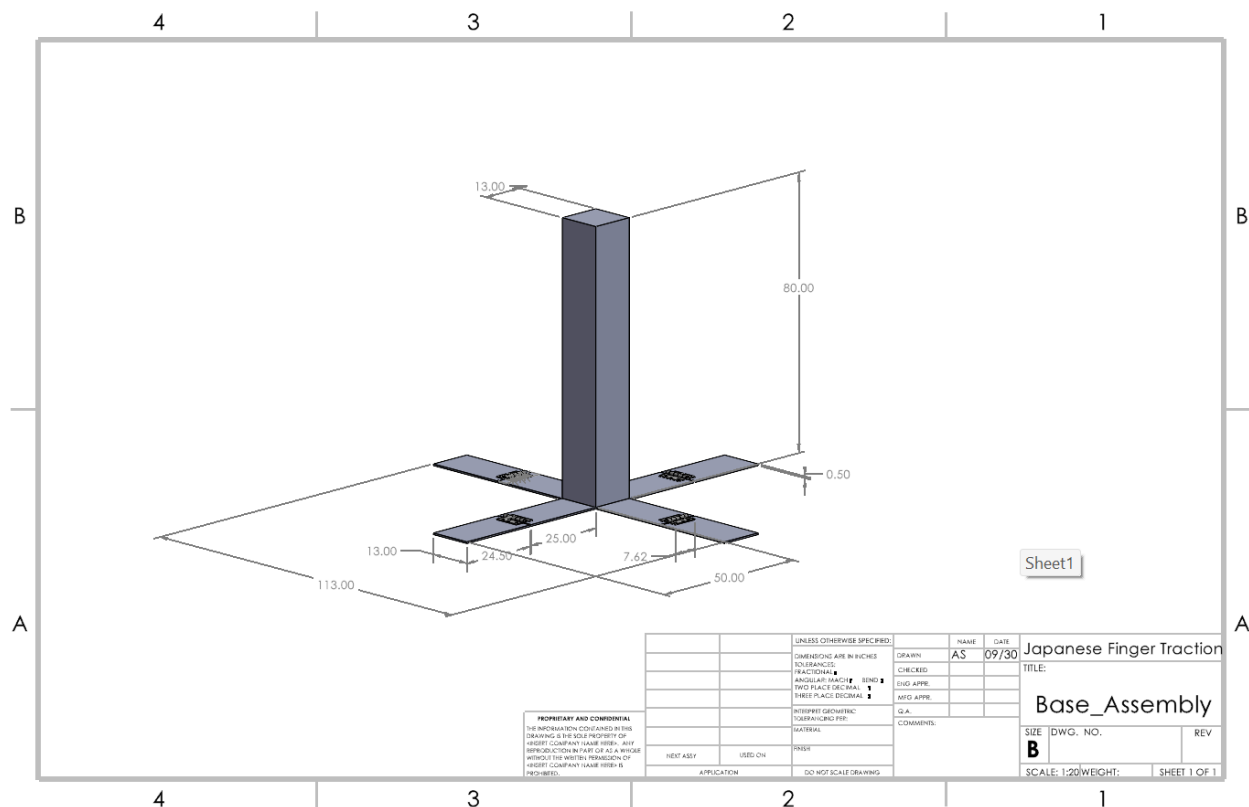


Figure 19: The Hinged Base - Base design for the Japanese finger sleeve traction device

The proposed final design for the traction device is the Guillotine Pulley design (Figure 17). The client has stated that having a safe and reliable way to apply traction during both casting and surgery is the most important. This design has a reliable form of applying traction through the pulley system that can be modified as much as needed to fit the client's needs. The pulley system can also be rotated into a horizontal position so that traction can be applied while the arm is on a table for surgery. The Guillotine is made from very simple parts, intended to be cut out with a waterjet, making fabrication very easy. The Guillotine Pulley will make use of the previous semester's hand traction plate, as shown in Figure 18, to connect the traction system to the finger sleeves to apply tension to the hand. Traction will be applied through the bottom pulley by attaching either a crank or motor to the pulley shaft.

The proposed final design for the base is a new design, the Hinged Base, different from any of the preliminary designs. After evaluating the preliminary designs, the team decided to take the best parts of each design to make a new proposed base design (Shown in Figure 19). This design features a plus-sign style base with hinged flaps that can be rotated to decrease the footprint of the device. This allows the operator to balance stability and footprint in areas like operating rooms, where space is limited. This base design is simple, which is beneficial for this project. It will allow us to make modifications easily and allow the team to consider different attachments, like table clamps to increase stability, or height adjustment pieces, in the future as the final design is being developed.

Fabrication

Materials:

The traction device will be fabricated using 1/2 cm thick aluminum sheets [26]. Aluminum is a durable, non-corrosive material that is also lightweight and cheap [27]. It is also a non-ferromagnetic material, and this would allow the device to be used in the presence of an MRI if needed [28].

Methods:

The base of the device will be fabricated using a waterjet to cut out pieces from the aluminum sheets. These pieces will include a cross-shaped sheet and four rectangular extension pieces of the same width as the cross for the base design. Hinges will be used to connect an extension piece to each arm of the cross. A tall, rectangular bar will be placed in the middle of the cross base. A tapping machine will be used to tap holes into the aluminum parts to allow for mechanical fasteners to hold the pieces together.

The traction device will also be fabricated using a waterjet to cut out two slim, vertical, L-shaped bars, two horizontal bars, two arced guide rails, and a rectangular plate out of the aluminum sheets [29]. A tapping machine will be used to tap holes into these pieces to allow for mechanical fasteners to be inserted to hold the assembly together. The vertical bars will be fastened to the horizontal bars to make a cross shape, and the arced guide rails will form another supporting connection. The rectangular plate will be fastened at the end of the horizontal plates, where an elbow pad will be fastened. Two bars will be inserted through the vertical bars and horizontal bars to act as a pulley system. The base and traction designs will be fastened together by lining using mechanical fasteners on the sides of the vertical bars and the middle pole to attach the two pieces.

