Climber's Forearm Trainer

University of Wisconsin - Madison
Biomedical Engineering Design 301
April 29th, 2020

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Abstract

Medial epicondylitis, also known as "Climber's Elbow", is a type of tendonitis in the elbow that affects many climbers. This condition is caused by imbalances in the flexors and extensors along with overuse that leads to microtearing. Last semester, a device was created that could be used to strengthen the forearm muscles to prevent imbalances and aid in the rehabilitation of the condition. Specifically, the current device is able to activate the pronator teres (a common muscle used in climbing), is adaptable, and is portable. This semester, the device was improved to have a more comfortable base structure, a new strapping mechanism that is more secure and easy to use, and new resistance tubing that is smaller and easier to maneuver. A grip strengthening feature was also created and incorporated into the handle of the current device to allow for increased grip strength, which is of great importance to a climber. The design is completely 3D printed out of PLA, with the ability to later be fabricated using injection molding for a complete, final prototype. Because of unforeseen circumstances, the only testing able to be conducted was finite element analysis (FEA) testing on the SolidWorks designs of the device in order to determine if the device is able to withstand the forces created by the resistance bands. Future plans have been made to do more in person testing including EMG and MTS testing, along with a survey to evaluate if important criteria were met by the device.

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I. Introduction

a. Background

Climber's Elbow, also known as medial epicondylitis, is a condition that can affect rock climbers and have a significant recovery time of up to six months. It is part of a series of problems commonly known as tendinosis, which occurs when healthy tendons develop tears or their collagen structure deviates from the normal, straight configuration [1]. In this case, the tendon affected is one that connects a set of four flexor muscles in the forearm to the medial epicondyle of the elbow.

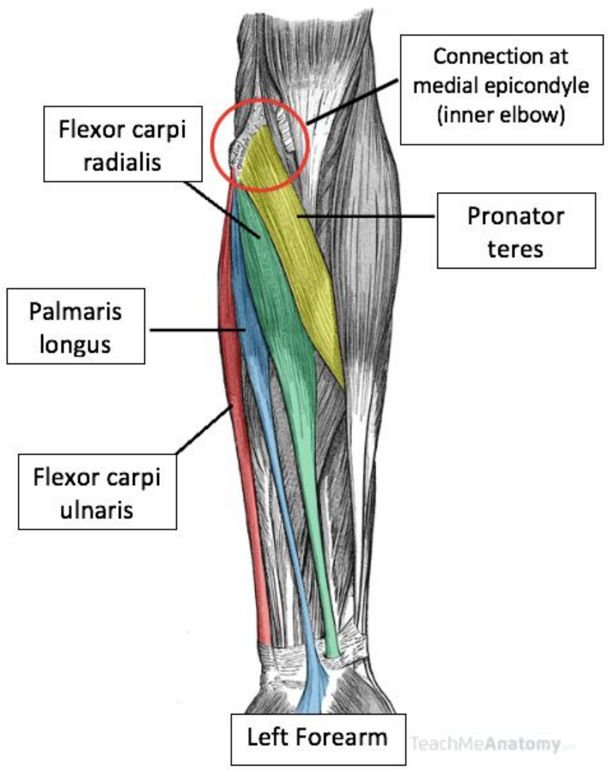

Figure 1: Depiction of the flexor muscles of the forearm and the location of the medial epicondyle [2].

When climbing, individuals often have their fingers flexed and hand pronated. The pronator teres is an important muscle for the pronation of the hand and is used extensively in rock climbing. This is opposed by the bicep which is involved in the supination of the hand. An imbalance of these can lead to excessive strain in the pronator teres and damage to the tendon [3]. An imbalance between the flexors and the extensors of the forearm can also lead to damage as well as simple overuse of the muscles without sufficient recovery time [4]. Symptoms such as chronic pain after use of the muscles are indicative of Climber's Elbow. Rehabilitation can involve stretches to aid in correcting the alignment of the damaged collagen in the tissues.

There are numerous devices on the market that try to address the need for strengthening the forearm muscles. However, no devices currently exist that incorporate resistance for flexion, extension, pronation and supination of the forearm and hand. Hangboards, as seen in Figure 2, are a common tool used by climbers to strengthen the flexor muscles. There are also devices that utilize resisted motion against a spring while flexing the fingers, such as the Vive Health Finger Exerciser in Figure 3. Other devices include resistance bands to allow for resisted motion while extending the fingers, as well as a rubber ball to allow resistance in flexion such as the Handmaster Plus shown in Figure 4.

Figure 2: Hangboard [5]

Figure 3: Vive Health Finger Exerciser [6]

Figure 4: Handmaster Plus [7]

Flexion, extension, pronation, and supination of the forearm and hand not only increase strength in the forearm muscles, but also general grip strength. It is important for climbers to use exercises that do not closely mimic the movements involved with climbing as this can exaggerate problems brought on by overuse. All of these movements need to be utilized by climbers during rehabilitation to prevent an imbalance that can continue to worsen the damage [8].

Along with the muscles of the forearm, it is also important for climbers to strengthen their grip. Oftentimes, grip muscles fatigue at a faster rate while climbing than doing a pull-up due to a smaller grip aperture, so climbers often have to focus on grip training [9]. The main muscles climbers use for grip are the digital flexors. Digital flexors lie on the palmar side of the hand and when contracted, pull the fingers towards the palm. The digital flexors can be seen in Figure 5.

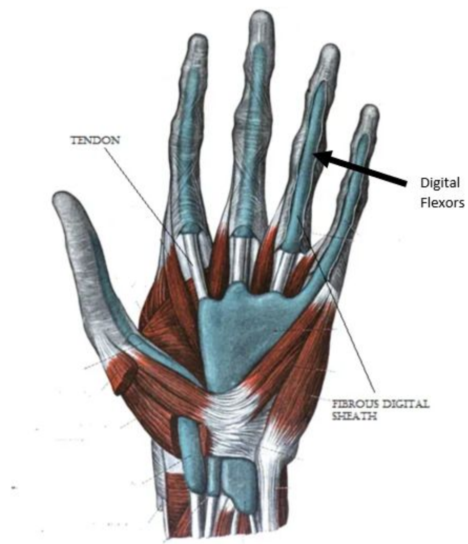

Figure 5: Digital flexors shown on the palmar side of the hand. [10]

b. Problem Statement

Many climbers may develop a condition known as Climber's Elbow in which the tendons between the pronator teres and forearm muscles to the medial epicondyle of the elbow develop microtears that accumulate over time. Currently, there are stretches available to climbers to help ease the discomfort and delay the onset of this injury. A device is needed to help build muscle strength in the forearm to help prevent this injury or at least slow its progression. The device will include adjustable resistances that will allow the user to increase the amount of force as the muscles grow. An adjustable resistance will also allow the device to be used for other athletes, not just climbers. The forearm trainer should also be able to strengthen as many of the forearm muscles as possible. The device also needs to be portable enough so that it can be used in a variety of applications. Finally, the device needs to include a component that will allow the user to improve their grip strength.

c. Design Research

Each individual has different sized forearms varying in length and in width. A device must be created that is adaptable for these different sizes. Anthropometric tables are used to determine the forearm and upper arm segment lengths based on the average lengths for the specified heights. Females, on average, are shorter than males, so the shortest height was taken from the 10th percentile of female heights, and the tallest height was taken from the 90th percentile from males yielding a range of 147.0 to 186.7 centimeters [11]. This data included subjects aged 20 to over 80 across a variety of ethnic groups. Since the shortest height is 4’ 9.9” (147.0 cm) and the tallest height is 6’ 1.5” (186.7 cm), the proposed device should incorporate these sizes and everything in between. Equations (1) and (2) show the calculation of the average lengths of the forearm and upper arm respectively.

Length for the forearm:

$$\text{Length} = 0.146H \tag{1}$$
$$\text{Max Length} = 0.146 * 186.7\ [\text{cm}] = 27.26\ [\text{cm}]$$
$$\text{Min Length} = 0.146 * 147.0\ [\text{cm}] = 21.46\ [\text{cm}]$$

Length for the upper arm:

$$\text{Length} = 0.186H \tag{2}$$
$$\text{Max Length} = 0.186 * 186.7\ [\text{cm}] = 34.73\ [\text{cm}]$$
$$\text{Min Length} = 0.186 * 147.0\ [\text{cm}] = 27.34\ [\text{cm}]$$

Knowing that the ranges of the forearm are roughly between 21.46 cm and 27.26 cm and that the upper arm is between 27.34 cm and 34.73 cm, an effective device was designed to fit a variety of users without causing any pain or discomfort.

The device is intended for climbers with, or those prone to developing, Climber’s Elbow. Grip is an important factor in climbing, and therefore is critical to incorporate into a design. An isometric grip, or static grip, is ideal for rehabilitation purposes because the muscles become less fatigued and is also idealfor those who may have limited motion [12]. The results of isometric training cause superior strength at specified angles and therefore, it may be beneficial to incorporate different grip sizes to strengthen muscles at varying angles. This means that specific positions and muscles can be targeted more effectively because isometric training increases strength in the specific training stance [13].

Unstable surfaces, such as free weights, are beneficial for muscle balance, but ideally the Climber's Forearm Trainer will want to target specific muscles. Unstable surfaces have also been known to cause greater muscle instability and could potentially place stress on the neuromuscular system [14]. Since the device will focus on specific muscles, and the device has the potential to be used for rehabilitation purposes, a stable surface is desired.

To limit bicep activation to focus on the forearm muscles, it is ideal that the muscles' sarcomeres are stretched outside of the optimal zone. This can be done by either lengthening or shortening the muscle. Shown in Figure 6, the bicep can generate the largest moment arm and therefore a larger force at a 90 degree angle. To ensure user comfort as well as limit bicep activation, 120 degrees would be an ideal angle for the design.

