Climber's Forearm Trainer

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Abstract

Climber's Elbow, also known as medial epicondylitis, is a type of tendonitis in the elbow that affects many climbers. It is caused by imbalances in the flexors and extensors and overuse that lead to microtearing. Last semester, a device was created to activate the flexors and extensors of the forearm. This device helps to strengthen the muscles to prevent imbalances and aid in the rehabilitation of medial epicondylitis. The current design activates the pronator teres (a common muscle used in climbing), is adaptable, and is portable. This semester, the overall design will be improved by redesigning the base so that it is more comfortable and easier to use. The Straps Design includes rounded sides to prevent lateral movement and allows for small changes in the elbow angle. A grip strengthening component, The Pinch Grip, will also be included to increase grip strength, as it is important for a climber's breakaway force. Both of the new designs will be 3D printed using PLA due to its durability, availability, and high density. Once the design is printed, electromyography (EMG) will be performed to ensure that the device continues to activate the correct muscles during flexion, extension, pronation, and supination. Tension testing will be conducted on the new tubed resistance bands to determine the increase of force per percent elongation. Finally, a survey will be completed by a variety of individuals to determine their thoughts on the ease of use, adaptability, and intuition of the device. Testing will help determine any improvements or adjustments that need to be made.

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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.

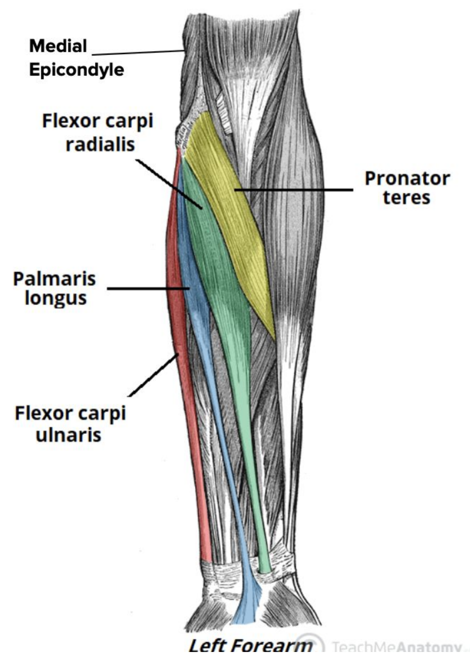

Figure 1: Depiction of the flexor muscles of the forearm and the location of the medial epicondyle [2].

When climbing, individuals have their fingers flexed and hand pronated. The pronator teres is an important muscle of 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 resisted 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 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 utilize 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].

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. As of March of 2019, 50% of male heights fall within the range of 170cm (5'7'') and 180cm (5'11''), whereas 50% of female heights fall between the range of 157cm (5'2") and 167cm (5'6") [9]. Anthropometric tables are used to determine the forearm and upper arm segment lengths based on the average lengths for the specified heights. Since the shortest height is 5'2" (157 cm) and the tallest height is 5'11" (180), 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:

$$\text{Length} = 0.146H \tag{1}$$

$$\text{Max Length} = 0.146 * 180.34\ [\text{cm}] = 26.3\ [\text{cm}]$$

$$\text{Min Length} = 0.146 * 157.48[\text{cm}] = 23.0\ [\text{cm}]$$

Length for the upper arm:

$$\text{Length} = 0.186H \tag{2}$$

$$\text{Max Length} = 0.186 * 180.34\ [\text{cm}] = 33.5\ [\text{cm}]$$

$$\text{Min Length} = 0.186 * 157.48\ [\text{cm}] = 29.3\ [\text{cm}]$$

Knowing that the ranges of the forearm are roughly between 23.0 cm and 26.3 cm and that the upper arm is between 29.3 cm and 33.5 cm, an effective device was designed to fit a variety of users without causing any pain or discomfort.

The device was intended for climber's with, or those prone to developing, Climber's Elbow. Grip is an important factor in climbing, and therefore is important to incorporate into a design. Grip force was found to be significantly larger when the wrist is fully extended than when it is held at an angle. An increase in grip aperture (distance between the thumb and the fingers) will also increase the grip force [10]. Incorporating different grip sizes could help strengthen all the muscles involved in gripping.

