Lower Extremity Rehabilitation Device For Developing Countries

University of Wisconsin Madison

Department of Biomedical Engineering

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Hannah Meyer, Amy Slawson, Andrea Schuster, Alenna Beroza, Maria Maza

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Abstract

As a team of five, female biomedical engineering students we are focused on the design and fabrication of a device that will be used to rehabilitate the lower extremities. This project will be carried out at the University of Wisconsin-Madison and the product will be transported to La Cieba, Honduras where it will be used at the rehabilitation clinic called CRILA. The device will be used by physical therapists to provide patients with a gradual physical therapy treatment plan that may be customized to each patient's specific needs. The device will also serve as a platform for women in the community to develop skills in science and engineering. The team intends to teach these women how to replicate multiple versions of this device. This would in turn improve the quality and access to medical care for a larger percentage of the population.

Problem Statement

CRILA is a rehabilitation clinic in Honduras that serves people with a variety of disabilities. Specifically, many young adults to elderly patients suffer from ailments in the lower extremities resulting in the need for unique treatment and rehabilitation programs. In order to strengthen the lower extremities resulting of the patients, we will design a device that allows the patient to lie on their back with their knees at a ninety-degree angle and feet pressed against a solid plate. The device will also include metal springs of increasing strength with carabineer end attachments to aid in strengthening of the lower extremities. Our client Karen Patterson from the UW PT department requests that the device be cost effective, locally manufactured, and easily assembled and replicated in Honduras. Additionally, it must be able to withstand a high frequency of use, require low maintenance, and be portable for ease of transport.

Keywords:

Lower Extremity Device,
Rehabilitation,
Closed Kinetic Chain,
CRILA Clinic,
La Ceiba, Honduras,
Women Empowerment

Acknowledgements

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I: Introduction

Need for Device in Honduras

The United Nations reports that Honduras has the highest rate of homicide on the planet. It is estimated that there is violent death every 74 minutes in Honduras (BBC, 2012). As a result of the high level of corruption, there is a great deal of physical violence which has left many Hondurans disabled. In addition, several viruses and degenerative diseases are also prevalent in Honduras, such as polio, leaving many citizens in need of muscle rehabilitation in their lower extremities. Consequently, there is a high demand for physical therapy in the area.

CRILA (Centro de Rahbilitation Integral del Litoral Alantico) is a rehabilitation clinic in La Ceiba, Honduras that serves people with a variety of disabilities. Specifically, many young adults to elderly patients suffer from ailments in the lower extremities resulting in the need for unique treatment and rehabilitation programs. Currently, the organization lacks the necessary resources to provide essential care to its population, as it services about 50 patients a day. It has access to open kinetic chain exercises, such as free weights and elastic bands. However, it has been proven that these types of exercises aren't as effective for gradual recovery as closed kinetic chain exercises.

Physiological Benefits of Closed Kinetic Chain Exercises

A closed kinetic chain exercise comprises of fixing the foot in contact with an immobile surface. It usually promotes compound movement of multiple muscles in conjunction and causes compressive loading, whereas open kinetic chain exercise isolation movement to a single muscle and incur more shearing forces, see figures 1 and 2. Closed kinetic chain exercises may then be viewed as an optimal choice in rehabilitating patients to regain movement requiring the use of large groups of muscles such as walking.

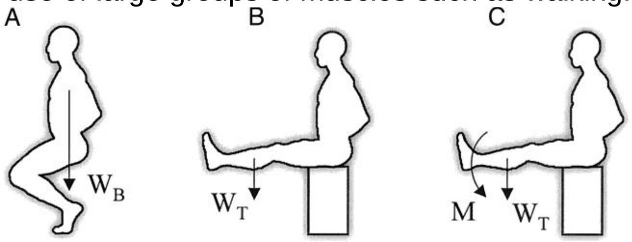


Figure 1: (A) Shows a person performing squats against the force of gravity, a closed kinetic chain exercise. Their feet are fixed and the knee and hip flexor and extensor muscles are all being strengthened as the person squats up and down. (B&C) Show a person performing leg lifts, an open kinetic chain exercise. As the person extends their knees against the force of gravity, they strengthen only the knee extensor muscles (1).