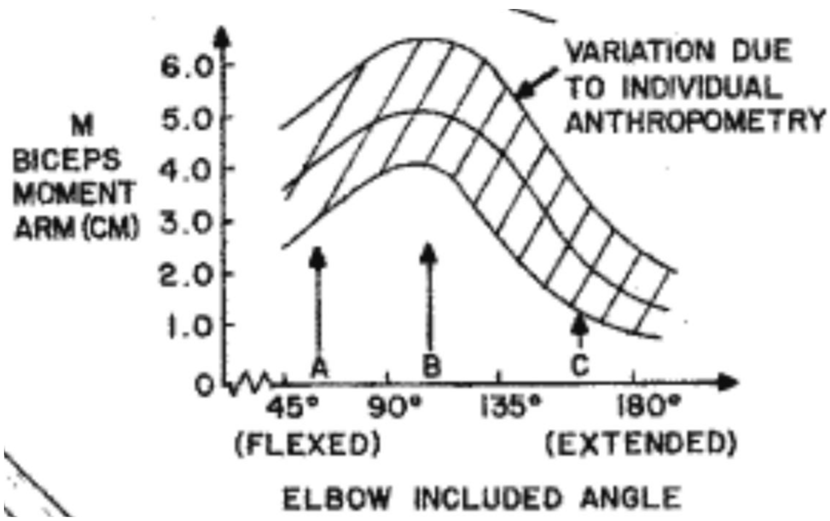

Figure 6: Graph of bicep moment arms along different elbow flexion angles. [15]

The device is to be able to withstand the force that can be exerted by the forearm muscles. Forearm muscles in experienced rock climber's have been found to produce forces up to 30 kg (294 N) during a maximum voluntary contraction (MVC) [16]. Most strength training is completed at 40% MVC for the desired number of reps, therefore, rock climbers training is done at a maximum of about 12 kg (118 N). It is important to understand the forces that the device will need to be able to withstand.

d. Design Specifications

This device has several important components that need to be included. Of particular importance is that it needs to target the pronator teres muscle in the forearm and include a component to increase grip strength. It must accommodate different sized forearms by incorporating forearm lengths of 22 to 27 cm and upper arm lengths of 27 to 35 cm. As different individuals will use the device, the same angle of the back piece will not be comfortable for all users. An angle of 120 degrees should be implemented with the ability to flex a small amount. This ensures comfort for the majority of users and limits bicep activation by moving the bicep out of its optimal range.The entire device needs to be portable and not rely on a table or surface of any kind. Finally, it must meet standards according to the ASTM Standards for Fitness [17]. See Appendix A for the complete list of specifications.

e. Client Information

Dr. Chris Vandivort is an Emergency Physician at UW-Health. In his free time, he enjoys climbing and has previously developed Climber's Elbow. This led him to be in need of a device to help rehabilitate and prevent Climber's Elbow.

II. Preliminary Designs

a. Base Designs

i. The Original Design

The original design was created during the Fall of 2019 and is shown in Figure 7. The design consists of a 3D printed L-piece that supports the forearm and the upper arm. The L-piece has velcro straps to secure the forearm and the upper arm to the device to prevent flexion at the elbow and to limit bicep activation. Limiting bicep activation allows the device to focus on the forearm muscles. Along the back of the L-piece are three downward facing hooks that allow for the resistance band to increase tension and therefore increase the amount of force experienced by the user. The upward facing hooks towards the top allow for the resistance bands to loop back up and provide the necessary angle for extension of the wrist. A wide, hollow handle is used to allow the resistance band to slide through the handle, and memory foam padding was placed along the L-piece to provide comfort for the user. While the design was effective in activating the forearm muscles, the design had several areas that could be upgraded involving its usability. One problem with the original design is that it did not prevent lateral movement while the user was performing exercises, and the 90 degree angle was found to be uncomfortable. Also, the rectangular resistance bands were too bulky for the design and made it difficult to loop through the hooks. The original design was also lacking a component to strengthen muscles incorporated with grip.

Figure 7: Pictures of three different angles of the original design. Image A is an isometric view of the design. Image B shows the handle. Image C depicts the back of the design, showing the adjustable resistance hooks.

ii. The Hinge Design

The Hinge Design was considered for the base of the forearm trainer. The Hinge Design was developed in order to allow for the change in angle deformation between the upper and lower parts of the arm and is shown in Figure 8. The ability to change the angle of the arm will be beneficial for the user of the forearm trainer when performing the strengthening exercises. As can be seen in Figure 8, a hinge mechanism is used to allow for the ability to change the angle of the arm between 60 and 180 degrees with the ability to lock into place. The hinge portion consists of two pieces attached to the posterior side of the upper and lower arm, with a circular plate to connect the two. The circular plate will have multiple holes drilled into it that will provide the ability for the arm to be secured at different angles by twisting a screw into the hole to provide the desired angle. The upper portion of the arm will be locked in place and will not be able to be changed. The lower portion of the arm will be secured using a screw that can be twisted into the desired notch. The design also includes side supports on the upper and lower arm portions to provide additional rigidity to the arm by preventing any arm movement from side to side.

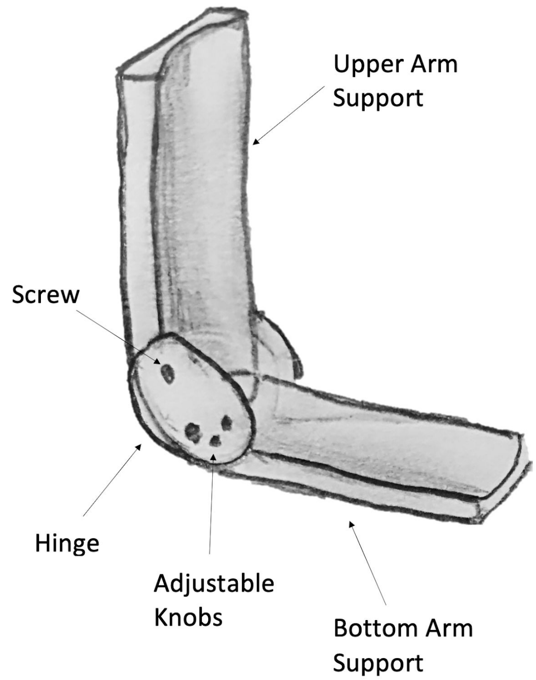

Figure 8: An image of "The Hinge Design" considered for the forearm trainer.

iii. The Straps Design

The Straps Design's most profound feature is the base arm support. The base is an L-shaped piece that similarly replicates the structure of the Original Design. The connected upper and bottom arm support gives a more rigid and stable design. Additionally, an added modification to this design is the arched walls that allow for more support on both sides of the lower arm. This added support will reduce undesired movement of the lower arm. It will eliminate horizontal movement of the lower arm support when performing the strengthening exercise. This design will be lined with a memory foam interior to allow for increased adaptability between users. As memory foam is extremely flexible, the interior will conform to the user's arm based on its size, weight, and structure. Also, the straps play an important role in this design, hence the name. They would similarly replicate the straps on roller blades. The strap allows for a slight 10 degree adjustment of the support. The rigidity of the plastic straps reduces potential of the straps to give during the exercises and allows for an intuitive way of tightening the straps. Different straps, likely covered with the memory foam will be used to keep the person's upper and lower arm in place. A sketch of the design can be seen in Figure 9.

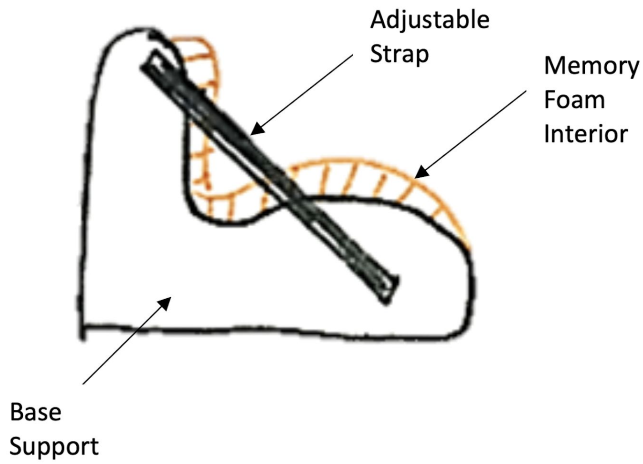

Figure 9: A sketch of the “Straps Design” for strengthening the forearm.

b. Grip Designs

i. The Pinch Grip Design

The Pinch grip design incorporates ideas similar to that of a hangboard. Handboards utilize only the tips of the fingers and thumb to strengthen both forearm flexors and digital flexors. A pinch grip hold is ideal for climbers, as it would resemble that of a hold on a climbing wall. The smaller grip aperture was included in this design because it is known that a larger grip aperture has a larger breakaway force (force required before an object is pulled from the grasp), so therefore, it is important to increase a climber’s breakaway force at a smaller aperture [18]. The design is made of a rectangular thin plastic that is durable enough to withstand the force exerted on the sides of the handle by the resistance bands. The loops on either end of the handle allow for the resistance bands to attach via carabiner clips. The carabiner clips allow for resistance force to increase as the forearm strengthens by simply changing the resistance band. A sketch of the pinch grip design can be seen in figure 10.

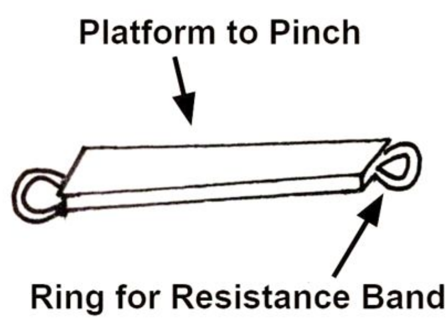

Figure 10: “The Pinch Grip Design” sketch for grip strengthening.

ii. The Stress Ball Design

The stress ball design utilizes a stress ball to ensure the user works the entire range of motion of their fingers. Using a handle similar to the one on the original design, a hole would be cut into the side of it to partially fit the ball. Shown in Figure 11, the Stress Ball Design will include small canals for the user's fingers to rest in. This provides the user the ability to work individual fingers at a time as well. The handle also consists of rings on each end in order to create a more adaptable handle. This gives the user the ability to switch out different handles if he/she would like to work more specific muscle groups.

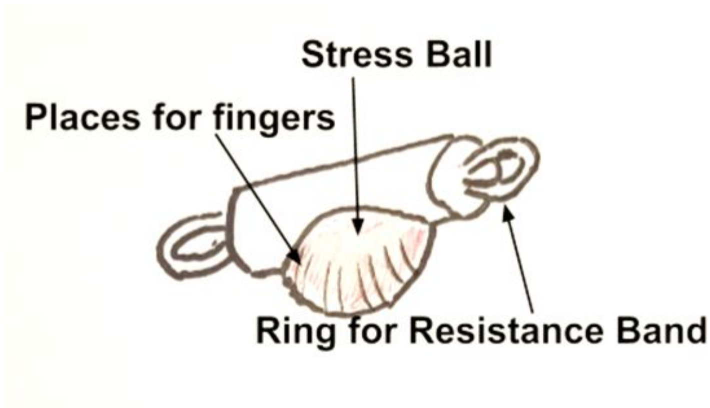

Figure 11: A sketch of the Stress Ball Design being considered as one of the grip designs

iii. The Gripper Design

The Gripper Design is based off of a model of a hand grip strengthener. This is a common item used by people in gyms and most likely will be familiar to the user. Figure 12 shows a rough sketch of the idea. The user will be able to squeeze the both handles to work hand grip strength as well as forearm strength. If only forearm training were desired, the user could simply grab one of the handles instead of squeezing both. Rings are added to the ends of the gripper in order to make the design compatible and interchangeable.