Final Prototype:

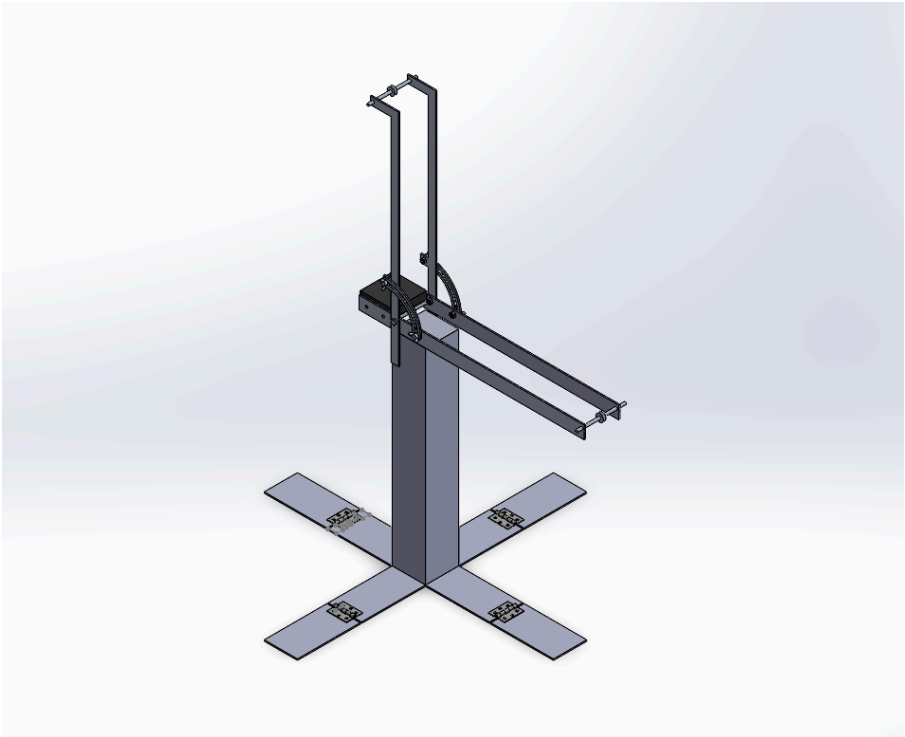


Figure 20: SolidWorks Assembly of Prototype Design

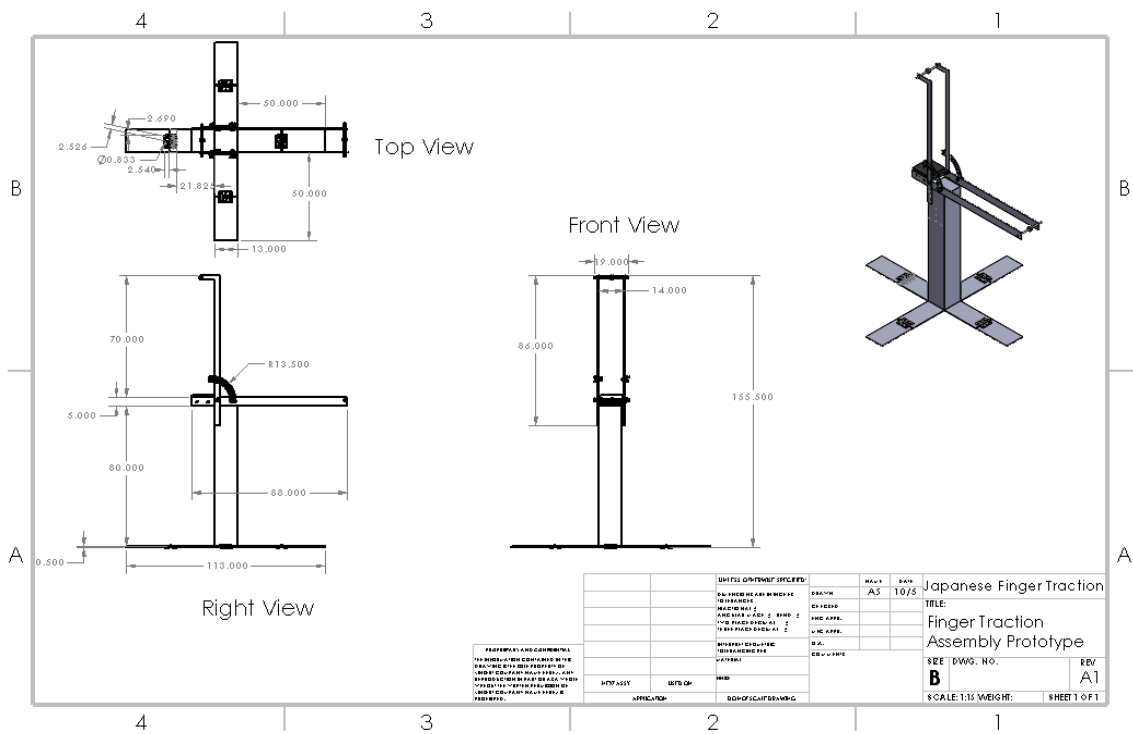


Figure 21: SolidWorks Drawing of Prototype Design

Testing and Results

After fabrication of the base and traction portion of the device, its performance and safety will be assessed through mechanical testing. First, the stand's mechanical integrity will be verified using a static proof load test in accordance with OSHA §1926.251(a)(4), which mandates that custom clamps and lifting accessories be proof-tested to 125 % of their rated working load limit (WLL) to ensure structural safety [30]. The stand will be mounted and then loaded vertically at its distal attachment point to $1.25 \times \text{WLL}$ for a half hour while monitoring for deformation, structural compromise, or tipping. If no damage occurs, a further ultimate load-to-failure test will be conducted to determine the breaking load and calculate the design safety factor, targeting $\geq 4 \times \text{WLL}$ as recommended for medical support mounts (See Appendix D for protocol) [31] .

The device's ability to accurately pull a traction load will be tested by setting up an external scale system [32]. A digital tension gauge or certified digital hanging scale will be attached to the mounting plate instead of the finger sleeves. The other end of the scale will attach to a prototyped frame at the same height as a patient's hand would be located. The pulley system will be set to loads ranging from 1-20 kg in increments of 1 kg using the cranking and locking mechanism. These set loads will be maintained for 5 minutes and be verified against the digital reading from the external scale to determine the device's ability to accurately pull traction loads (See Appendix E for protocol).

To ensure safety of the finger sleeves, a slippage test will be performed. One finger sleeve will hang from the mounting plate of the traction device to fully stress one sleeve to its maximum load. Each finger will be placed in the sleeve for 10 total minutes and overall slip displacement will be measured in millimeters. Finally, participants will complete comfort and usability questionnaires after all fingers have been tested to evaluate subjective comfort, pain, and perceived exertion (See Appendix F for protocol).

To ensure that the traction device is reusable, an aluminum sheet and a finger sleeve will go through tensile testing before and after autoclaving. The tensile testing will be conducted using the MTS machines in the BME teaching lab (See Appendix G for protocol). The testing protocol will be used to determine how much tensile force the finger sleeve can withstand before damage to the finger sleeve and before total failure of the finger sleeve. Additionally, the sleeve should maintain these strength properties after being autoclaved. This is important because the finger sleeve must be reusable and be able to withstand 60 N of force without damage as stated in Appendix A (Product Design Specification).

Discussion

Ethical and safety concerns

Ensuring the safety of this device during use will be the ultimate responsibility, as it will be used in surgical procedures and casting. The main possible hazards that are to consider include loss of base support, pulley system slippage, or the overtraction of the patient's finger. The design, therefore, addresses these issues through the implementation of the hinged base that allows for adequate safety along with the option of a reduced footprint if needed. Additionally, there will be a locking mechanism for the set load. The proof load and

load accuracy test will ensure that any weak points are recognized before any human uses of the device. If any weak points are found, design changes will be made until the device functions without failure.