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 23.0 to 26.3cm and upper arm lengths of 29.3 to 33.5cm. As different individuals will use the device, the same angle of the back piece will not be comfortable for all users. Angles between 90 and 110 degrees should be implemented. 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 [11]. 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 likes to climb, and he has developed Climber's Elbow in the past. This led him to be in need of a device to help prevent and rehabilitate Climber's Elbow.

II. Preliminary Designs

a. Base Designs

i. The Original Design

The Original Design was created in the Fall 2019 semester. The design consists of a 3D printed L-piece that is used for the support of the forearm and the upper arm. This piece has a velcro strap that wraps around the upper arm and the forearm to prevent flexion of the bicep, focusing only on the forearm muscles (Figure 5A). There are three downward facing hooks (Figure 5C), that allow for increasing the resistance of the resistance band and therefore increasing the amount of force experienced by the user. The upward facing hooks allows for the resistance band to loop back up and provide the angle necessary for extension of the wrist. A wide hollow handle was used that allowed for the resistance band to slide through the handle (Figure 5B). A foam padding was placed on the bottom of the L-piece to provide comfort for the user. The 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, resistance bands used were too bulky for the design and difficult to loop through the hooks.

Figure 5: 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. 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 6, 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 providing 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.

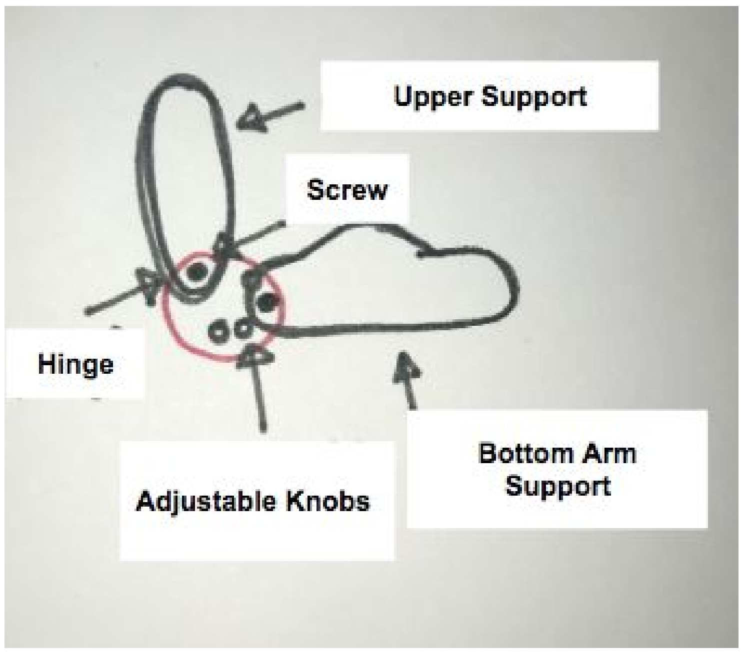

Figure 6: An image of “The Hinge Design” considered for the forearm trainer.

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 maneuverability of the lower arm. It will eliminate horizontal movement off 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. 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 7.

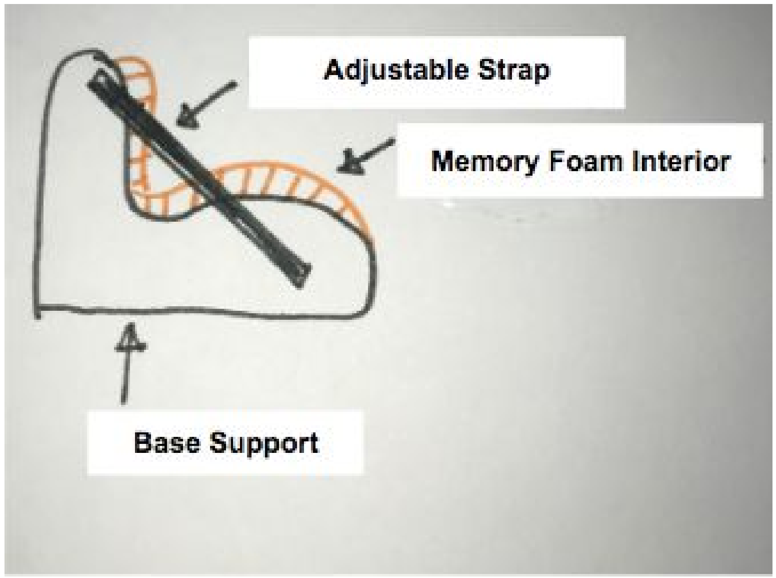

Figure 7: A sketch of the "Straps Design" for strengthening the forearm.