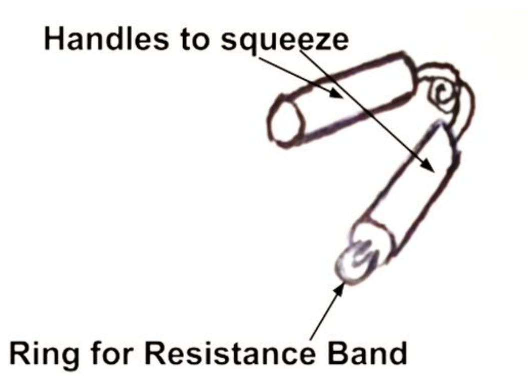

Figure 12: A sketch of the Gripper Design that is being evaluated as a grip design option.

III. Preliminary Design Evaluation

a. Base Design Matrix

Table 1: Base Design Matrix. Each of the three designs are scored 1-5 on the six criteria in the left-most column and then weighed based on the priority in parentheses. Red highlight signifies the highest scoring category.

Criteria	Design 1 "The Original"		Design 2 "Hinge"		Design 3 "Straps"	
Ease of Use (25)	3/5	15	4/5	20	5/5	25
Comfort (25)	3/5	15	5/5	25	4/5	20
Adaptability (20)	5/5	20	5/5	20	4/5	16
Ease of Fabrication (15)	5/5	15	2/5	6	4/5	12
Safety (10)	5/5	10	5/5	10	5/5	10
Cost (5)	5/5	5	4/5	4	5/5	5
Total (100)	80		85		88	

Justification of Criteria

Ease of Use: The design needs to be easily understood by the user with minimal instructions. This will simplify the time it takes to put on and take off the design. This category has the highest weight at 25%, as it is important for the device to be easily understood to ensure quality use. The Straps Design ranks highest in this category because it incorporates the roller blade straps that are commonly used by many people.

Comfort: The design needs to be comfortable. This will allow the user to properly perform their exercise with minimal discomfort. This category was tied for the highest weight at 25%. The Hinge Design was determined as being the most comfortable due to the separated upper and lower arm support. This allows for a greater range of motion and less confinement of the arm.

Adaptability: Two components were assessed for the adaptability category. Both the adjustable angle and the ability to adapt to a variety of arms. This category had a high weighting at 20%. The Original Design adapts to a wide range of varying arm sizes. This is because it does not have the forearm walls to confine a person's arm to one space. The Hinge Design has a very adaptable angle between 60 to 180 degrees. For these two different reasons of adaptability, these two designs tied.

Ease of Fabrication: This category determined how easy or difficult it would be to make the base support. The category was weighted at 15%. The Original Design is easiest to fabricate due to a lower complexity and less features, including no forearm wall.

Safety: The design needs to be safe for all users, reducing the overall risk of injury. This category was weighted at 10%. All three designs tied in this category.

Cost: The cost of the product is the summation of each individual component that will be incorporated in the design. This category was weighted at 5%. The Original Design and Straps Design tied in this category. They don't have components like the hinge or adjustable knobs that the Hinge Design has, making them comparatively cheaper.

b. Grip Design Matrix

Table 2: Grip Design Matrix. Each of the three designs are scored 1-5 on the six criteria in the left-most column and then weighed based on the priority in parentheses. Red highlight signifies the highest scoring category.

Criteria	Design 1 "Pinch Grip"		Design 2 "Stress Ball"		Design 3 "Gripper"	
Ease of Use (25)	5/5	25	4/5	20	5/5	25
Effectiveness (20)	4/5	16	2/5	8	3/5	12
Ease of Fabrication (20)	5/5	20	3/5	12	5/5	20
Compatibility (15)	4/5	12	3/5	9	4/5	12
Safety (15)	5/5	15	5/5	15	4/5	12
Cost (5)	5/5	5	4/5	4	3/5	3
Total (100)	93		68		74	

Justification of Criteria

Ease of Use: The ease of use of the design is determined based on the steps taken by the user to properly understand and utilize the grip strengthening aspect. Both the Pinch Grip and Gripper designs were given full points in this category because they both have simple mechanisms that will be intuitive for the person using the product. This criteria was also given the highest weight (25%) due to the fact that it is most important for the chosen design to be easy to use by anyone.

Effectiveness: The effectiveness of the product is determined by how well the device strengthens the finger flexor muscles, as well as its ability to alter the levels of resistance. The effectiveness was also weighted as one of the most important criteria because the main purpose of the design is to strengthen the grip and increase maximum force that the finger muscles can endure. The Pinch Grip was given the highest score in this category due to the fact that it is the only design that allows for the user to change the level of resistance being applied to the grip. The ability for different levels of resistance applied to the grip strengthening portion of the product is what ultimately led to the Pinch Grip being the winning final design.

Ease of Fabrication: The ease of fabrication of the design is based on the expected ability for the team to be able to produce the chosen design in the lab. This criteria was also given a high weight because it should be a main focus of the team to choose a design that can be fabricated the most effectively while still meeting the needs of the client. The ability to create a device that provides the necessary stretching and strengthening abilities that the team desires is of great importance. The Pinch Grip and Gripper designs were given full points because of their simple make-up that will allow the team to be able to manufacture in the lab and incorporate in the existing handle without having to fabricate a new handle. The third design would require machining into the existing handle in order to implement the stress ball element, and would ultimately lead to more difficulty in fabrication.

Compatibility: The compatibility of the product is determined based on how well each grip design will be able to be incorporated and work cohesively with the rest of the forearm trainer. It is important that the design chosen be able to work with the rest of the components of the arm trainer to create the most effective and complete product. No design was given full points due to the fact that all three designs will require slight readjusting of the other components of the arm trainer. However, the Pinch Grip and Gripper were given four out of the five points because they will both be able to easily be implemented into the handle while not affecting the functionality of the rest of the product.

Safety: The safety of the product is also important to consider when dealing with a product that involves human use. In the case of the arm trainer, it is also important to consider safety because the purpose of the device is to help with rehabilitation and strengthening muscles in the forearm in order to avoid later injury. A design that follows these needs must be chosen rather than one that opposes them and could lead to further injury. While all the designs were deemed to be safe for the use in the forearm trainer, it was decided that the Gripper did not get full points because of the possibility of pinching the hand when in use.

Cost: The cost of the product is determined by the price of each of the components that will be included in the design, plus the cost of fabrication. It was determined that cost was not of great importance to the team, as all of the designs will be relatively inexpensive to fabricate. However, the Pinch Grip was determined to be the most ideal in the cost category, because it is the most simple design of a single piece of material. The other two designs would require the team to purchase materials of either a stress ball or a wounded spring mechanism for the Gripper.

c. Proposed Final Design

The proposed final design is the combination of the Straps Design and the Pinch Grip. Both of these design ideas won in their respective design matrices and best accomplish the client's requirements. The Straps Design uses a familiar strapping method, making it easily understandable. It can also accommodate various forearm sizes due to the use of its memory foam interior. This memory foam interior also ensures comfort for the user. The Pinch Grip Design is also very intuitive and can be understood with minimal instructions. Additionally, the Pinch Grip is very effective as it not only increases overall grip strength, but also is an added exercise for the forearm. The resistance can also be easily adjusted. As the resistance in the band changes, it mutually affects the overall forearm and finger strength difficulty. The incorporation of both designs into one, simplifies the process for the user increasing the overall ideality of the design. SolidWorks models of the design can be seen in Figure 13 and 14.

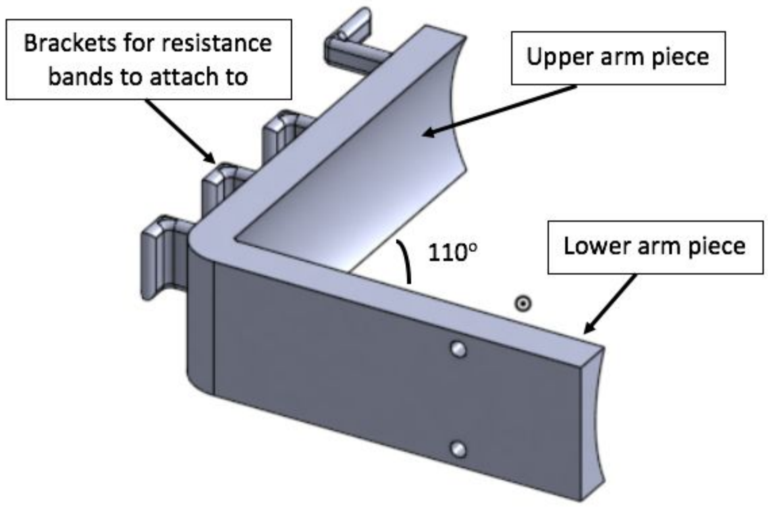

Figure 13: Proposed L-shape base design

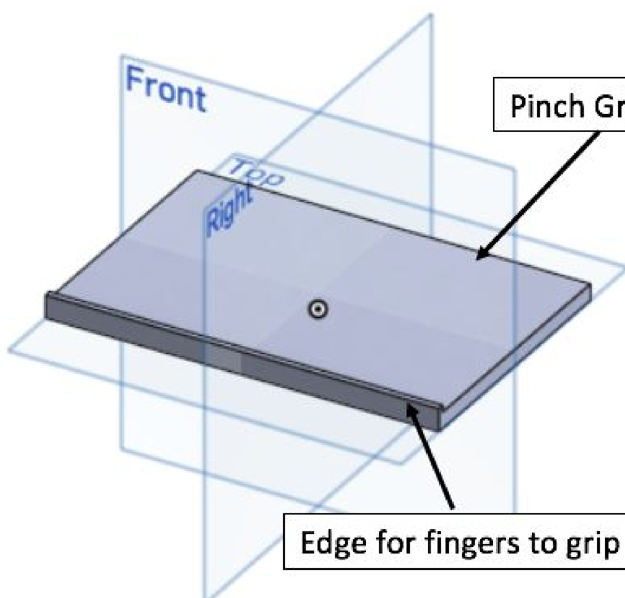

Figure 14: Proposed pinch grip addition to handle of the final design.