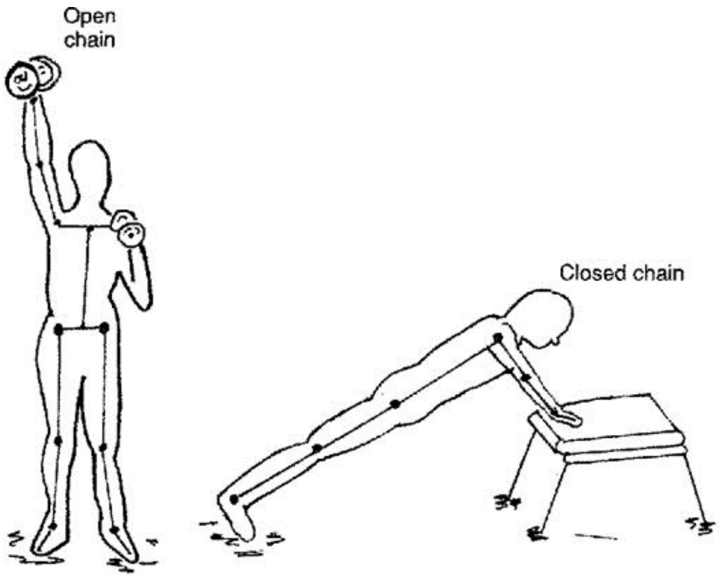


Figure 2: Another example of closed versus open kinetic chain exercise. When using free weights, the arm (as the final link of the system) is free, and movement is isolated to contraction of one muscle. With fixed hand position, the chain is closed, and multiple muscles are activated (2).

A study done by the Department of Rehabilitation Medicine at Göteborg University in Sweden compared closed and open kinetic chain exercises (Augustsson *et al* 1998). By the end of the study, the participants that exercised with closed kinetic chains improved 31 percent, while the participants exercising with open kinetic chains improved 13 percent. Though both groups experienced significant improvements, the results indicated that closed kinetic chain exercises are much more efficient in rebuilding leg muscles than open-kinetic chains. A more recent study also supports this data, explaining that closed kinetic chains are much more effective as long as several contributing factors of flexibility are included. Examples these parameters are “type of exercise, length, and frequency of intervention, intensity, repetitions, sets, and specific technique” (Harvie 2011).

Another key aspect in demonstrating the physiological need for our product was a study that compared normalized knee-extension strength and leg press power to determine which is more effective for performance function (Aalund *et al* 2012). It found that normalized leg press power correlated much more closely to performance-based and self-reported function. The study then rationalizes that leg press power, a closed kinetic chain exercise, much more closely mimics the average person's daily muscle movement, such as walking or rising from a chair.

Since our device will be a closed kinetic chain device, it will be a great resource for those needing muscle rehabilitation.

Our Solution

In order to strengthen the lower extremities of the patients, we will design a device that allows the patient to lie on their back with the knees at a ninety-degree angle and feet pressed against a solid plate. The device will also include springs of increasing strength with caribeeners as hooks to aid in strengthening of the lower extremities. Our client Karen Patterson requests that the device be cost effective, locally manufactured, and easily assembled and replicated. Additionally, it must be able to withstand high frequency of use, require low maintenance, and be portable for the ease of transport.

II. Background Research

Patents and Commercial Products

A lot of our research was put into closed kinetic chain devices and resistance bands. One of the most challenging parts of our device would be the resistance aspect. We were unsure of how to minimize costs, while finding resistance bands that would provide the necessary strength required for rehabilitation purposes. During our research, we looked into the fabrication of elastic resistance bands, as well as prices and types of various bands that could possibly work in our device. Another important aspect of our research was looking into existing commercial products and incorporating certain components of these devices into our design. We found many products on the market and created a list of pros and cons for each one as explained below.

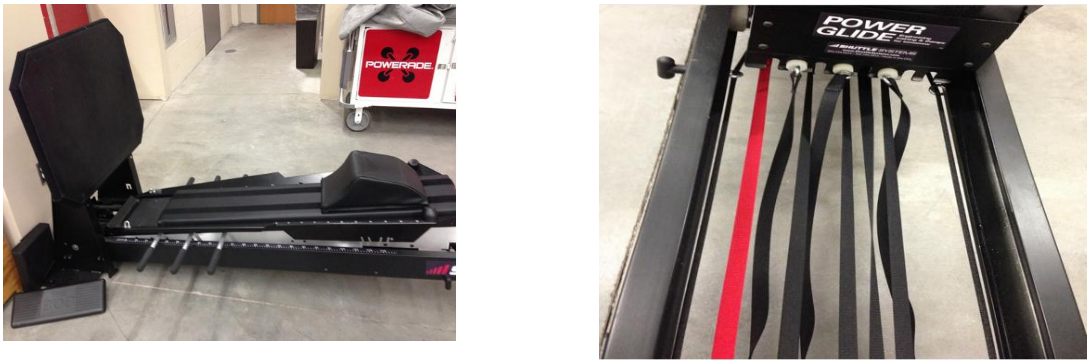
The "Shuttle Systems" such as the MVP, Recovery, and 2000-1, as shown in figure 3A, are designs suitable for the clients needs. Shuttle products feature movable backrests which creates individual comfort. The footplate for these products was quite large which made it simple for each person to put their knees at a 90° angle. The footplate was also lifted off the base of the machine, so that the device could also be used for other exercises such as calf raises. Although these devices were more complicated than others that we looked at, the ease of use of the Shuttle products was very appealing.