b. Grip Designs

i. The Pinch Design

The Pinch Grip design includes a similar idea of that of the hangboard, where only the tips of fingers and thumbs are used. A pinched grip is used because it models the type of hold a climber would use. It is known that an increased grip aperture has a larger breakaway force (force required before an object is pulled from the grasp), so therefore, it is important for climber's to increase their breakaway force with a smaller grip aperture rather than a large aperture [12]. The design is made of a rectangular thin plastic that is durable enough to withstand the force exerted on the sides of the handle from the resistance bands. The loops on either end on the handle allow for resistance bands to attach to the handles via a carabiner clip. The Pinch Grip design allows for resistance to increase as the forearm increases strength by simply changing the resistance bands.

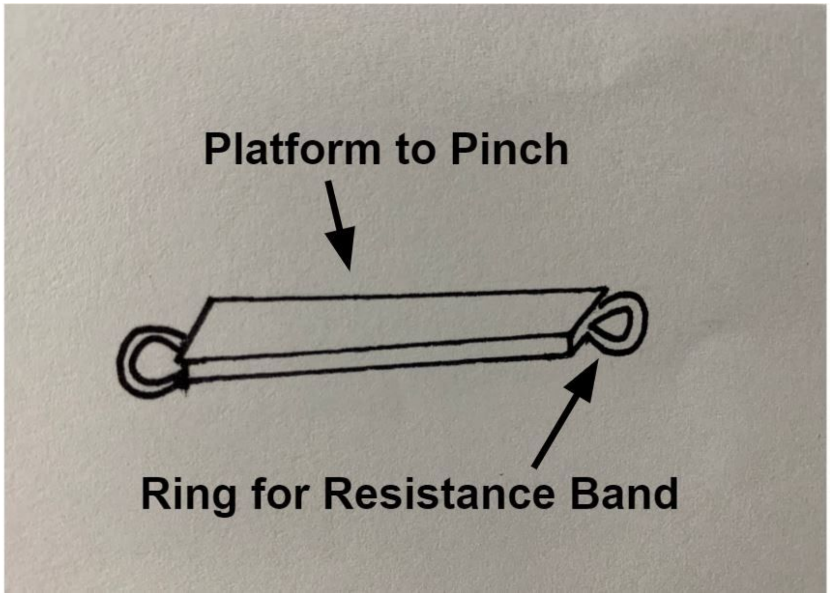

Figure 8: “The Pinch Grip Design” sketch for grip strengthening.

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 9, 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 is also comprised 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.

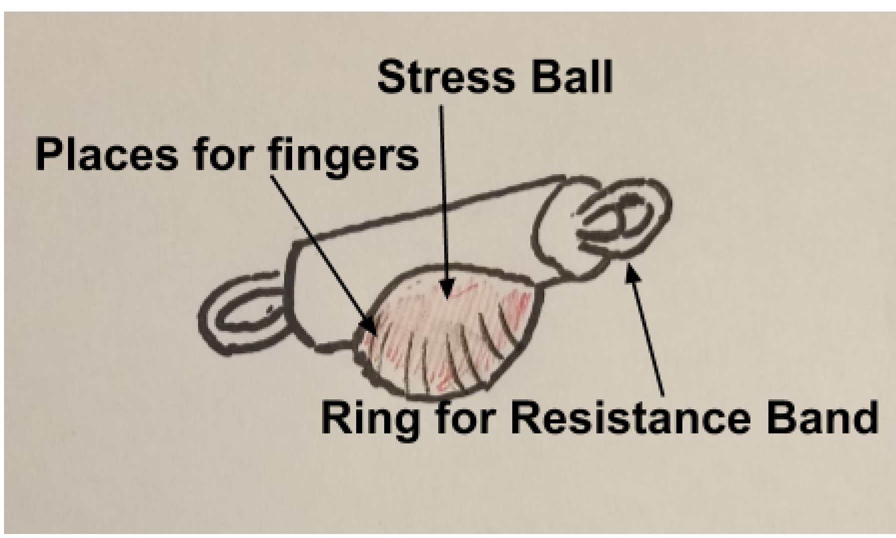

Figure 9: A sketch of the Stress Ball Design being considered as one of the grip designs

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 10 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 was 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.