IV. Fabrication

a. Materials

The foundation of the entire forearm trainer design would comprise a 3D printed polylactic acid (PLA) base L-piece shape. It is positioned at a 120 degree angle. It is also where a person's arm would reside during the duration of the exercise. Both the handle and pinch grip are also made of PLA. The handle is where the palm of the hand would be placed. The pinch grip is what the person's fingers would grasp. This addition would be used to increase grip strength. PLA was the chosen material for these three components due to its high density, durability, availability, and low cost. The PLA would be sprayed with flex seal for a more sleek, finished look. It also provides the added benefit of covering surface roughness. The base would be lined with body molded foam padding. The padding conforms to the person's arm and provides added comfort. Rollerblade straps would be used to secure a person's arm in place. It is an intuitive way for the user to easily tighten the straps on their own. Resistance bands would also be used. The resistance bands vary in strength. This provides variability in the difficulty of the exercise. They can easily be switched with one another on the arm piece design. Resistance bands would be attached from the back of the L-piece to the handle. Nylon webbing would be attached to the ends of resistance bands. The carabiners would then be attached to the nylon webbing and clipped to the hook eye screws in the design. The brass knurled inserts are needed to screw the hook eye screws into the plastic. This ensures the 3D printed PLA material is not damaged. The hook eye screws would be screwed on the circular ends of the handle. See appendix C for material expenses.

b. Fabrication Process

The current plan for fabrication will begin with SolidWorks models of both the base design and pinch grip design. The SolidWorks models will then be used for 3D printing that will be printed using PLA. Flex spray will then be applied to all PLA components. Rollerblade straps will be added to the base design using the threaded inserts and corresponding screws. One will be inserted in a position to secure the upper arm, and another would be inserted to secure the lower arm in place. Body molded padding would also be added in the L-piece with an adhesive glue. The sides of the handles will contain small holes where brass knurled inserts will be inserted by using a soldering gun to heat the insert. The heated insert will then be pressed into the plastic. Hook eye screws will be screwed into the inserts. The resistance bands will be looped around the hooks on the back of the base design, and the carabiner clips will be attached to the handle. The resistance bands will be tied within a nylon webbing. The nylon webbing would then be used to be attached to the carabiners which are then attached to the handle.

c. Final Prototype

The proposed final designs above were slightly altered to better accommodate the usability of the device, and the following SolidWorks models were created. The angle at the elbow was increased to 120 degrees to move the elbow out of the range of greatest bicep activation. The pinch grip portion was also rounded at the end to fit more comfortably in the palm of the user's hand. The SolidWorks of the final design are pictured in Figures 15 and 16, and a modified design is pictured from two different angles below in Figures 17 and 18. Because of unforeseen circumstances, the only alteration to the design that was able to physically be made was the less bulky resistance bands, and the connection using hook eye screws and carabiner clips to handle. Rollerblade straps for securing the upper and lower portions of the arm into place will replace the current black straps seen below. The new SolidWorks designs for the L-shape base and pinch grip handle will be printed and replace the existing base and handle pieces as well.

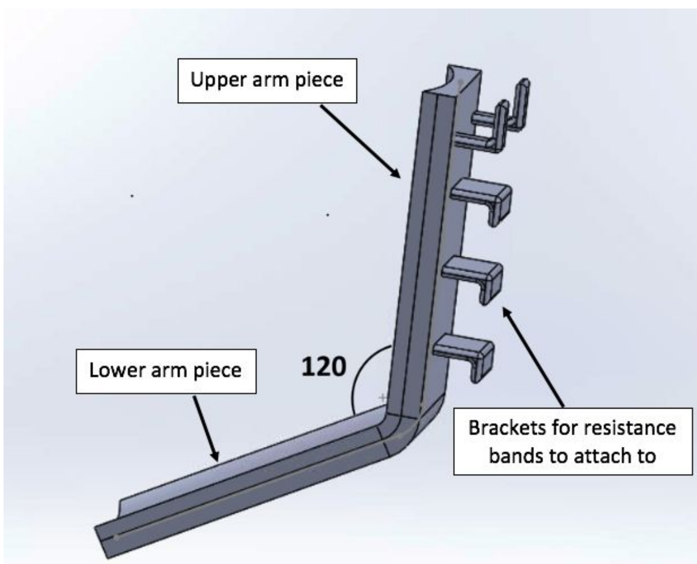

Figure 15: SolidWorks of the L shape base with revised angle of the final design.

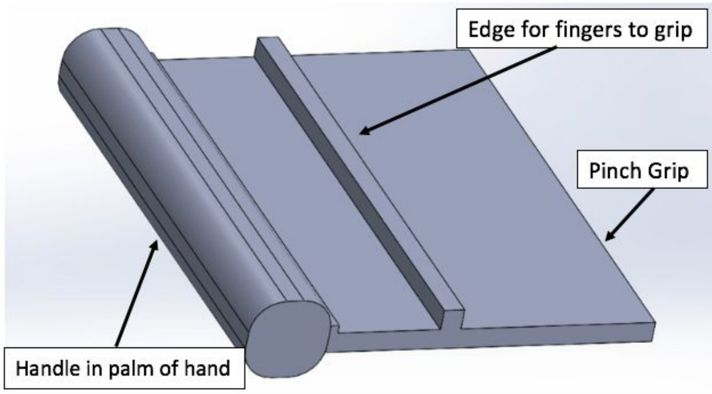

Figure 16: SolidWorks of the revised pinch grip handle piece of the final design.

Figure 17: Lateral view of the original prototype with updated resistance bands.

Figure 18: Posterior view of the original prototype with updated resistance bands.

V. Testing, Results, and Analysis

Initial testing was meant to cover multiple aspects of the device to determine the overall efficacy based on the criteria established in the PDS. However, the testing does not address all categories of the PDS due to surrounding circumstances, limitations in testing capabilities, and a lack of a fully functioning prototype.

a. Finite Element Analysis (FEA)

This test will be used to evaluate the ability of the prototype to withstand the maximum force stated in the PDS. Finite element analysis will be completed on both the base design and handle design in SolidWorks. To get the most accurate simulation, the most fine mesh settings will be used. SolidWorks does not have PLA as an applied material, so ABS will be used. ABS is similar to PLA and also a widely used 3D printing material. As stated earlier in the research section, most experienced climbers can produce about 294 N (30 kg) via their forearms. During strength training, approximately 40% of the force is used which is approximately 118 N (12 kg) [16]. To be safe, the model will be tested under 30 lbs (134 N). For the base design, the model will be fixed at the bottom to replicate someone using the device. The 30 lb force will act on the top edge of the design where the bands are connected. The handle design will also be put under a 30 lb force, but only 15 lbs at each connecting point. The fixtures on the handle model will be placed on the bottom and top of the design to replicate the user pinching the handle. A step by step procedure can be found in the Appendix E. After the FEA, the strain plot and maximum deformations for each model, shown in Figure 19, will be analyzed. The maximum deflections were calculated by SolidWorks and came out to be 2.33 µm and 18.8 mm for the handle and base designs respectively.

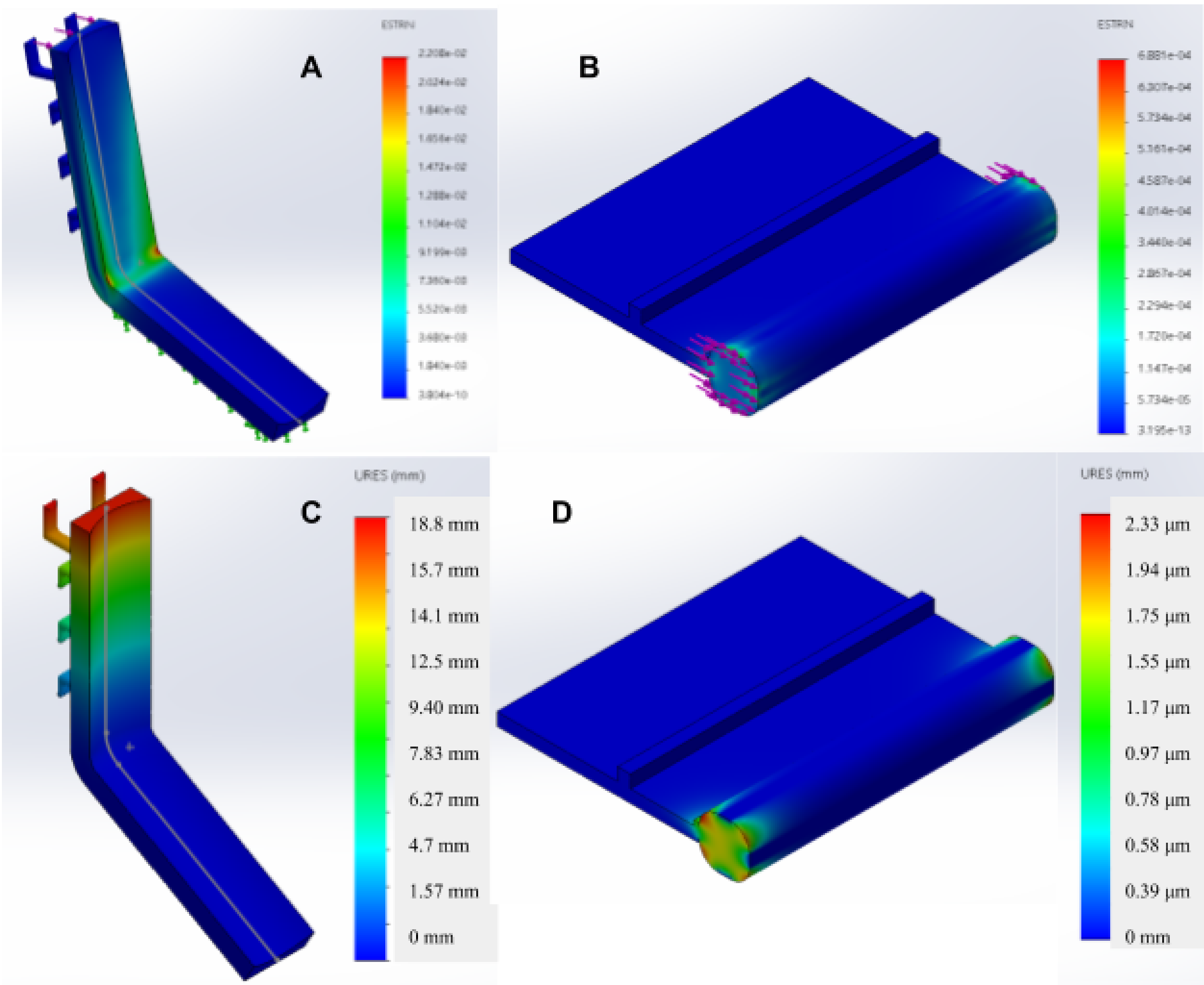

Figure 19: Strain plots of the base (A) and handle (B) designs. Any red on the model represents a larger strain and any blue represents a much smaller strain. Images C and D show the deformation plots for the base and handle designs respectively.