Figure 3: Reformer with simplistic design and ease of fabrication

The Physical Therapy department at UW Madison has the Shuttle MVP, so we were able to get a close up view of the product. This was very helpful in our design process and allowed us to get a better look at how each aspect of the device worked in conjunction with the next. We spent a lot of time looking at the resistance aspect of the product, as well as the track that the carriage slid on while in use. The product had two different size bands of differing resistance, and they incorporated "pull straps" attached to the bands. The pull straps made it easier for the user to change the resistance. When resistance was added, the user pulls the pull straps back and simply hooks a stopper into an open U shaped hook. The track on this device was very interesting. There were vertical wheels as well as horizontal wheels. The vertical wheels were used for the sliding up and down the machine, and the horizontal wheels prevented the carriage from moving side to side while being used.

Looking into commercial products was very helpful in our brainstorming and design process. Not only was it helpful to have the overall product knowledge, but also it was helpful to look into minute details such as the size of the footplate and carriage, the connection of resistance bands, and the handles for stability. Many of the aspects we liked from current products, we were able to incorporate into our own device. We decided to use the large static footplate, the handles on the sides of the carriage, and the comfortable seat. We also used many of the dimensions we found from commercial products.

Our next step in the design process was to decide on our design specifications. From our client, the design must be cost effective, portable, and easily replicable in Honduras with local materials. The device will be used as a rehabilitation for the lower extremities, so it will be necessary for our device to strengthen the lower extremities. Because patients will be using this machine, our device must be very safe and should accurately fit all patients from young adults to elderly. It will not be designed for children due to the fact that the dimensions used to create the device were based off of average adult height. Since many people will be using the device each day, the device must be able to withstand high frequency of use, and the elastic bands should provide the same amount of resistance with each use. Due to the humid environment, it is necessary to make our device out of materials that can withstand these conditions. The device should last for approximately ten years and the bands should last for three to five years. The device must be made for under $500.



(a) **(b)**

Figure 4: a) Shuttle Recovery found in the rehabilitation center at UW-Madison; b) Elastic bands connection to the Shuttle MVP.

III. Design Considerations/Decision Matrix

Material Considerations

The design requirements provided by our client, greatly affected the materials that we chose for this device. Because of the fact that it is going to be used in the humid, and occasionally termite infested, environment of Honduras we chose to build with treated lumber for the major structural components of the device. Major structural components in this context refer to the base of the device as well as the most of the carriage. We made this decision based on the fact that treated lumber is significantly more durable in these types of conditions. Another material decision that we made right away was the use of steel for components under a lot of shearing stress such as the footplate and its respective supports that extend to the ground. Other components of the device such as the design of the track and the attachment of the bands required further brainstorming and evaluation. For these categories we used a decision matrix broken up in the following design criteria: feasibility, functionality, accuracy/precision, cost and safety. Out of these criteria we listed feasibility and functionality as the most important criteria. We chose these two criteria to hold the most weight because having the device function is essential and we also want the women on La Cieba to be fabricate additional versions of the device as necessary.

Track Designs

Our initial track ideas came down to three main designs. Design number one we referred to as the "side track" because the track would be secured directly to the sideboard of the frame. This design was appealing because it kept things simple and was similar to the reformer and Shuttle MVP Pro. However, we ruled it out due to functionality, accuracy, and safety.

The second track design that we had was the "base track". This design was similar to the first design however it had an additional reinforcing board underneath the track. This design provided two options for attachment of the track, either on the side or on the bottom. This design scored the most points on our decision matrix as you can see from the table.

The third design that we had was the "Bolt Track". In this design a bolt would slide within a lubricated block. This design received the fewest number of points due to limitations with feasibility and functionality. After numerous discussions with a fabrication expert, Chet, we determined that none of these original ideas would be sufficient. Instead, we took his advice and used a plastic track and plastic slats that are attached to the bottom of the carrage. Each of the plastic pieces were coated with a silicon lubricant in order to reduce friction forces and ensure smooth movement.

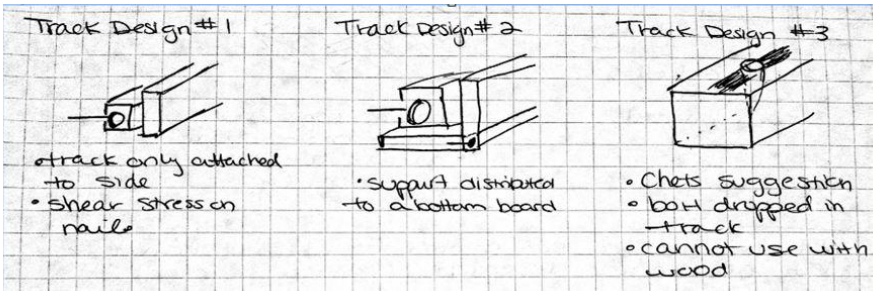


Figure 5: Original Track Designs. Track design #1 is the "Side Track", track design #2 is the "Base Track" and track design #3 is the "Bolt Track".

Table 1: Decision matrix for the track designs. Based on the decision matrix, we decided that the base track would be the best choice out of these options because it would provide additional support for the load-bearing track.