Tests on human subjects will require care. Any prospective subject will need to be informed of possible risks and prototype restrictions such as comfortability, fall risks, and traction risks. The subjects must have the ability to back out of testing at any moment if they wish. During the finger sleeve slipping test, loads will increase gradually, and the test will stop if the participant reports any pain, numbing, tingling, or any other uncomfortable sensations. As the device is a prototype, it is important that the client has full knowledge of all of the capabilities of the device. Additionally, it is important that they know of the limitations and possible modes of failure so that they have realistic expectations of the device. Full disclosure will lead to the minimization of client dissatisfaction and provide proper safety, which is especially needed for the context of surgery and casting.

Finally, cost will be an important ethical consideration. The device will be placed in Senegal, where resources are not as prominent as in the USA. Although it will be at the biggest hospital in Senegal, it will still be important that this device can be affordable, simple to build, repair, and clean from local available materials. This will allow for the device to be used to its maximum potential.

Design Evaluation

This project continues the work of the Fall 2025 BME 200/300 project. During their project, they focused on an IV pole with an aluminum plate, which was tested for strength and its ability to hold a hand under a load. However it did not have a way to set or adjust traction load, nor could it be used in a horizontal manner. This semester our team will focus on a more stable base, flexible traction angles, and adjustable traction loads.

Potential Sources of Errors

There are a few sources of error that could affect fabrication. There could be discrepancies in the measurements when the sheet metals and other various parts are being cut. This would lead to parts that don't align properly, which can be unsafe as it will create instabilities.

Additionally, the mechanical tests have their limits. When implementing the proof load test, variations in how weight is applied and how mechanical deformations are measured can bring in testing discrepancies. These factors may generate structure stress data that differ from what the device experiences in clinical settings. During the traction accuracy test, the digital scale accuracy, pulley friction, and any slipping in the crack/lock can cause differing readings. In order to reduce this inaccurate reading, repeating each load several times and checking the scale with a known weight will be crucial for accurate results.

The finger sleeve slippage test will be performed on healthy patients without any fractures, so the group of people will not match the people who will use the device. Also, with a small sample size, hand sizes may be limited, leading to ambiguity for the hand sizes that aren't tested.

The comfort questionnaires may perhaps have the most variability. This is because the questions on comfort are subjective from person to person based on their own ability to withstand discomfort. Additionally,

the subject's expectation of the device can affect their answers. The team will provide the same procedure for each patient to ensure that they are not influenced by outside forces when providing their answer.

Conclusions

The goal of this project is to develop a cost efficient, reusable digital traction device that applies controlled traction to a patient's fingers during the setting and casting of distal radius fractures. The design developed contains a Guillotine Pulley system with a locking crank that holds the desired set traction load. This traction system will be mounted on a hinged base that is stable and can be folded for storage. The device will feature store bought surgical finger sleeves and also reuses the previous semester's hand traction mounting plate to attach to the pulley. The pulley's frame offers positional flexibility, as it can turn between vertical and horizontal positions, to be used in casting and surgery. This device is a continuation of the previous year's work, and it aims to fix the problems that were presented in their prototype to provide a safe, adjustable, and affordable traction device for the client.

Future Work

The next steps for this project include fabrication, testing, and adjustments. The base and traction system will be fabricated using the methods listed above, while the finger sleeves will be bought to be attached to the hand traction plate. Once this is completed the following tests will be conducted: mechanical testing of the stand's strength and stability, testing the accuracy of the traction load, and finger sleeve slippage test. With the results of these tests, the device will be readjusted to fix any issues that come along. Once the device has been tested and improved, the team will review the final prototype and documentation to the client to ensure it meets all functional requirements and operating expectations.

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Appendix

Appendix A: Product Design Specifications



Digital Traction with Japanese Finger Sleeves

PRODUCT DESIGN SPECIFICATIONS

BME 200/300

Section 303

Client:

Mr. Pape Samb

Group members:

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Co-Leader: Sean Carey

Communicator: Anshpreet Sohal

BWIG: Henna Razeq

BSAC: Patricia Prakasam

BPAG: Karthik Anem

September 18th, 2026

Table of Contents

Function.....	2
Client requirements.....	2
Design requirements.....	2
1. Physical and Operational Characteristics.....	2
a. Performance requirements.....	2
b. Safety.....	3
c. Accuracy and Reliability.....	3
d. Life in Service.....	3
e. Shelf Life.....	4
f. Operating Environment.....	4
g. Ergonomics.....	4
h. Size.....	4
i. Weight.....	4
j. Materials.....	5
k. Aesthetics, Appearance, and Finish.....	5
2. Production Characteristics.....	5
a. Quantity.....	5
b. Target Product Cost.....	5
3. Miscellaneous.....	5
a. Standards and Specifications.....	5
b. Customer.....	7
c. Patient-related concerns.....	7
d. Competition.....	7
References.....	9

Function

The product must provide mechanical and digital traction to precisely position the arm and fingers during hand and wrist orthopedic procedures. The product must utilize Japanese finger sleeves to provide traction and tension through the digits to prevent broken bones from tangling while also stabilizing the arm. The product aims to minimize the manual traction efforts from hospital staff.

Client requirements

The client, Mr. Pape Samb, of Jamarek Corp, requested the following specifications of the product design for the digital traction with Japanese finger sleeves project.

- Support the arm at 90-180° during surgery or casting for at least 50 minutes.
- Pull traction at 10% of the patient's body weight.
- The device should allow for the wrist to rotate 180° during the procedure.
- The finger sleeves should not compress the fingers to limit stiffness and complications.
- The finger sleeve material should be strong, elastic, and latex-free to prevent allergic reactions.
- Accommodate different hand sizes through adjustable sizing finger sleeves or multiple sleeve sizes.
- A cost-effective, reusable design that can be sterilized without compromising functionality.
- Durable design to survive high-volume hospital traffic (~25,000 orthopedic patients every 6 months).
- The overall traction device should use non-ferromagnetic material to be MRI compatible.
- The device should have a robust base that can clamp onto the procedure table and be modular for ease of transport and storage.
- Potentially include sensors to detect elbow bending angle, finger pressure, and usage duration and alert if complications arise.

Design requirements

1. Physical and Operational Characteristics

a. Performance requirements

- i. The sleeve must fully secure and support the full weight of the patient's hand/forearm without damage such as tearing, permanent stretching, or slipping off the patient's hand. The target load for the sleeves to support is no more than 60 N total as a safety factor [1].
- ii. Devices must maintain peak elasticity, strength, and surface texture through a minimum of 50 uses.
- iii. Inner finger sleeves must provide a coefficient of friction of 0.4 under standard operating room conditions to ensure grip, while preventing slippage under load [2].
- iv. The base frame of the device must securely hold the suspension mechanism.
- v. The sleeve material must be able to stretch to adequately wrap around different finger lengths. The material will aim to stretch 15-25% beyond the relaxed state, which should secure the fingers without overconstricting them [3].