Of the two finite element analysis tests run, the base design saw a much larger deformation of 18.8 mm. Although the base design was modeled to flex at the elbow to ensure comfort for multiple users, this was much larger than what was expected. However, due to the rigidity of the users upper arm, the device will likely not flex nearly as much as simulated. In order to run the FEA, assumptions were made to estimate where the forces would be acting, and the magnitude of the force. It is also very likely that not all of the 30 lbs would be acting on just the edge of the upper part of the base design. This would also decrease the amount of strain and deflection. Lastly, 30 lbs left a large room for error as the majority of climbers only use about 40% of their MVC when strength training [16]. Therefore, the conclusion of the test is that the base design can withstand multiple uses under the load of varying resistance bands.

The handle design was simulated to have a max deformation of 2.33 µm. This value was closer to what we expected. The handle design is not made to flex or deform and a very small max deformation confirms that. The handle design is also able to withstand multiple uses under the load of varying resistance bands.

As mentioned earlier, unforeseen circumstances did not allow for other tests to be completed. To complete the FEA, assumptions were made on force placement and fixtures, as well as the magnitude of the force. All three of these assumptions could have led to a variability in the results. Additionally, PLA was not an available testing material within SolidWorks. With that being said, FEA is a simulation that is supposed to give a rough estimation as to how a model will act under specific circumstances, which is exactly what it did.

b. Free Body Diagrams

To determine the amount of force required for the muscle to overcome the force of the resistance bands, free body diagrams (FBD) were used to model the forces. The FBDs can be seen in Figures 20 and 21.

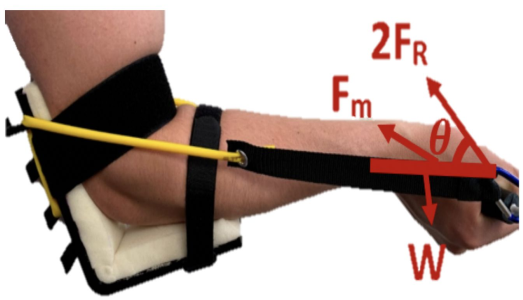

Figure 20: Free body diagram showing the force directions for flexion and extension of the wrist.

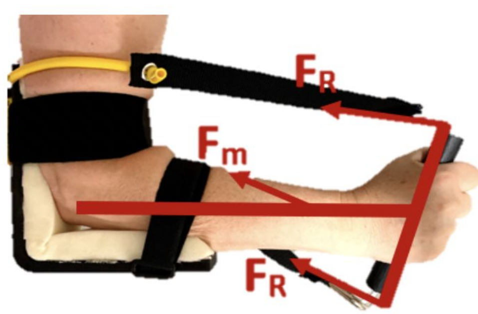

Figure 21: Free body diagram showing force directions for pronation and supination.

To determine the force of the muscles for flexion and extension, the sum of the moments about the wrist's axis of rotation. The equation for the force of the flexors and extensors can be found in Equation (3), where F_R represents the force of the resistance band, F_m represents the force of the muscle, and MA represents the moment arm. The moment arm is the distance to the joint axis perpendicular to the muscle's line of action.. For the force of the supinator and pronator of the forearm, the moment was taken about the axis along the forearm. The moment for pronation and supination was taken about the elbow rather than the wrist because the insertion point of the pronators and supinators is along the radius rather than at the hand. The corresponding equation for pronator and supinator muscles can be found using Equation (4).

$$F_m = \frac{L * 2F_R \sin\theta - W * d_w}{MA} \tag{3}$$

$$F_m = \frac{2F_R \sin\theta}{MA} \tag{4}$$

VI. Conclusion

a. Overview

Medial epicondylitis, more commonly known as Climber's Elbow, affects many rock climbers. This condition can be caused by muscular imbalances in the flexor and extensor muscles that can turn into microtears and elbow pain. The client has asked for a design that will work both flexor and extensor forearm muscles, as well as resisting pronation and supination of the wrist to either slow or stop the development of Climber's Elbow. Currently, there are no devices found on the market that hit all of these requirements. A previous design team came up with an idea that successfully targets the desired muscles, but it could use some improvement in terms of comfort and handle designs.

This semester's team redesigned the base structure to have a 120 degrees bend elbow and has added curved walls on either side to cradle the user's arm. The interior will be lined with body molded foam padding to increase the comfort of the user as well as accommodate multiple forearm sizes. The second improvement to the original design was an added grip strengthening device on the handle. The handle will have a thin, rectangular piece of plastic that forces the user to grip with his/her fingers and thumb. It also has loops on each end for the resistance bands. The bands will be cylindrical and also have the capability of connecting to a carabiner clip. This not only makes it compatible with the base design, but also interchangeable. In order to verify the stability and safety of the device, FEA analysis was used to find the deformation and strain when the maximum exertion by the user was conducted.

b. Future Work

To ensure that the device continues to accurately activate the forearm muscles, electromyography will be performed. Testing will be completed by placing electrodes on the flexors and extensors of the forearm and plotting the signals on a time based graph. The amplitude of the flexor's signal should spike during pronation and flexion of the wrist, while the amplitude of the extensor signal should increase during supination and extension of the wrist. If other signals were monitored during a specific motion, this could indicate that the device does not activate the correct muscles. A third electrode will be placed on the digital flexors to test for the muscles associated with grip. Since the handle design is intended for continuous flexion, it would be expected that this signal will be activated throughout the testing process. To test the limitation of bicep activation, an electrode will be placed on the bicep. Activation of the bicep should be limited as the device should focus on muscles of the forearm.

Mechanical testing of the resistance bands will be conducted to determine how force varies with elongation of the bands. Tension testing will ensure that by lengthening the band, an increase in tension will occur meaning that there would be an increase in force exerted and felt by the user. Mechanical testing will also ensure that there is a noticable difference from one resistance band to the next (light, medium, heavy). Testing will be performed using the MTS Sinetech Machine with new resistance bands so that no pre-stretch skews the results [19]. Each resistance band will be cut to the same length to have similar slimness ratios to minimize the effects of change in dimensions due to elongations [20].The Slimness Ratio can be seen in Equation (5) where "L_g" is the gauge length and "A" is the area.

$$Slimness\ Ratio\ =\ \frac{L_g}{\sqrt{A}} \tag{5}$$

The test will be conducted until the failure of the band. The break will be examined to determine if a sliver appears. A sliver generally indicates a stress concentration and will alter the values of the results.

After all tests and changes have been conducted on the 3D printed SolidWorks designs, injection molding can be used for the final product. This will provide one complete piece with softer edges and a more finished look. This can be done by outsourcing the design to a company like Protolabs. The SolidWorks designs can be uploaded on their software to be determined if it is capable of being molded or if some aspects need to be altered first. The company will then provide a quote for the mold, which they will then create and fabricate for you.

A survey will also be conducted using a variety of individuals. Ideally, it would include climbers at one of the local gyms to obtain their feedback on fit, ease of use, and whether they feel the exercise in the targeted areas. The survey will consist of fifteen statements in which the user will reply if they agree, disagree, or are unsure. The results of the survey will provide differential statistics which can be used to make inferences for the rest of the population. Reference Appendix E for the full testing protocols.

Other than testing, it would also be beneficial to focus on changing the tightening mechanism of the resistance bands. Currently the device uses a series of hooks on the back to increase the length of the band, but that feature only allows for three intermediate forces, is not intuitive, and is bulky. Using a tension buckle, similar to those on a backpack, could be added to the nylon strapping to increase the resistance band length and simplify the design.

Another way to improve the usability of the device would be to design a removable cover that would serve to protect the device and allow for easy cleaning. The foam padding would likely become soiled with sweat and could deteriorate with any friction. Neoprene would be a possible choice of material because of its current use in joint braces and its ability to protect the foam from sweat. This cover could be made to grip over the ends of the device and be secured at the bend in the L-piece through two velcro straps — one above and one below the curve. As neoprene is slightly elastic, this would allow it to secure tightly to the device, but not enough to slide around with movement. It would also provide an additional layer of padding beyond the foam padding.

Modifying the handle design to become more adaptable could also be beneficial. This could include ideas such as involving a rail that would allow the flat part of the handle design to be removed if the user prefers to focus on the forearm muscles separately. It could also include modified handles with different gripping angles to isometrically train muscles at specific positions, as rock holds on a climbing wall are inconsistent. By modifying these aspects of the design, it would allow for the device to become more commercializable.

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VIII. Appendix

Appendix A: Product Design Specifications

Climber's Forearm Trainer

Product Design Specifications
Client: Dr. Chris Vandivort
Team: Brittany Glaeser, Kaitlin Lacy, Zoe Schmanski, Marissa Harkness, Jonathon Murphy
2/11/2020
Last updated 4/25/2020

Function:

Many climbers may develop a condition known as "Climber's Elbow" in which the tendons between the pronator teres and forearm muscles to the medial epicondyle of the elbow develop microtears that accumulate over time. Currently, there are stretches available to climbers to help ease the discomfort and delay the onset of this injury. A device is needed to help build muscle strength in the forearm to help prevent this injury or at least slow its progression. The device will include adjustable resistances that will allow the user to increase the amount of force as the muscles grow. An adjustable resistance will also allow the device to be used for other athletes; not just climbers. The forearm trainer should also be able to strengthen as many of the forearm muscles as possible. The device also needs to be portable enough so that it can be used in a variety of applications.

Client Requirements:

- The device must not cause the client any discomfort as it could affect the amount of force they are willing to exert; therefore, negating the purpose of the device.
- The device should include a component that allows the user to vary the resistance.
- The device should act on the four major groups of forearm muscles (flexor capri radialis, pronator teres, palmaris longus, flexor capri ulnaris).
- The end position should end in an eccentric stretch of the wrist, this will allow the device to not only strengthen but stretch the muslces, preventing muscle strain.

- The setup of the device should be simple enough so that the user will not require any additional help.
- The cost should be kept as minimal as possible without affecting the quality of the design, with small grip strengtheners costing about five dollars and hangboards ranging in price from $80 to $450. This would allow for a larger profit margin if the device would be used for commercial sale.
- The device should be able to be used freestanding, without any other supporting structures such as a table.