Criteria	Side Track	Base Track	Bolt Track
Feasibility (15)	13	11	5
Functionality (15)	11	14	7
Accuracy/Precision (10)	8	9	8
Cost (10)	10	9	6
Safety (15)	4	5	5
Total (55)	46	48	31

The plastic for the track was chosen as an adequate material, as it can withstand high amounts of strain that the sliders will experience due to patient loading. The maximum bending moment will be located at the center of the plastic planks as shown in Section IV. SolidWorks 3D Modeling Section, and thus this is the location of maximum strain. By knowing the maximum strain values for elastic deformation of our plastic material (ε_{max}, a material constant), along with the dimenstions of the plastic, we can determine the maximum weight of a patient that they may support. This is done using the equation

$$\varepsilon_{max} = (M_{max}\ C) / IE \qquad \text{(Equation 1)}$$

where the moment (M) is affected by the length of the sliders and the weight of the patient, C is a factor of plastic thickness, the moment of inertia (I) is also a factor of width and thickness, and E represents the modulus of elasticity. Thus we could make an informed decision when selecting the type and dimensions of our plastic in relation to the amount of loading the sliders will experience.

The plastic track was also selected as a more feasibly replicable design. Plastic is a locally available material in Honduras and is much easier to cut an extrusion for a track out of a rectangular piece of plastic than weld it out of metal. Welding a metal track requires expert metal-work experience, and wheels require tremendous accuracy in alignment. These criteria reduce the life expectancy of the design should the wheels become misaligned. Having slates slide along the track reduced the chances of misalignment causing issues with the carriage movement. With smooth cut plastic there is essentially no friction between two pieces, and increased downward force due to patient loading increases sliding ability. Friction is further reduced by spraying a silicon layer that lasts up to ten years and can be easily reapplied as necessary.

Resistance Connection

The way in which the resistance mechanism was attached became another design component that required a design matrix. The first design idea was a simple hook which consisted of a thin metal plate with holes that allowed for attachment of the individual bands as shown in figure 5. In this design, the ends of the band will consist of hooks very similar to a bungee cord. This design scored high in our decision matrix for a variety of reasons as shown in table 2. Most importantly, it is a material that is easily obtained near La Ceiba and therefore can be replaced when necessary.

The second resistance attachment design was the puzzle or knot attachment. This design is similar to the first however, instead of attaching with a hook, the end of the band would attach into a fitted puzzle piece like slot. This resistance attachment was used on both the Shuttle MVP and reformer. Nevertheless, the design was ruled out for safety reasons because the band could potentially slip from the attachment and shoot toward the patient.

The third band attachment design was the eye hook attachment. In this design, a hook on the end of the resistance mechanism would connect into an eye hook located at the front of the frame. Originally, there was concern about whether the eyehook would remain fixed when undergoing more than 30 lbs. of force; however, this problem was alleviated by attaching the eyehooks to a metal sheet.

The fourth and final band attachment design was the simple hook with an adjustable bar. The adjustable bar could be moved backward or forwards in order to increase or decrease the resistance. One benefit of this design is that the resistance could be adjusted without having to unhook a single band. Ultimately, it was decided that this design would not be used for safety reasons as shown in table 2.

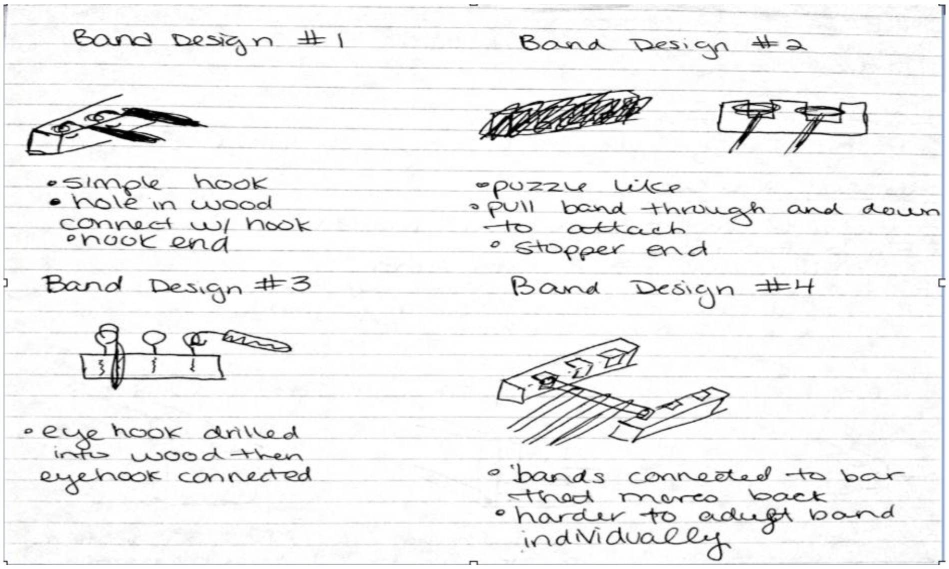


Figure 6: Band attachment designs. Band attachment design #1 is the "Simple Hook", band attachment design #2 is the "Puzzle/Knot Attachment", band attachment #3 is the "Eye Hook" Attachment, and band attachment design #4 is the "Simple Hook with Adjustable Bar". Based on the decision matrix shown below we have decided to go with the "Simple Hook" design however this may change upon further testing.