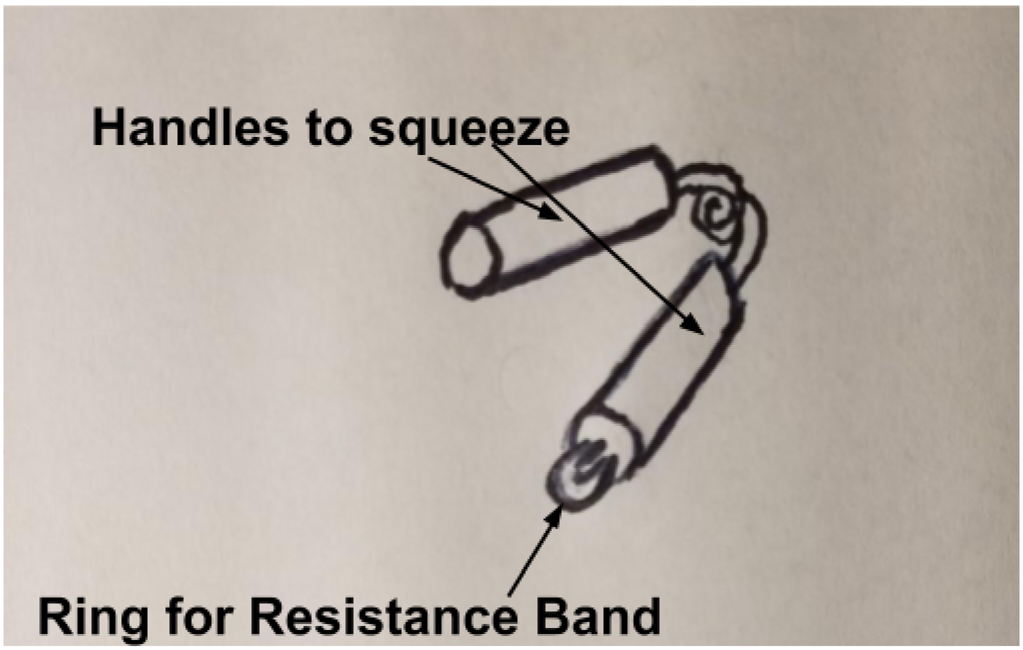

Figure 10: A sketch of the Gripper Design that is being evaluated as a grip design option.

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 design winning that 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 design winning that 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 the comfort of 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.

IV. Fabrication

a. Materials

The base of the design will be made from PLA due to its high density, durability, and availability. The Pinch Grip will also be made from PLA and hook eye screws will be used for the hook's on the edges. The hook eye screws are durable enough to withstand the force of the resistance bands. A set of tubed resistance bands with carabiner clips will be used to provide resistance.

b. Fabrication Process

The current plan for fabrication will begin with CAD models of both the base design and the grip design. The CAD models will then be used for 3D printing that will be printed using PLA (polylactic acid). The sides of the handles will contain small holes where brass knurled inserts will be inserted by using a soldering iron to melt the plastic slightly. Hook-eye screws will then be screwed into the inserts. Velcro straps will be added to the base design also using the threaded inserts and corresponding screws. Thicker straps will be attached on the upper arm part of the design to go around the bicep, while the thinner straps will be on the lower piece and strapped around the forearm. The resistance bands will be threaded around the hooks on the back of the design and then the carabiner clips will be attached to the handle.

V. Testing

Electromyography will be done to ensure that the device targets the forearm muscles (specifically the pronator teres) as well as those associated with grip. Testing will be done 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 increase during pronation and flexion of the wrist while the amplitude of the extensor singal 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 target the correct muscles. Also, an electrode will be placed on the bicep. Activation of the bicep should be limited as the device is meant to focus on the muscles of the forearm.