- vi. The device will have monitoring capabilities that will measure and display the total traction load applied up to 60 N at a precision of ± 4.2 N.
- b. Safety**
 - i. Medical-grade material must be nontoxic and hypoallergenic (latex-free) to avoid skin irritation/allergic reaction [4].
 - ii. Design must avoid excessive finger compression (< 5 N) to minimize the risk of circulation loss (ischemia) or nerve damage during the procedure [5].
 - iii. The entire device must use non-ferromagnetic materials that are MRI compatible to prevent projectile risks, heat risks, and other risks that may harm the patient or corrupt imaging data.
 - iv. The device must have a minimum safety factor between 2.5 and 6 [6]. This will prevent catastrophic failure, like tearing, that could result in a falling arm and thus injury.
 - v. The materials of the design must be compatible with standard hospital sterilization techniques, such as steam autoclaving, chemical sterilants, etc. It must be able to withstand this without degrading, to prevent any cross-contamination. [7]
- c. Accuracy and Reliability**
 - i. For multi-size compatibility, each finger sleeve must consistently and accurately fit the intended range of finger diameters.
 - ii. Any force sensors must provide accurate and repeatable readings within ± 0.1 N accuracy to be clinically viable for training.
- d. Life in Service**
 - i. The finger sleeves must reliably perform at least 50 full uses and autoclave sterilization cycles over their service lifetime [8].
 - 1. Idrissa Pouye General Hospital receives 25,000 orthopedic patients every 6 months. Assuming that 17.5% of all orthopedic visits are Distal Radial Fractures (DRF), the finger sleeves will be used about 8750 times per year [9].
 - 2. The finger sleeves should maintain full function for 3 months.
 - 3. There will be a stock of 40 sets of finger sleeves, assuming 25 DRFs per day and a 1.5x sterilization turnover buffer.
 - ii. Elastic and sensor components should endure 100,000 loading cycles within the expected operating force range (< 60 N), with sensor accuracy drift less than $\pm 5\%$ [10].
- e. Shelf Life**
 - i. The device must retain functionality for at least 3 years in standard storage conditions: 10-30 °C, relative humidity less than 70%, and away from direct UV light [11].
- f. Operating Environment**
 - i. The device must function in standard operating room conditions: 20-24 °C, and 20-60% relative humidity [12].
 - ii. Surfaces should be resistant to corrosion or degradation by blood, saline, antiseptics, and common disinfectants [13].
 - iii. The device must tolerate occasional jostling or movement without loss of alignment or sensor calibration.
 - iv. The device must be MRI compatible with no ferromagnetic metal parts and any electronics either shielded or safely located to avoid interfering with imaging.
- g. Ergonomics**
 - i. Limit peak interface pressure to 50 N/cm², which is below reported pressure pain thresholds [2].

- ii. Inner finger sleeves must remain below a coefficient of friction of 1.0 to avoid excessive shear and possible skin damage [14].
- iii. Limit total axial traction force to 60 ± 4.2 N per finger to avoid excessive loading on finger joints and the DRF site [1].

h. Size

- i. The device must be small, easily movable, and fit within the surgical field without interfering with other instruments [15].
- ii. Should accommodate all hand and finger sizes, specifically for the Senegalese, whose typical finger length is 8.26 cm for females and 8.69 cm for males with a diameter of 1.94 ± 0.10 cm in females and 2.11 ± 0.12 cm in males at the PIP joint of the largest finger [16].
- iii. Must be compact enough to not block MRI coils or distort imaging [15].
- iv. Must be adjustable to increase or decrease tension and create a larger or smaller overall sleeve structure [17].
- v. Must be able to fit easily and securely on a bedside without disrupting the patient's procedure or recovery.
- vi. Must be able to withstand the force of the MRI machine and not move when the MRI machine is active [18].

i. Weight

- i. The device must be lightweight (<16 kg) for the following reasons:
 - 1. Easy handling and help reduce surgical fatigue in delicate surgical procedures [19].
 - 2. Reduce the risk of interfering with radiofrequency energy during scans [20].

j. Materials

- i. The product must be MRI-safe, designed with nonferromagnetic materials, non-conductive, and tissue-compatible.
- ii. The material must be non-irritating to prevent patient pain, tissue damage, skin irritation, and swelling. [13]
- iii. The material must withstand 50 cycles of sterilization [20].
- iv. The product must be made with ceramic, plastic, titanium, or non-magnetic materials in order to be usable in both the MRI machine and operating room [20].

k. Aesthetics, Appearance, and Finish

- i. The material must be finished with a non-reflective material to prevent glare that can occur due to the surgical light.
- ii. Padding must be available where any soft tissue would come into contact with hard material to ensure patient safety.
- iii. This device has no major need to be aesthetically pleasing, as functionality is prioritized.

2. Production Characteristics

a. Quantity

- i. The main goal for this project is to develop a single digital traction device to precisely position the fingers and arm during orthopedic hand and wrist surgery, such as wrist arthroscopies. The product should accurately apply finger tension in both the left and right hands during surgery, while still allowing the client to easily maintain its structure and cleanliness through repeated use.

b. Target Product Cost

- i. The client has not yet provided a set budget for prototyping and prior steps.
- ii. The university allows for a budget of \$50 for use in the Design Labs.

- iii. The device is designed for utilization in a hospital in Senegal, where financial resources are less available. The final product should be of a relatively low cost compared to similar products on the market.

3. Miscellaneous

a. Standards and Specifications

This device will be classified as a Class 2 medical device. Power traction equipment are classified as Class 2, non-powered traction devices are classified as Class 1, and non-invasive traction components are classified as Class 1 [22], [23], [24], [25], [26]. The device must abide by the following standards:

- i. ISO 10993-1:2025 - Biological evaluation of medical devices Part 1: Requirements and general principles for the evaluation of biological safety within a risk management process [13].
 - 1. This standard provides guidance for evaluating the biological risks related to materials, design choices, and tissue contact during use.
- ii. ISO 10993-10:2021 - Biological evaluation of medical devices Part 10: Tests for skin sensitization [4].
 - 1. This standard specifies the procedure for assessing medical devices and their materials with regard to their potential to cause skin sensitization.
- iii. ISO 13485:2016 - Medical devices — Quality management systems — Requirements for regulatory purposes [27].
 - 1. This standard establishes a framework to ensure consistent design, development, production, and delivery of medical devices during their intended use through regulatory requirements and risk management.
- iv. ISO 14971:2019 - Medical devices — Application of risk management to medical devices [28].
 - 1. This standard specifies terminology, principles, and processes for risk management of medical devices to identify hazards and estimate and control risks.
- v. ISO 15223-1:2021 - Medical devices — Symbols to be used with information to be supplied by the manufacturer Part 1: General requirements [29].
 - 1. This standard specifies symbols used to express medical device information.
- vi. ISO 17664-1:2024 - Processing of health care products — Information to be provided by the medical device manufacturer for the processing of medical devices - Part 1: Critical and semi-critical medical devices [7].
 - 1. This standard specifies requirements for the processing of medical devices prior to reuse including: initial treatments, preparation before cleaning, cleaning, disinfection, drying, maintenance, packaging, and sterilization.
- vii. IEC 60601-1-8:2006 - Medical electrical equipment Part 1-8: General requirements for basic safety and essential performance — Collateral standard: General requirements, tests and guidance for alarm systems in medical electrical equipment and medical electrical systems [6].
 - 1. This standard specifies basic safety and performance requirements and tests for alarm systems employed in medical electrical systems.
- viii. IEC 60601-1-11:2015 - Medical electrical equipment Part 1-11: General requirements for basic safety and essential performance — Collateral standard: Requirements for medical electrical equipment and medical electrical systems used in the home healthcare environment [30].
 - 1. This standard applies to basic safety and performance of medical electrical equipment for use in home healthcare environments regardless of operator.

- ix. IEC 62304:2006 - Medical device software — Software life cycle processes [31].
 - 1. This standard defines the life cycle requirements for medical device software, establishing a set of processes, activities, and tasks.
- x. IEC 62366-1:2015 - Medical devices Part 1: Application of usability engineering to medical devices [32].
 - 1. This standard specifies processes for manufacturers to analyze, develop, and evaluate the usability and safety of medical devices to mitigate risks with correct and normal use.
- xi. 21 CFR 888.5850 - Nonpowered Orthopedic Traction Apparatus and Accessories [23].
 - 1. This federal regulation applies to nonpowered orthopedic traction apparatuses aiding in exerting therapeutic pulling forces on a patient's body with nonpowered traction accessories.
- xii. 21 CFR 888.5890 - Noninvasive Traction Component [22].
 - 1. This federal regulation applies to noninvasive traction components that do not penetrate the skin in a medical device used to apply therapeutic pulling forces on the skeleton
- xiii. 21 CFR 890.5900 - Power Traction Equipment [24].
 - 1. This federal regulation applies to powered traction equipment intended for medical use in conjunction with traction accessories to exert a therapeutic pulling force on a patient's body
- xiv. 21 CFR 890.5925 - Traction Accessory [25].
 - 1. This federal regulation applies to nonpowered accessory devices intended to be used for medical purposes with powered traction equipment to exert therapeutic pulling forces on a patient's body.
- xv. ANSI ST79:2006 - Comprehensive guide to steam sterilization and sterility assurance in health care facilities [8].
 - 1. This standard covers steam sterilization in health care facilities, guiding healthcare professionals in the proper use of processing equipment.

b. Customer

- i. This device is intended for use in hospitals, surgical facilities, rehabilitation centers, and other medical facilities that are involved in orthopedics. The customer's most crucial priority is that the device is able to safely hold traction on the patient's fingers. The device needs to be able to hold the arm upright for casting and horizontally for surgery. The client would prefer that the traction system be electronic and detachable for when it goes into the MRI, but the priority is getting a device that works safely and reliably. The customer wants thorough testing to ensure the device's safety.

c. Patient-related concerns

- i. This device is intended to be used during surgery and rehabilitation of the hand, making safety and stability critical. The design must be able to withstand the traction forces along with secondary forces due to use in the operating room without losing stability. To maintain the safety of the patient, the sleeves and the traction system must support the weight of the patient's arm with minimal risk of failure due to the delicate nature of rehabilitation and surgery [22], [22], [23], [24], [25], [27], [28]. The sleeves cannot compress the patient's fingers to constrict blood flow [5]. The sleeve and device need to be made of medical-grade, hypoallergenic, latex-free, and non-ferromagnetic materials to prevent any adverse reactions in the patient or an MRI machine [4], [13].

d. Competition

- i. Competing Design #1: Digi Grip [33], [34]
 1. The Digi Grip is a manual traction system intended for use in physical therapy. It features an adjustable-height IV pole with a custom attachable plate to suspend the fingers from. The associated finger sleeves are like finger traps and are connected to the custom plate using chains.
 2. The traction in this system is very simple. An arm sleeve is wrapped around the user's bicep, and weights are attached to the bottom so that the elbow is at a ninety-degree angle and pulls vertically on the fingers.
 3. This device is very similar to what the client is looking for, but it is lacking in a few areas. While this device has a lot of mobility, the base is unstable and therefore unsuitable for use while casting hands. It is also unable to be adjusted horizontally so that traction can be applied to the hand while in surgery, making it ill-suited to the client's needs.
- ii. Competing Design #2: Traction Wrist Tower [17]
 1. The Wrist Tower was a custom-made medical traction device developed by surgeons. The design features a circular base plate with a cuff that locks the arm in. There are height-adjustable rods that extend from the base and attach to a traction plate. The plate has finger spacers that allow it to pull the fingers in traction without them slipping through. The traction is performed using a tourniquet system.
 2. This device is an adequate solution to adding traction to the hand during surgery, but it needs to be developed further. The system for traction needs to be improved to reduce compression on the fingers. This device also cannot be used to apply casts because it interferes with the forearm, making it unsuitable for our client.
- iii. Competing Design #3: Traction Reducer
 1. This design is fully attached to a table. It features a multi-jointed arm that extends from the table with a traction device attached to it. The traction device is a winch that connects to strings with finger traps. The arm is held in place by a cushioned support attached to the table.
 2. This design is an effective design for surgery, but it is immobile and unable to be used during casting of the arm. It is also very complex and would be expensive to make. While this design is effective, it does not suit the need to be mobile and low-cost in our client's environment.