Table 2: Decision matrix for band attachment designs. Thus far, we have decided to go with the simple hook design however this may change with further testing and analysis.

Criteria	Simple Hook	Puzzle Knot	Eye Hook	Adjustable Bar
Feasibility (15)	14	14	15	8
Functionality (15)	9	9	6	8
Accuracy/Precision (10)	15	15	13	7
Cost (10)	8	8	9	4
Safety (15)	5	4	3	2
Total (55)	51	50	46	29

Prior to fabrication, it was thought that the simple hook design was the best option for band connection as it appeared to be very easy to fabricate. However, upon putting the device together it became apparent that the eye hook design combined with carabineers would not only be safer but a more simplistic design. The final design and fabrication of the band attachment consists of eight eye hooks secured to the footplate support and underside of carriage. This allows for the resistance connection to remain linear and parallel to each other; allowing for the device to produce a consistent force load.

Resitance Selection

The most difficult design decision was determining the type of band resistance and placement of the band attachment. Originally, elastic bands/bungee cords appeared to be the easiest method and most locally available in Honduras. At one point, making our own bands from a sheet of rubber was considered as well, but these bands would be less likely to be easily replaced when damaged. After performing a spring load testing it became obvious that rubber/elastic bands would not stretch far enough to allow the patient to fully extend while providing the desired resistance. We decided to explore other options and tested different types and lengths of springs. The springs worked better in extending to the essential length. The only disadvantage to using elastic bands or springs is that resistance in not perfectly consistent as opposed to free weights. As they stretch further, more force is exerted as exhibited in the spring force equation

$$F= k \Delta x \qquad \text{(Equation 2)}$$

where F is the force in lbs, Δx is the displacements, and k is the spring constant. Through testing, we were able to establish what amount of force each spring provided when stretched at different lengths.

Spring attachment was located along the front of the frame where it could be bolted to the sides of the frame as well as welded and bolted to the metal supports of the footplate for increased reinforcement. The attachment on the carriage will also be located at the front. The disadvantage of this is that when springs are not in use, they must be fully removed from both connection locations. We considered a design in which the bands or springs ran along the bottom of the carriage in a taught orientation, so when they were not used they would not dangle downwards. Then when increased resistance was desired, one simply had to extend the band and attach it to the front of the frame. Issues came about in applying this approach when bands were already extended thirty inches along the bottom of the carriage and it limited the distance at which they could further extend. Consequently, the attachment site was moved to the front of the carriage closer to the feet of the patient.

IV. Overall Design and SolidWorks 3D Modeling

While considering the availability of local materials, feasibility of replication, ease of use, and cost effectiveness, we made our final design selections. Whereas many of the commericial products that we reseach cost up to $1500, we have proposed a design that can be built for under $500.

The majority of the device is constructed out of treated wood. This enables it to last longer and withstand the humid weather conditions of Honduras and other developing countries. The legs support the frame one foot off the ground and the carraige adds another foot of height. Thus, the overall device stands two feet allowing the clinic therapists to assist patients in the rehabilitation and use of the device. At the end of the frame there is a solid plate cut from a sheet of diamond steel plating. As patients press against the plate, the lower steel supports will be an area of high stress. To reduce bending at this location, the steel supports extend down through the wood bolted to a wooden base support in contact with the lower end of the frame. Additionally, the steel supports are welded and bolted to the front ridge of the frame.

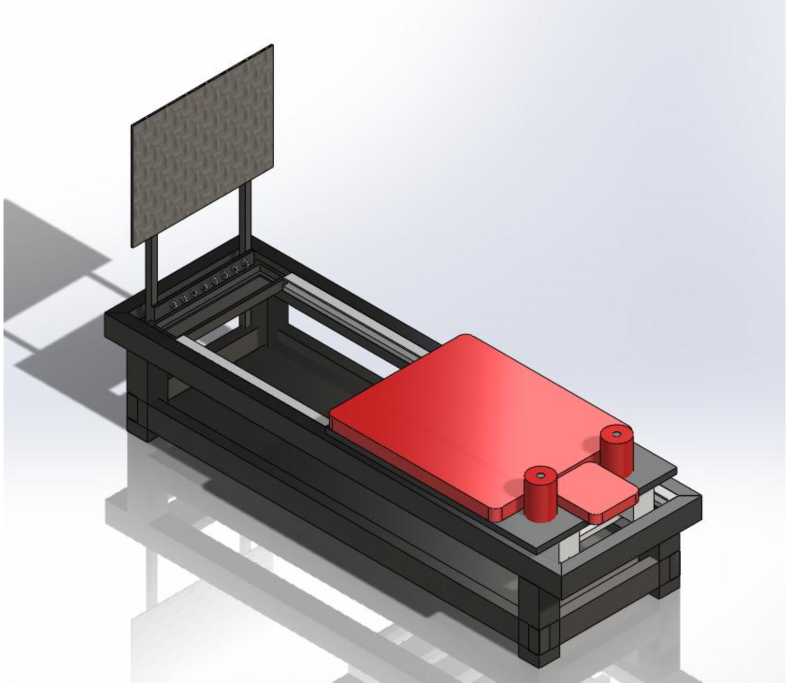


Figure 7: The base is composed of a rectangular frame, steel plate with steel supports extending to the bottom of the base, band attachment bar with eye hooks, and plastic track.