Design Requirements:

1. **Physical and Operational Characteristics**

    a. **Performance Requirements:**

    - The device can be used either at home or in a gym
        1. It will most likely be used daily if used in a home setting.
        2. If in a gym setting, multiple uses per day would be expected. Each use would most likely take five to ten minutes.
    - Range of force exertion by the resistance bands between 0 to 133.4N (0 - 30 kgs) [16]
    - Able to withstand force exerted by the user
    - Holds the biceps and upper arm relatively rigid in comparison to the forearm at an angle larger than 90 degrees but no more than 130 degrees such as 120 degrees.
    - Targets the flexors and extensors of the forearm, especially the pronator teres.
    - Incorporates a component to improve grip strength

    b. **Safety:**

    - Must be comfortable enough so that the user can exert force without any pain.
        1. No sharp edges or corners.
        2. No unwanted pressure; may include cushioning.
    - Accommodate climber's with various size forearms ranging from 16-33cm in circumference; this could be adjustable size or creating devices with varying sizes. [21]
    - Must be strong enough so that the user's force would not alter the device in any way.

- Must include a safety release system if the user is unable to quickly detach themselves from the resistive components.

c. **Accuracy and Reliability:**
   - If resistance bands or tubes are used, increasing the elongation or thickness of the resistance bands or cables needs to increase the force that the user is exerting by increasing force exerted by resistance bands
   - Must consistently and accurately exert force on the forearm muscles equivalent to the weight or resistance added.

d. **Life in Service:**
   - Five to ten years for the permanent components of the device.
   - If resistance bands or other removable components (such as cushioning or straps) are incorporated, these would need to be changed out if they wear or fray

e. **Shelf Life:**
   - Resistance components used on the device must be good quality so that they would not deteriorate over time.

f. **Operating Environment:**
   - The device will be used at home or at a gym.
   - The portability of the device could mean that there is a chance of damage when the device is being moved.
   - As the device will be used indoors, there will not be any exposure to extreme temperatures or other damaging outdoor conditions. The likelihood of chemical exposure will also be minimal as it will be stored indoors and should only come in contact with products that would not be harmful to the user.
   - Damage could arise while attempting to change the weight/resistance of the device.
   - Damage could occur as the subject is placing their forearm into the device

g. **Ergonomics:**
   - The device needs to be able to incorporate different sized forearms ranging from 16-33cm in circumference [21].
   - The device needs to be able to incorporate different sized forearm lengths ranging from 22 to 27 cm [11]

- People with different forearm strength will be using the device, so it needs to be accommodating for a range of strengths.
- The device should be able to be attached to one's forearm without help from others

h. **Size:**
   - Large enough to comfortably fit an average adult forearm. No larger than 28x11x35 cm

i. **Weight:**
   - Less than 4.5 kg (10 lbs), including any detachable weights.

j. **Materials:**
   - No material restrictions have been made at this time.
   - The device needs to be fairly comfortable to use so some type of padding will need to be incorporated.

k. **Aesthetics, Appearance, and Finish:**
   - No unfinished points or sharp edges.
   - Should be comparable to a professional product that is appealing to a consumer's eye.
   - No excess material should be hanging or protruding from the device.

2. **Production Characteristics**

a. **Quantity:** Only one Forearm Trainer needs to be produced for the time being; only needed as a prototype and testing purposes.

b. **Target Product Cost:** A starting budget of $500 will need to be kept, but keeping the cost as minimal as possible will increase profit margin if it were to be used for consumer sales.

3. **Miscellaneous**

a. **Standards and Specifications:**
   - Values stated in SI units are standard.
   - Should be stable in storage, unloaded, and in the intrinsically and extrinsically loaded use conditions.

- Should support user loads and additional loads without breaking.
- All sides and corners should be free of burrs and sharp edges.
- All corners should smooth ("radiused or chamfered").
- Areas where pinching, crushing, "shearing" could occur should be "guarded" or avoided.
- All locking mechanisms shall function securely at all available adjustment positions.
- Knobs and levers shall not interfere with the user's range of motion.
- Integral hand-grips- conspicuous and reduce slippage.
- Applied hand-grips- reduce slippage and withstand an applied force of 90N (20.2 lb) with movement in the direction of applied force [17].
- Rotating hand-grips: reduce slippage and also be "constrained against lateral movement along their rotational axis."
- All attachment devices (ropes, belts, chains, links, shackles, end fittings, termination means, etc) should not fail under a load equal to six times the maximum static tension produced in normal conditions.
- User supporting surfaces - able to withstand single static load equal to a loading factor times the greater of 135kg (300lb) or max user weight without breakage.
- Consumer fitness equipment leading factors = 2.5 [17]
- Test load: $F_{test} = [W_p + 1.5F_a]$ S [21]
  1. F_{test}= total reactionary load to be applied during test
  2. F_a = max user applied load at point of user contact with machine or max capacity of machine
  3. W_p = proportionate amount of user's body weight being applied (or max user weight)
  4. 1.5 = dynamic coefficient
  5. S = factor of safety (2.5 for consumer fitness equipment & 4 for institutional fitness equipment) [17]
- Components that provide a resistance means and the components that transmit the load shall not fail.
  1. When cycled as intended at max user load for a minimum of 80% of range.
  2. Number of cycles at minimum= 20min of exercise * 3 times per week * 52 weeks * safety factor of 2

- Need detailed instructions if equipment requires assembly or warning for safe use.
- Details instructions for the multiple operations capable of being performed on device. [17]

b. Customer:

- Variable resistances of 0 to 133.4 N (0 to 30 lbs) load [16].
- Contains unique features from a variety of existing devices.
- Safety release.
- Fits on the forearm of a variety of different people.
- Ideally could be used for a variety of forearm muscles and injuries.

c. Patient-Related Concerns:

- Failure of removable components.
- Difficult to change the weights/resistance.
- Unnecessary pain or discomfort from the device that could affect the amount of force they are willing to exert.
- Targeting wrong muscles.
- Overloading and injury.
- Difficulty inserting forearm in the device without the help of others.

d. Competition:

- Gyroscopic balls [22]
- Hang Boards - does not target extensor muscles [5]
- Finger Savers - only works the extensor muscles [6]
- Grip Saver by Metolius - does not target pronator teres [7]

References - See Reference above

Appendix B: Suggested Exercises

The final prototype can be used in many different exercises to strengthen the muscle groups involved in medial epicondylitis. The four main target movements are flexion, extension, pronation, and supination.

Instructions - Extension and Pronation (Figure 21)

1. Hold onto the handle with the palm facing upward, keeping the wrist and hand in line with the forearm.
    a. Bend the wrist down through a full range of motion (extension) and return to the starting position.
        i. Perform desired number of repetitions
    b. Rotate the hand so the palm is facing downward (pronation) and return to the starting position
        i. Perform desired number of repetitions

*A suggested number of repetitions is 15-20 per exercise, per set. A suggested number of sets is 2-3.

Figure 22: Forearm motions for extension and pronation that can be performed with the device.

Instructions - Flexion and Supination (Figure 22)

1. Hold onto the handle with the palm facing downward, keeping the wrist and hand in line with the forearm
    a. Bend at the wrist down through a full range of motion (flexion) and return to the starting position
        i. Perform desired number of repetitions
    b. Rotate the hand so the palm faces upwards (supination) and return to the starting position
        i. Perform desired number of repetitions

*A suggested number of repetitions is 15-20 per exercise, per set. A suggested number of sets is 2-3.

Figure 23: Forearm motions for flexion and supination that can be performed with the device.

Appendix C: Expenses

Table 3: Expenses. Summary of all the expenses from the semester.

Item Name	Part Number	Link	Description	Vendor	Cost	Quantity	Subtotal
Theraband Professional Latex Resistance Tubing	B0037IUXFY	https://www.amazon.com/TheraBand-Resistance-Professional-Exercise-Physical/dp/B0037IUXFY/ref=asc_df_B0037IUXFY/?tag=hyprod-20&linkCode=df0&hvadid=198076111901&hvpos=&hvnetw=g&hvrand=15866532437678886062&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9018948&hvtargid=pla-349230062310&psc=1	3, 5ft tubed resistance bands to provide resistance for the device	Amazon	15.99	1	15.99
Alemon 2 Pieces Replacements Inline Roller Skating Shoes Energy Strap with Screws Nuts Skates Buckles Accessory	B07DVNKH3G	https://www.amazon.com/Pieces-Replacements-Skating-Buckles-Accessory/dp/B07DVNKH3G/ref=asc_df_B07DVNKH3G/?tag=hyprod-20&linkCode=df0&hvadid=312035433248&hvpos=&hvnetw=g&hvrand=18872887538718498819&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9018948&hvtargid=aud-801381245258:pla-568406064936&psc=1	Two 10in straps, mounting screw included	Amazon	10.99	1	10.99
L-piece/Handle/ Pinch Grip - PLA	N/A	N/A	3 3D printed components of PLA	Makerspace	15.00	1	15.00
Body molded foam padding	B075LFHNS8	https://www.amazon.com/Rolyan-Adhesive-Support-Self-Adhesive-Protection/dp/B075LFHNS8/ref=sr_1_1?dchild=1&keywords=body+molded+foam+padding&qid=1587863253&sr=8-1	Self adhesive foam padding, for braces/splints/casts	Amazon	38.00	1	38.00
Flex Seal	FSR20	https://www.amazon.com/Flex-Seal-Rubber-Sealant-Coating/dp/B00CD9FGNW/ref=sr_1_1?dchild=1&keywords=flex+seal&qid=1587863439&sr=8-1	Black, thick adhesive that clings to the surface	Amazon	12.39	1	12.39
CarabinerClips	B01L4IS4I6	**https://www.amazon.com/Tartelette-Shaped-Chain-Carabiner-Aluminum/dp/B01L4IS4I6/ref=sr_1_33?dchild=1&keywords=1.5+inch+carabiner+clip&qid=1587351743&s=industrial&sr=1-33**	Carabiner clip that is about 4cm in length. Comes with 10	Amazon	4.99	1	4.99

Nylon webbing	B07Q7XFG4P	https://www.amazon.com/FANDOL-Nylon-Webbing-Strapping-Repairing/dp/B07Q7XFG4P/ref=sr_1_2?dchild=1&keywords=1%2Binch%2Bnylon%2Bwebbing&qid=1587351899&s=industrial&sr=1-2&th=1	Nylon webbing that is inch wide and 10 yards in length	Amazon	9.99	1	9.99
Hook eye screws	B07TDM1D9T	https://www.amazon.com/AxeSickle-Thread-Eyebolt-Eyelet-Screw/dp/B07TDM1D9T/ref=sr_1_17?dchild=1&keywords=1%2Bin%2Bwide%2Bhook%2Beye%2Bscrews&qid=1587351392&sr=8-17&th=1	0.9 inch (2.2cm) wide hook eye screws that are 0.79 inches (2 cm) deep. Comes with 30	Amazon	9.99	1	9.99
Brass knurled inserts	B01IYWTCWW	https://www.amazon.com/Uxcell-a16041800ux0824-Knurled-Threaded-Embedment/dp/B01IYWTCWW/ref=sr_1_5?crid=1KGMCOVCVYDA4&dchild=1&keywords=m3+5x5+brass+knurled+insert&qid=1587864123&sprefix=brass+knurled+inse%2Caps%2C185&sr=8-5	110 pcs., made of brass, used to tightly screw to injection molding	Amazon	5.99	1	5.99