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Appendix B: Expenses - Fall 2025

Item	Description	Manufacturer	Mft Pt#	Vendor	Vendor Cat#	Date	QTY	Cost Each	Total	Link
Finger Sleeve										
Cable Ties	Velcro reusable 6 in cable ties 100 pack	VELCRO® Brand	VEL-40095-USA	Amazon	B0DYJWL6QS	11/20/2025	1	\$7.94	\$7.94	Cable Tie Link
D Ring	Connection piece between sleeve and chain	Grainger	B38R	Maker Space	N/A	11/21/2025	6	\$0.45	\$2.69	D Ring Link
Velcro Scrap	Double-sided Velcro strap used for prototype	VELCRO® Brand	VEL-30836-USA	Maker Space	N/A	11/20/2025	1	\$0.18	\$0.18	Velcro Tie Link
Ballistic Nylon	Fabric for the finger sleeve	Canwil Textiles	N1050D/60BK	Maker Space	N/A	11/20/2025	1	\$15.00	\$15.00	Nylon Link
Silicone Rubber	Attachable fabric to increase grip on finger	Yuhangilx	B001	Amazon	B0DFH DYDS8	11/20/2025	1	\$9.98	\$9.98	Silicone Link
Mechanical Stand										
Rubber Stopper	Secures sleeve-to-stand attachment piece, restricts unwanted rotation	NRS	77405.01	Maker Space	N/A	11/21/2025	1	\$0.15	\$0.15	Stopper Link
Medline Stand	IV stand to be rolled and clamped onto hospital	UISKOOPW	87260610	Amazon	B0F5W8CK8X	11/20/2025	1	\$27.99	\$27.99	Stand Link

BME Design: 200/300

	bed									
Beads	Connection method for the sleeve and stand	Tiparts	BSK8 042	Amazon	B07HT1 TCRR	11/20/2025	1	\$7.99	\$7.99	Bead Link
								TOTAL: \$71.92		

Appendix C: Preliminary Fabrication Plan - Fall 2026

1. Use waterjet to cut out a 63 cm by 63 cm cross out of the 36 in by 36 in aluminum plate with the following dimensions:

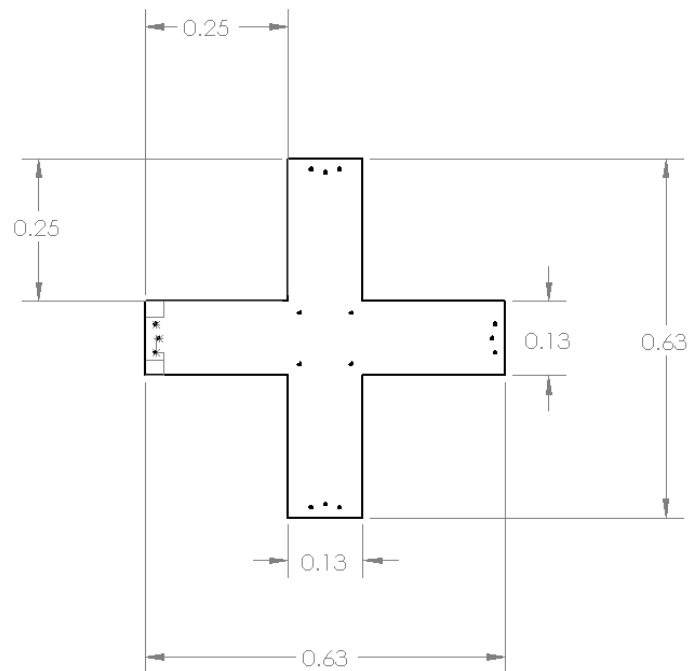


Figure 22: Drawing of Cross Base Design Part

2. Use a waterjet to cut out two .88 m by .05 m horizontal bars out of a 36 in by 36 in aluminum plate.
3. Use a waterjet to cut out four .25 m by .13 m slabs out of a 36 in by 36 in aluminum plate.
4. Use a water jet to cut out a vertical bar with the following dimensions in meters:

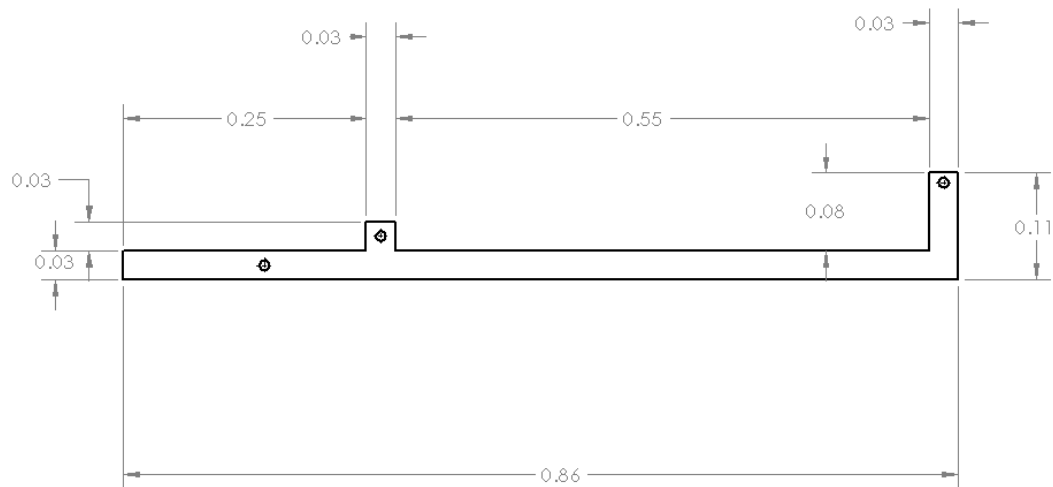


Figure 23: Vertical Bar Design Drawing

5. Use a waterjet to cut out two guide bars at the following dimensions in meters:

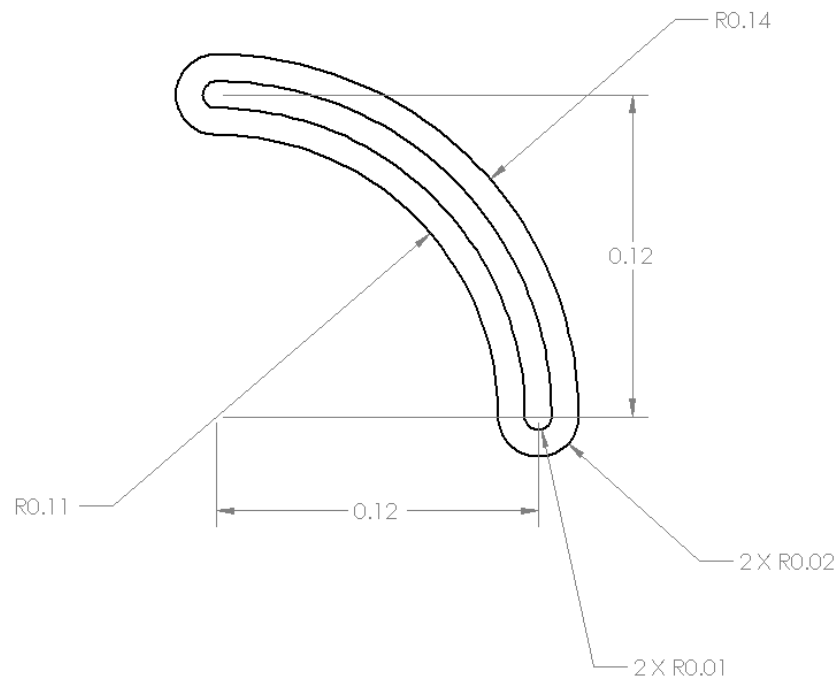


Figure 24: Guide Bar Design Drawing

6. Use a waterjet to cut out a .13 m by .13 m by 0.03 m piece out of the 12 in by 12 in aluminum plate for the elbow pad.
7. Use a mill to countersink four flat head screws in the center of the cross base to screw in a .13 m by .13 m by .8 m aluminum shaft.
8. Use a mill to countersink three holes at the end of each arm of the cross base and three holes at one end of each of the four slabs to use flat head screws to attach hinges to join the cross base and each of the slabs to create the base:

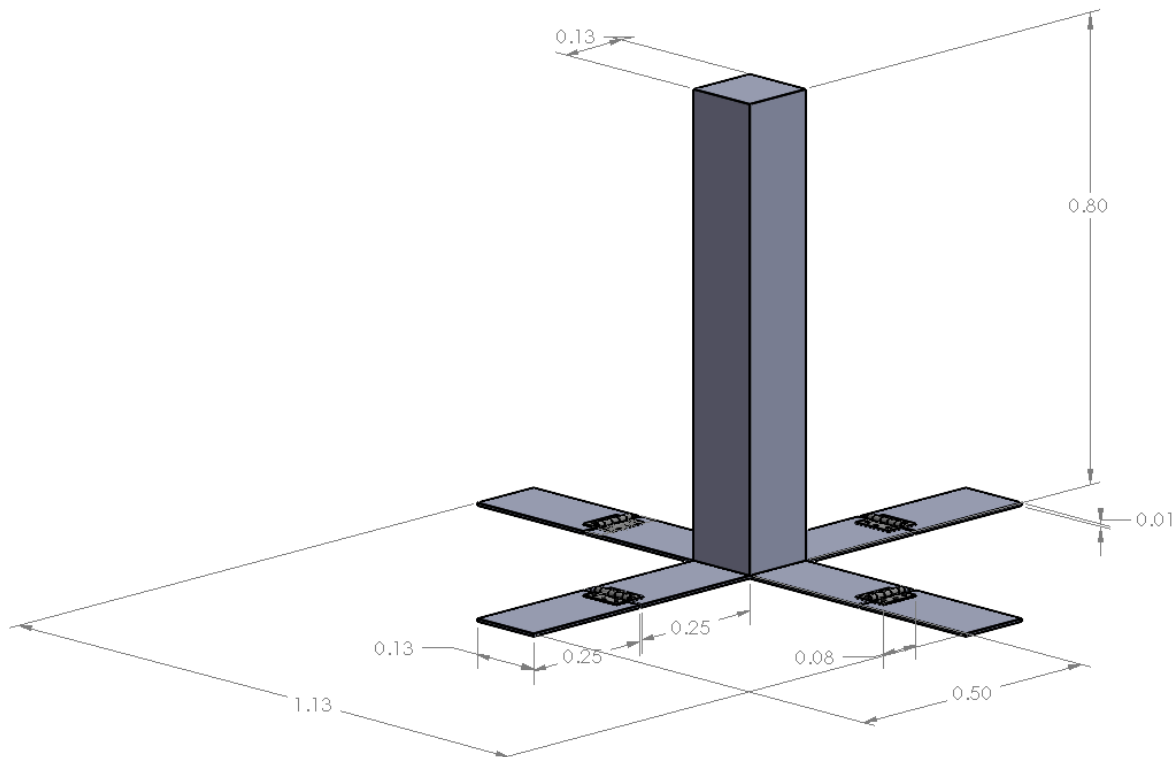


Figure 25: Base Design Drawing

9. Use a mill to countersink two holes at one end of each of the horizontal bars.
10. Line the edges of the horizontal bars to the elbow pad plate and mark where to drill holes
11. Use a Tapping Machine to tap holes into the elbow pad plate and use screws to fasten the horizontal bars to the plate.
12. Use a tapping machine to tap a hole into the square appendage of each of the vertical bars and at the bottom, straight edge of the bars.
13. Line up the bottom holes with the center of the horizontal bars to mark and tap holes there.
14. Use screws to fasten the guide bar and horizontal bars and vertical bars.
15. Drill holes into the “L” edge of the vertical bars and at the edge of the horizontal bars opposite from the elbow pad.
16. Insert the pulley pole attachments into the hole inserts.
17. Adhere a foam elbow pad onto the elbow pad plate

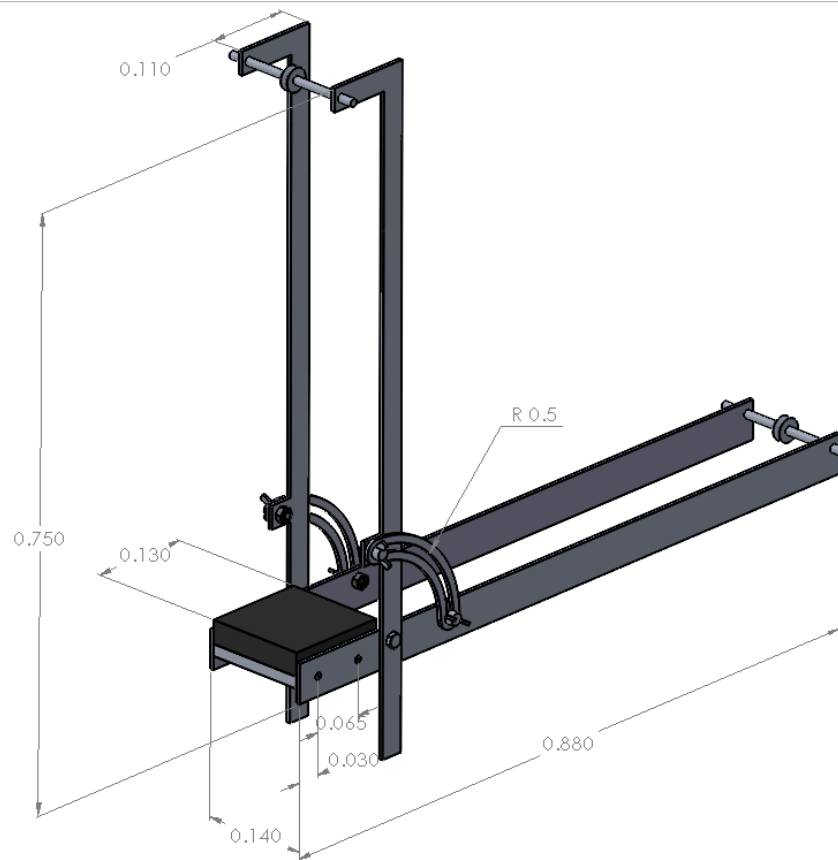


Figure 26: Traction Design Drawing

18. Tap holes into the overhanging vertical bars of the traction mechanism and vertical shaft of the base and use screws to fasten the attachments together.