Each side of the frame is constructed from a 4-by-4 with a 1.5-by-2 extrusion along which the track and band connection plate lay. The end of each side was cut at a forty-five degree angle and fit together at the corners.

After multiple designs ideas and matrices, we have taken the advice of Chet to use a mortise tenon joint to connect the legs of the device to the frame. A mortise is a recess cut into a piece of wood that accepts a tenon while the tenon is the cheek at the end of a board that fits into a mortise. Using a mortise and tenon joint provides not only simplicity to the design but strength. The legs will be the tenon and the frame of the device the mortise.

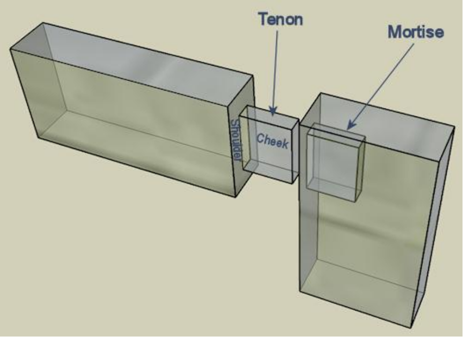
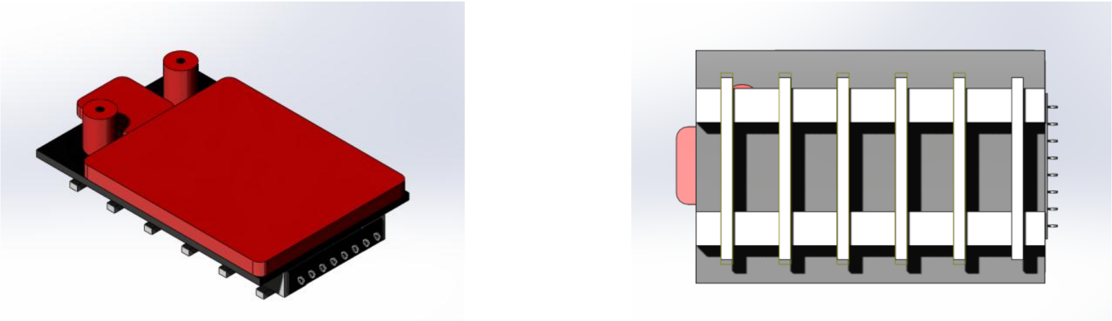


Figure 8: Tenon and mortise joint used for connecting the legs to frame of device.

The side of the frame is further reinforced by support beams running parallel to the frame. These beams will prevent the legs from shifting outwards when a patient lays on the device. When performing the exercise, the patient will lie on his or her back with their feet pressed against the steel plate at a 90° angle. As they extend their legs, the carriage will slide along the plastic track resisted by metal springs. Up to eight springs may be connected via carabineers on eye hooks to the front of the frame and the front of carriage. When one desires to increase resistance of their exercise, they may simpy hook another spring to the connection bar at the front of the frame.

The carriage component will be composed of a cushioned back and headrest and padded shoulder supports. The shoulder supports will be the site of the reaction force due to the spring resistance and must be composed of a lot of padding to reduce shoulder injury. To alleviate some of this stress and provide patients with further stabilitity, implementation of handles is still being considered, and must undergo comparative decision making when destermining the safest way of including them. In addition, the carraige has a set of five plastic sliders located on the bottom, which extend outwards and insert into a plastic track. The carriage may then slide along the track which will be sprayed with a silicon lubricant to reduce friction. This silicon layer should last up to ten years, but may be reapplied if needed.



(a) **(b)**

Figure 9: The carriage component. a) Top view shows cushioned back and headrest, shoulder supports, and set of handles. b) Bottom view shows incorporation of plastic sliders to be inserted in the plastic track

V. Safety Concerns

The device should not put the patient at risk of injury due to treatment. To prevent this from occurring, a system of varying spring strengths was implemented to compensate for the varying physical needs of all patients. The maximum and minimum weights that can be used for patient treatment are 160 lbs. and 10 lbs., respectively. To ensure that the patient would not be injured by the springs, they are attached to eye hooks with carabineers thus eliminating the possibility of slipping during use of the device. The carriage component was also moved forward to cover the eye hooks in order to minimize potential patient injury if one of the springs were to fail.