Estimated Total Costs: $123.33

Appendix D: CAD Drawings

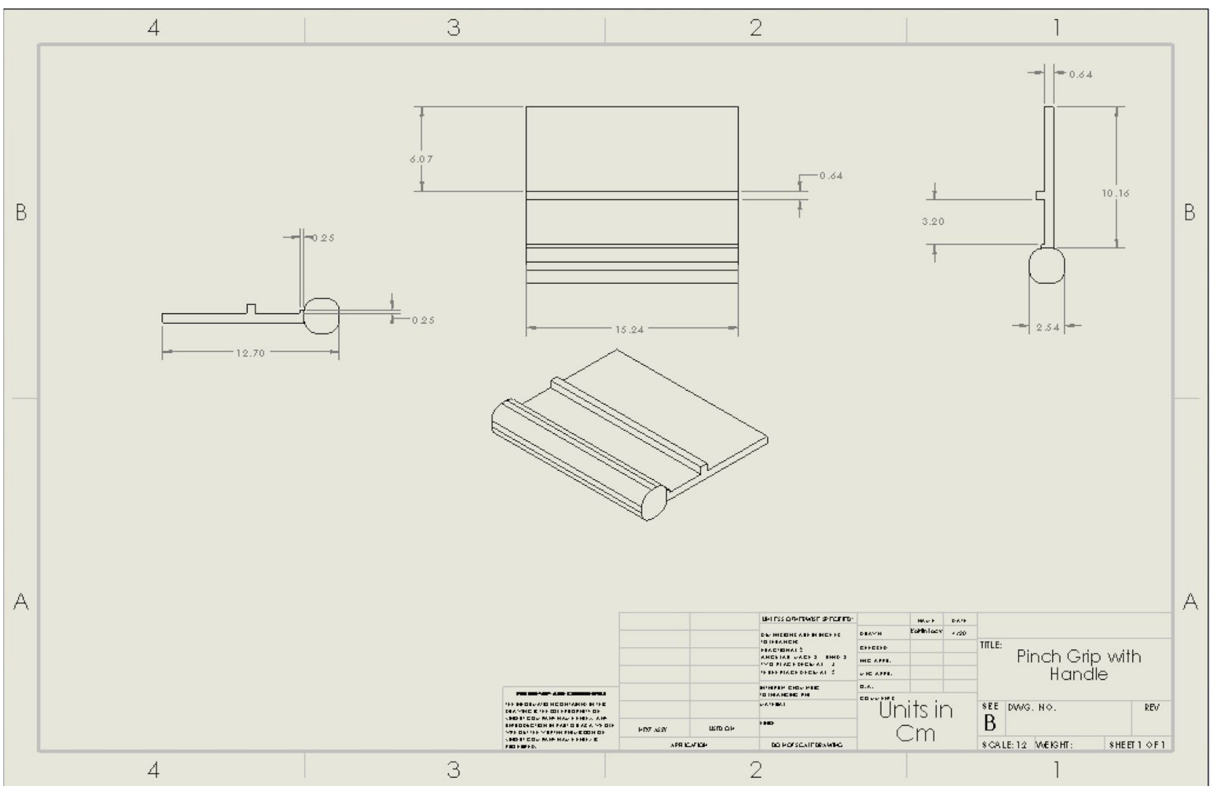


Figure 24: Detailed drawing of pinch grip with handle including dimensions in centimeters.

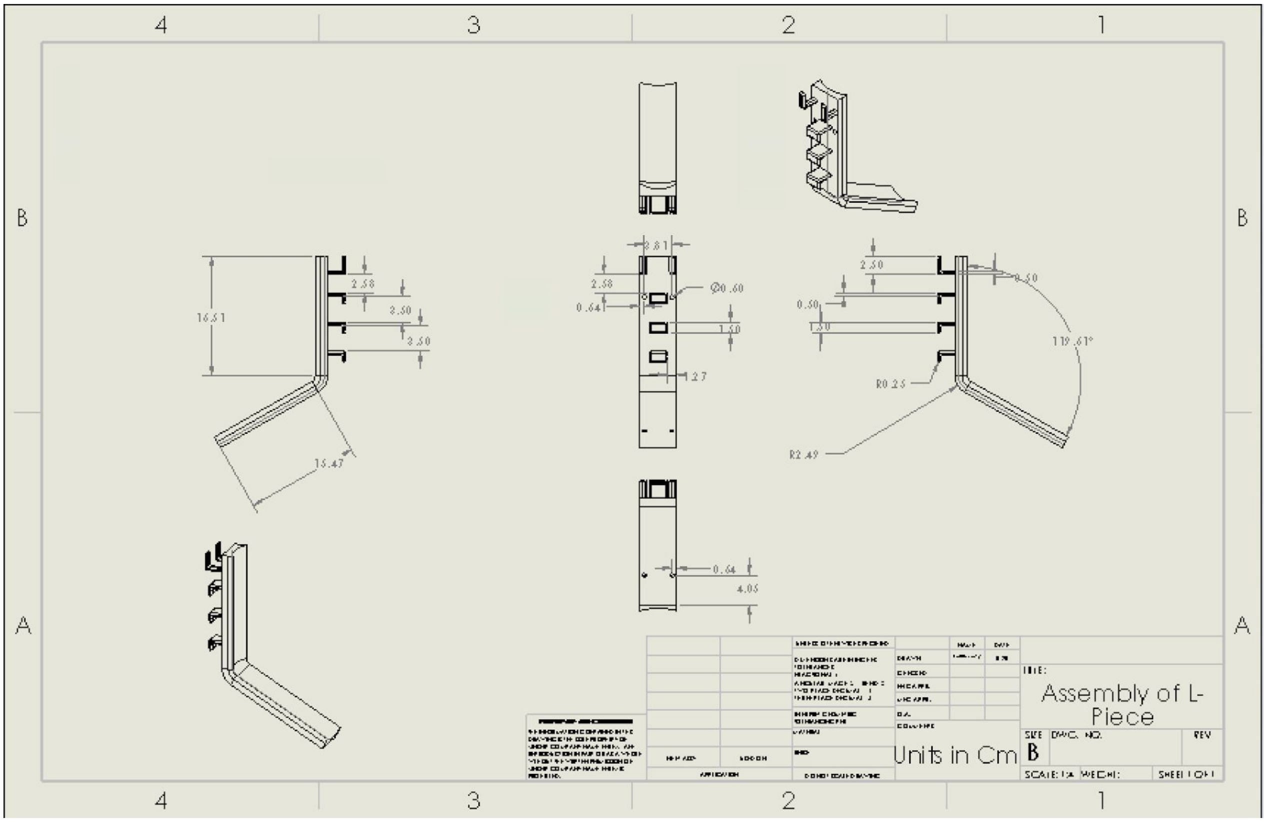


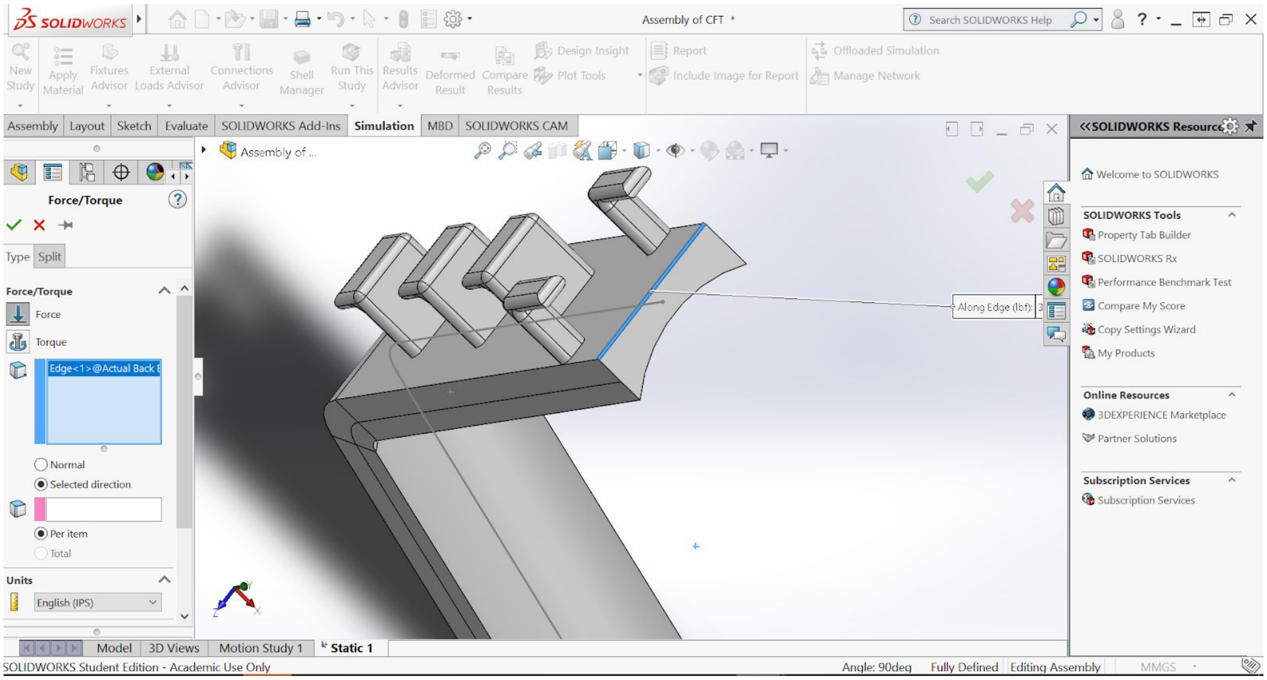
Figure 25: Detailed drawing of L-Piece including dimensions in centimeters.