Mechanical testing of the resistance bands will be conducted to determine the varying force with the percent elongation of the band. Testing the resistance bands will ensure that by increasing the tension in the resistance band there will be an increase in force exerted and felt by the user. It will also ensure that there is a noticable difference from one resistance band to the next (light, medium, high). Testing will be completed using the MTS Sintech Machine with new resistance bands so no pre-stretching affects the results[13]. Each of the resistance bands will be cut to the same length to have similar slimness ratios to minimize the effects of changes in dimensions due to elongation [14] . The Slimness Ratio can be seen in Equation (3) where "L_g" is the gauge length and "A" is the area.

$$Slimness\ Ratio\ =\ \frac{L_g}{\sqrt{A}} \tag{3}$$

The test will be conducted until the fracture of the band. The break will be examined to determine if stress concentrations were the cause of the fracture. Generally, if a sliver appears it indicates a potential stress concentration.

A survey will also be conducted using a variety of individuals. Ideally, a survey would be conducted by using climber's at one of the local gyms to obtain information on fit, ease of adjustment, and whether or not the device is intuitive. The survey will consist of questions that the user will answer and rate their answers on a scale of 1-10. The results from the survey will provide differential statistics which can be used to make inferences for the rest of the population.

VI. Conclusion

a. Overview

Medial epicondylitis, more commonly known as Climber's Elbow, affects 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 be adjustable at the elbow by 10 degrees and has added walls on either side to cradle the user's arm. The interior will be lined with memory foam to accommodate multiple forearm sizes. The second improvement to the original design was an added grip strengthening device on the handle. The handle will be 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 to attach to using carabiner clips. Due to this feature, new resistance bands will be used. These 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.

b. Future Work

The primary focus of this semester has been to improve on the original design from last semester's team. The next step will be to fabricate both the base design as well as the grip design. Both designs will be 3D printed using PLA due to its low cost and high durability and density. After fabrication, testing of the product will need to be done to ensure it meets the clients requirements listed in Appendix A. Electromyography is planned to be used to validate that the correct muscles are being worked by the new design. The new resistance bands will also undergo mechanical testing to determine the elongation and resistance of each band level. Lastly, a survey will ask individuals to scale a number of factors of the design from 1-10.

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VIII. Appendix

Appendix A: Product Design Specifications

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 a large variety of the forearm muscles.
- 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:

- It will most likely be used daily if used in a home setting. If in a gym setting, multiple uses per day would be expected. Each use would most likely take five to ten minutes.
- Will likely undergo various changes in weights to fit the strengths of various users.
- Able to withstand force exerted by the user.
- Holds the biceps and upper arm relatively rigid in comparison to the forearm at an angle other than 90 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; this could be adjustable size or creating devices with varying sizes.
- 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 cables are used, increasing the elongation or thickness of the resistance bands or cables needs to increase the force that the user is exerting.
- 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 periodically.

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 most likely 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
        1. The damage could be in potential straps or bands.

g. **Ergonomics:**
    - The device needs to be able to incorporate different sized forearms.
    - People with different forearm strength will be using the device, so it needs to be accommodating for a range of strengths.
    - The device will not incorporate weights above 30 lbs.

h. **Size:**
    - Large enough to comfortably fit an average adult forearm. No longer than one and a half feet.
        1. May have adjustable components to fit a larger variety of people.

i. **Weight:**
    - Less than 30 pounds, including any detachable weights.
        1. Ideally, it will weigh much less than this.

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.
            1. If not, need a specific warning label.
        - 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.
        - 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.
    1. Consumer fitness equipment leading factors= 2.5
- Test load: $F_{test} = [W_p + 1.5F_a]\ S$
    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)
- 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.

b. Customer:

- Variable weights and resistances.
    1. Five to thirty pounds of load.
- 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
- Hang Boards
    1. Don't target the extensors, but do work the forearm.
- Grip Saver by Metolius
    1. Squeezable ball with elastic finger holds to allow for flexor and extensor strengthening.
- Finger Savers
    1. Rings with slots for fingers to open up against, therefore working the extensors

Appendix B: Suggested Exercises

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

2. 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.