The device itself should also not pose any possibility of causing the patient harm. To minimize potential injury from falling, the height of the device does not exceed two feet and the carriage was designed to be wide enough for patients of larger stature to lie comfortably on their back. Additionally, the device was designed to be free of sharp edges and protruding parts. For this reason, the addition of handles has currently been removed from the design. Having handles that protrude from the device would be a potential obstacle when getting on and off as well as a potential source of failure if a patient were to apply their entire weight an individual handle. Support beams were also incorporated around the entire base of the device to ensure structural stability when experiencing large forces due to patient loading.

The large forces that will be exerted on certain components of the device were also a safety concern. To ensure that the footplate and its supports would not fail, they were constructed out of stainless steel and welded together. This entire component was then attached to the inside of the wooden frame to increase the number of connection points between the steel and wood. The spring connections were also made from steel and incorporated in the footplate component because of they need to be able to withstand repeated forces of up to 160 lbs. The shoulder supports were the final component made from steel. They were designed to spread out the reaction forces experienced by the shoulder during leg extension and were covered with padding for patient comfort. Additional shoulder padding will also be supplied with the device to ensure that repeated use of the device does not cause the patient physical discomfort or harm.

In regards to sanitation, the cushioned components of the carriage are covered with vinyl that can be wiped down and cleaned with disinfectant spray after each time that the device is used. This will reduce the spread of disease amongst patients will maintain a healthy environment within the clinic.

VI. Standards and Regulations

The regulations regarding medical devices that are constructed in the United States and implemented in Honduras are virtually nonexistent. Decisions regarding the approval of medical devices for use in the United States are directed through the American Society for Testing and Materials (ASTM) as well as the International Organization for Standardization (ISO). The ASTM produces an international standard for testing methods as well as specific standards for a variety of medical devices. The ISO also provides a list of regulations associated with best testing practices that are used all over the world. The device that we designed is considered to be a class one medical device because it is not intended to support or sustain life. In addition to this, it is also not substantially important in preventing human health impairment and does not present an unreasonable risk of illness or injury (FDA). Despite the lack of regulations associated with this device, we designed and tested the each component based on ethical standards such as the accuracy of treatment, patient safety and ergonomics.

VII. Spring Testing

Once the design decision was made to use springs as our resistance forces, it was necessary to create a setup for testing the forces and displacements within the springs. We ordered extension springs from The Hillman Group (The Hillman Group). It was decided to purchase three different springs each with different maximum loads. Spring #193 had an overall length of 9.0 in and maximum load of 9.75 lbs.; in our testing this spring was referred to as ‘Spring B.’ Spring #198 had an overall length of 10.0 inches and maximum load of 20.94 lbs.; this spring was referred to as ‘Spring A’ in our testing. Spring #200 had an overall length of 10.25 inches and maximum load of 44.12 lbs.; this spring was referred to as ‘Spring C’ in our testing. From the Hillman Spring information sheet the lbs./inch was also provided. Spring A had 2.28 lbs./inch, Spring B had 0.93 lbs./inch, and Spring C had 0.80 lbs./inch. All of this information was vital in ensuring our data from testing was valid and accurate.

The testing setup consisted of using clamps, a 2000 lb. capacity winch, and a weight scale. The springs were clamped down on one end and attached to the weight scale on the other. The weight scale was then connected to the winch which was clamped securely down see figure 15. The testing began with recording the springs initial coil length and loading the spring into the setup. The spring was loaded until the weight scale read a certain increment in pounds. For Spring A these increments were 20, 30, 40, 50 lbs., for 'Additive Testings' the increments were 20, 30, 40, 50, 60, 70 lbs., for Spring B the increments were 10, 15, 20, 30 lbs., and for Spring C the increments were 40, 60, 80 lbs. When these loadings were reached the length of the coil was measured again, the displacement was calculated, and a run was considered complete. Spring A and Spring B testing consisted of three runs and done on two different springs, resulting in a total of six runs per spring type. This was to ensure enough data and that the runs were consistent. Spring C consisted of only one run due to the fact that it had a higher maximum load than our device required. Additive testing was done using sets of two and three combinations of Spring A. From the data collected graphs of the force (lb.) versus displacement (in) for Spring A, Spring B, Spring C, and the Additive Testing were created see figures 9-13.