Appendix D: Testing Protocol - Static Load Test

Description:

This test is designed to verify the stand's mechanical integrity with a static load test.

Calculations:

20 year old 95th percentile

- body weight: 120 kg [1]
- total arm weight: $\text{body weight} \times 0.05 = 120 \text{ kg} \times 0.05 = 6 \text{ kg}$ [2]

The total arm weight is the working load limit (WLL) for this device.

$1.25 \times \text{WLL} = 1.25 \times 6 \text{ kg} = 7.5 \text{ kg}$ (17 lb) → Use a 20 lb dumbbell

$4 \times \text{WLL} = 4 \times 6 \text{ kg} = 24 \text{ kg}$ (53 lb) → Use a 55 lb dumbbell

Materials:

- Traction device
- Carabiner
- Rope
- Dumbbells: 20, 30, 40, 50, 55 (lb)

Protocol:

1. Assemble the traction device without the finger sleeves attached to the mounting plate.
2. Hook a carabiner onto the center hole of the mounting plate.
3. Tie a rope securely onto the carabiner.
4. Tie the other end of the rope securely to a 20 lb dumbbell to test $1.25 \times \text{WLL}$.
5. Monitor the traction device for 30 minutes.
 - a. Take note of deformations, structural compromise or tipping.
 - b. A test is passed if no damage occurs.
6. If the test is passed, repeat steps 4-5 with an increase in weight until failure or until the device successfully passes all weights.
 - a. Weights to use: 30 lb, 40 lb, 50 lb, 55 lb

Date	Weight (lb)	Pass or Fail	Notes
	20		
	30		
	40		

	50		
	55		

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Appendix E: Testing Protocol - Traction Load Accuracy Test

Description:

This test is designed to verify the device's ability to accurately pull a traction load.

Materials:

- Traction device
- External scale (digital tension gauge or certified digital hanging scale)
- Wooden Board
- Hammer
- Nail
- Clamps

Protocol:

1. Assemble the traction device without the finger sleeves attached to the mounting plate.
2. Attach an external scale to the center hole of the mounting plate.
3. Take the nail and hammer it into the wooden board to act as a hook.
4. Place the wooden board on an elevated table.
 - a. Clamp the wooden board to a table so that it doesn't move when traction loads are applied.
5. Attach the other end of the external scale to nail on the wooden board.
6. Set the pulley crank system at 1 kg.
 - a. Maintain the load for 5 minutes
 - b. Test is passed if digital reading on external scale remains within $\pm 7\%$ of set load for the 5 minute duration.
7. If the test is passed, repeat step 5 with a 1 kg increase in traction load until failure or until all loads have passed.
 - a. Test traction loads from 1-20 kg in increments of 1 kg

Date	Traction Load (kg)	Pass or Fail	Notes
	1		
	2		
	3		
	4		
	5		
	6		

	7		
	8		
	9		
	10		
	11		
	12		
	13		
	14		
	15		
	16		
	17		
	18		
	19		
	20		

Appendix F: Testing Protocol - Finger Sleeve Slippage Testing Protocol

Description:

A testing protocol to determine how much the finger sleeve will slip on the average finger, so that the finger sleeves can be used for 50 minute operations without the risk of the finger sleeve losing grip of the finger.

Materials:

- Traction device
- Finger sleeves
- Caliper
- Willing participants
- Permanent marker

Protocol:

1. Assemble the traction device with one finger sleeve attached to the center hole in the mounting plate.
2. Have the participant sit in the chair and properly position their arm to use the traction device.
 - a. Make sure that the participant's arm is hanging from the stand with their shoulder and elbow at a 90 degree angle.
 - b. Make sure that the participant's arm is not resting on the chair and that the forearm is hanging perpendicular to the floor.
3. Insert one finger into the finger sleeve and use the permanent marker to mark the initial pretested point.
4. Once, the participant is in the proper position, start the stopwatch
5. Wait for the timer to reach 10 minutes, and then make a mark on the finger of the participant, after the dot is created the sleeve can be disconnected and the participant can relax their arm
6. Using the caliper, measure the distance in mm to the nearest tenth between the first mark and the second.
7. Repeat this process for each participants finger
8. After all fingers have been tested, conduct a survey that evaluates the comfort of the finger sleeve.

Appendix G: Testing Protocol - Finger Sleeve Slippage Testing Protocol

Description:

A testing protocol to determine how much tensile force the finger sleeve can withstand before damage to the finger sleeve and before total failure of the finger sleeve. Additionally, the sleeve should maintain these strength properties after being autoclaved. This is important because the finger sleeve must be reusable and be able to withstand 60 N of force without damage.

Materials:

- 5 cm x 5 cm aluminum sheet
- 3 finger sleeves
- Primus gravity autoclave
- 2 sterilization pouches
- MTS Insight - Model 5kN
- 1 kN load cell
- 100 N tensile grips
- Ruler

Protocol:

Autoclaving:

1. Place 2 finger sleeves into a sterilization pouch and put the pouch into the Primus autoclave.
 - a. The 3rd finger sleeve can immediately be tensile tested.
2. Run an hour long gravity cycle with a max temp of 251 °F (30 min sterilize, 30 min dry).
3. Pull the sterilization pouch out of the autoclave and allow it to reach room temperature.
 - a. Check if the sterilization strip on the sterilization pouch has changed colors, indicating that it has been properly sterilized.
4. Remove one finger sleeve from the sterilization pouch, this can be tensile tested.
5. Transfer the other finger sleeve into a new sterilization pouch and put the pouch into the Primus autoclave.
6. Run an hour long gravity cycle with a max temp of 251 °F (30 min sterilize, 30 min dry).
7. Pull the sterilization pouch out of the autoclave and allow it to reach room temperature.
8. Repeat steps 6-7 three more times in the same sterilization bag so that the finger sleeve has been autoclaved 5 times.
9. Conduct tensile testing on the last finger sleeve.

Tensile Testing:

1. Attach the 1 kN load cell and the 100 N tensile grips to the MTS Insight - Model 5kN system.
2. Power on the TW Elite software and the MTS machine.
3. Set the machine to tensile testing and change the test rate to 0.05 mm/s.
4. Right click on load and zero the signal.
5. Unlock the hand held machine control to be able to move the crosshead up.

6. Secure the finger sleeve prototype between the tensile grips of the system, making sure the sleeve is aligned along the axis of tension to avoid uneven loading (pictured below).
7. Set the initial grip separation to match the relaxed length of the finger sleeve (measured without tension) and record this starting length for strain calculations.
8. Zero the load again and also click the crosshead box to zero it.
9. Lock the hand held control.
10. Begin running the MTS machine until it reaches a max force of 1 kN or until the material fails.
11. Right click on the data and export the raw data to a folder.
12. Repeat this process for each ballistic nylon dog bone.
13. Turn off the machine, close the software, return all components to their original storage area, and clean the MTS machine.