Appendix E: Testing Protocols

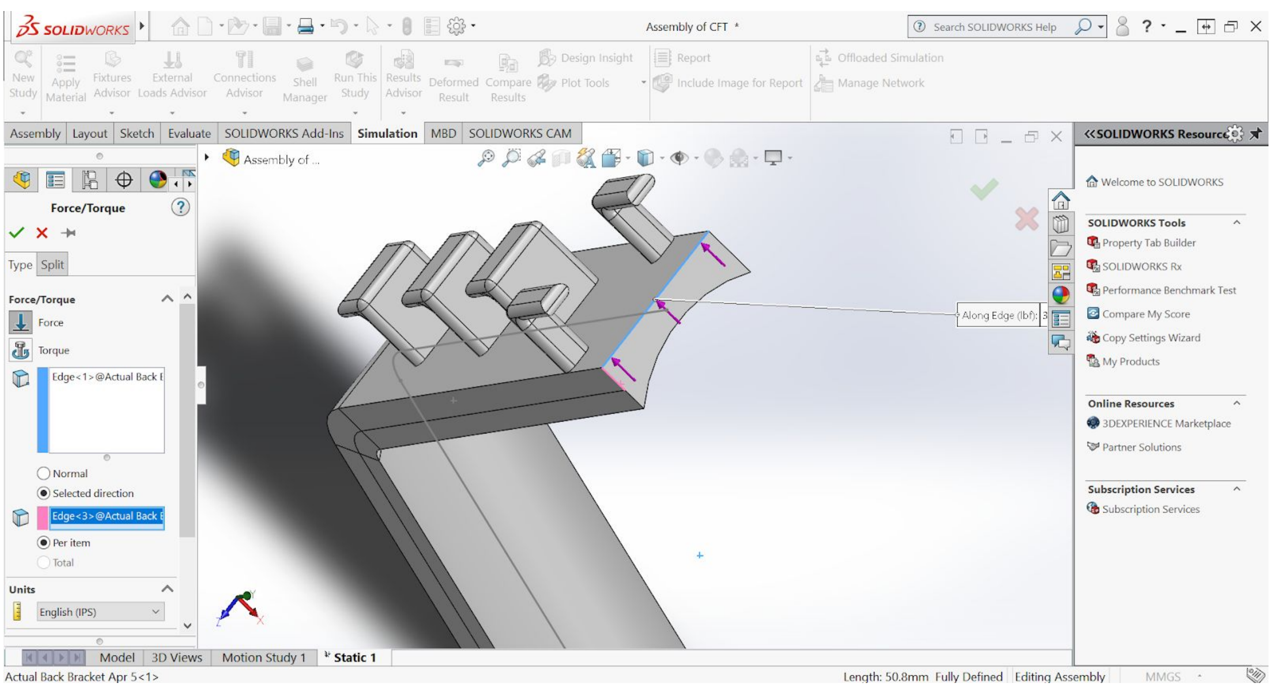
i. FEA

1. Open SOLIDWORKS on computer
2. Open Base Design File
3. Under the "Simulation" tab select "New Study"
   - select the "Static" study and click the green check mark to complete
4. In the menu on the left, right click on "Mesh" and select "Create Mesh"
   - Adjust the slider bar to the finest mesh possible and click the green check mark to complete
5. Make sure your applied material is "ABS"
   - under "Apply Material" select "ABS" and click "Apply"
6. In the menu on the left, right click on "Fixtures" and select "Fixed Geometry"
   - Select the bottom face of the model to fix and click the green check mark to complete
7. In the menu on the left, right click on "External Loads" and select "Force"

- Select the top edge of the model shown in blue in the image.



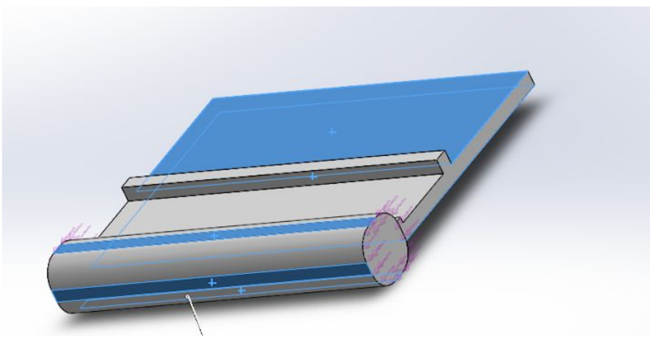
- Next, select "Selected Direction"
- Select the edge perpendicular to the edge you first selected, shown in orange in the image.

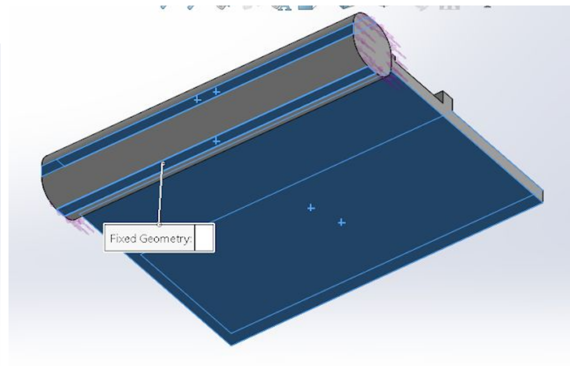


- Under "Force" apply a 30 lbf

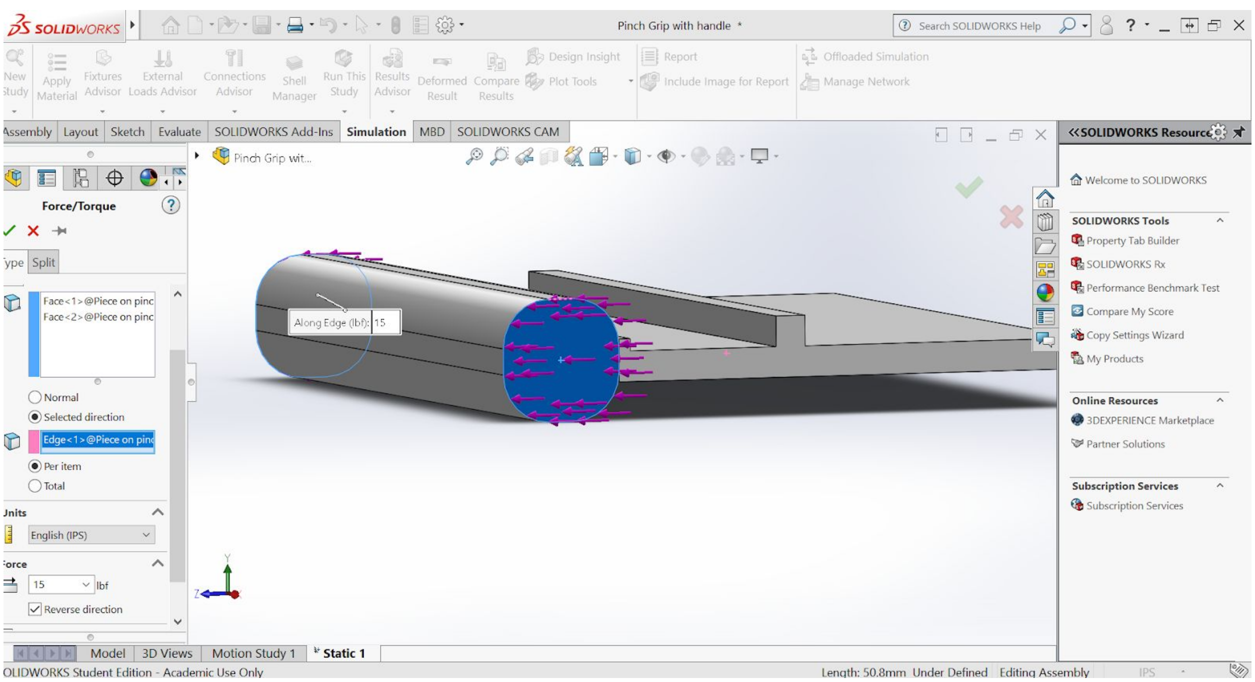
- Check the direction of the force and if in the incorrect direction, select reverse direction
- Click the green check mark to complete

8. Under the top menu, select "Run This Study"
9. Note the simulated maximum deflection
10. In the menu on the left, under "Results," select "Strain"
11. Repeat steps for Handle model with some specific changes
    - Fixed geometry is shown in the two images below





    - Forces are shown in the image below, 15 lbs each (half of 30 lbs each side)
    - For "Selected Direction," select top edge, also shown in the image



ii. EMG Protocol

1. Electrodes are placed on the flexors, extensors, digital flexors, and bicep
2. Complete testing motions without the device
    a. The testing motions include: Flexion, pause, supination, pause, extension, pause, pronation
3. A three minute break was given for the muscles to relax
4. Complete steps 2 and 3 with the device and then again with a weight
5. Save data on flash drive
    a. Data is saved via text file
6. Complete testing procedure with new subject

iii. MTS Protocol

1. Program must be loaded onto the desktop computer
2. Obtain the 1 kN load cell
3. Ensure the emergency stops are set
4. Obtain smaller grips with the rubber padding
    a. Pin must be inserted through the grips to prevent translation and then tightened with the wrench to prevent rotation
5. Turn on MTS machine
    a. The emergency stop button must be pulled out
6. Each resistance band to be tested should be cut to 3’’ (7.62 cm)
7. The resistance band is first loaded into the upper grip and then into the lower grip
    a. The resistance band should be secure enough so it cannot slip and skew the results
8. A slight tension should be added to the resistance band
    a. This can be done using the handheld control
9. At this point, the crosshead data and the load should be zeroed
10. Gauge length is measure and recorded
11. The play button is pressed and the test will begin
    a. If working on the desktop, the handheld control must be locked
    b. The program should be set up so that the test will cease when the resistance band fractures. If the test stops before a fracture occurs, this likely indicates slip
12. Once the test stops, the grips will move back to their original position and the resistance band can be removed
    a. The grips must be completely stopped before the band can be removed
    b. Each band can only be tested one time, even if slip occurs. A pre-stretched band can skew the results.
13. Save the data file onto the desktop computer

    a. The review tab within the program will allow for one to see the data before it is saved

14. Each level of resistance band is tested five times for a total of fifteen tests

iv. Survey Protocol

1. The user will perform the desired exercises using the climber's forearm trainer
    a. Exercises include flexion, extension, pronation, and supination
2. The below list of statements would be stated and the user would reply by agree, disagree, or unsure:
    1. Stretching can be felt in the forearm
    2. The motion of the bicep is limited
    3. There was no lateral movement
    4. The handle is easy to grip
    5. Grip position is comfortable
    6. The elbow angle is comfortable
    7. The device padding is comfortable
    8. No discomfort is experienced
    9. The device is intuitive to use
    10. The tightening aspect is easy to understand
    11. Range of motion is not limited
    12. The straps are comfortable
    13. The straps were easy to secure.
    14. The design looks like a finished piece.
    15. What improvements do you think could be made to the design?