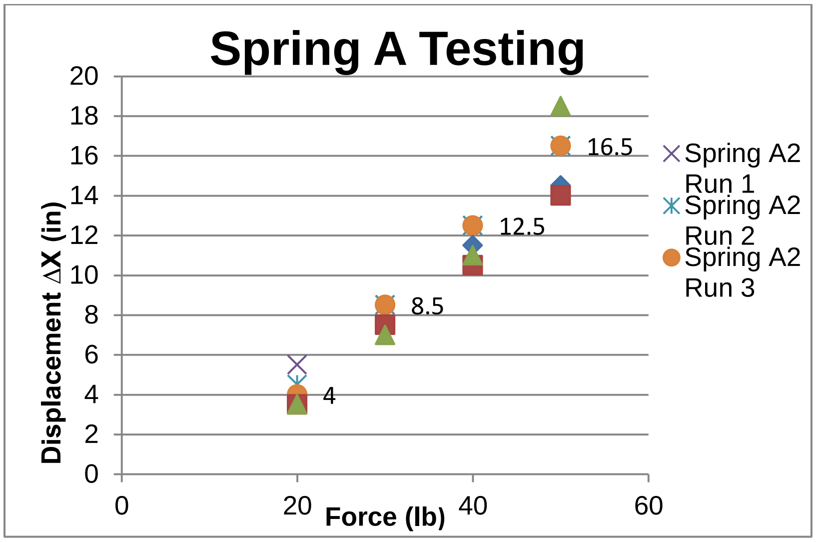


Figure 10: Spring A had a maximum load of 20.94 lb. This data was gathered by individually testing how much force was felt by the spring as well as the corresponding displacement. This test was run a total of three times.

Our analysis consisted of using the force-spring equation

$F= k \Delta x$ (Equation 3)

This force-spring equation can be manipulated to show the addition of forces when loaded in parallel.

$F_1=k\Delta X_1$ (Equation 4)

$F_2=k\Delta X_2$ (Equation 5)

$F= F_1+F_2= k_2 (\Delta X)$ (Equation 6)

The additive tests were also consistent with the provided data and the parallel force-spring equation. A succession test consisting of loading Spring A and Spring B was also performed. This demonstrated that when loading Spring A and Spring B simultaneously that Spring B did not contribute to the load until a displacement of 4 in was made see table 3. From the graphs it can be seen that our runs were consistent with each other for each spring testing. The data label on one of the runs shows that our testing is comparable to the data of the spring rate provided from Hillman Spring Group.

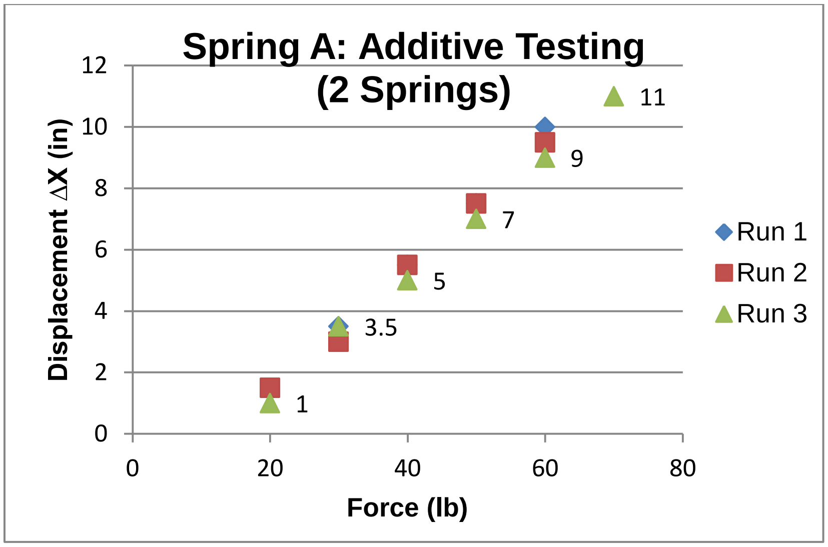


Figure 11: Two idential versions of Spring A were used to show that the springs would have an additive effect when subject to a force in parallel.

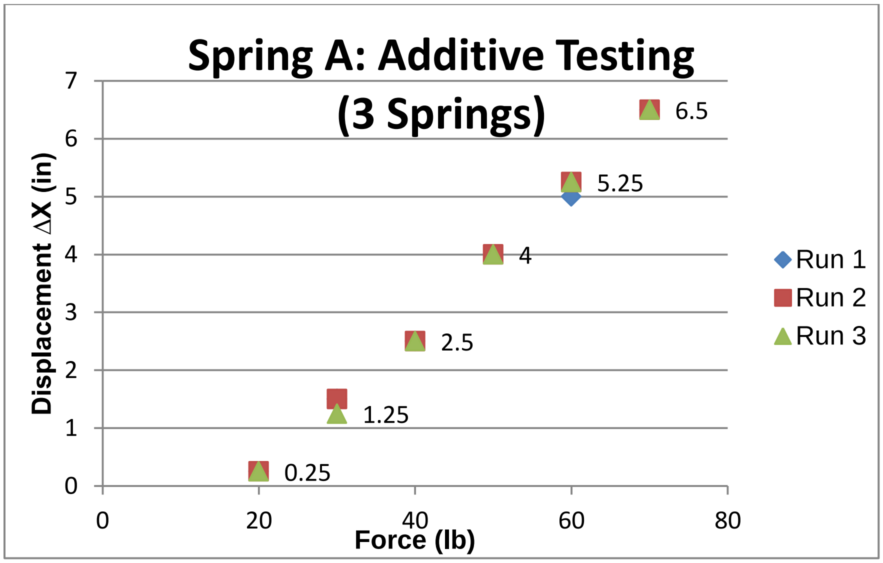


Figure 12: Three idential versions of Spring A were used to show that the springs would have an additive effect when subject to a force in parallel.

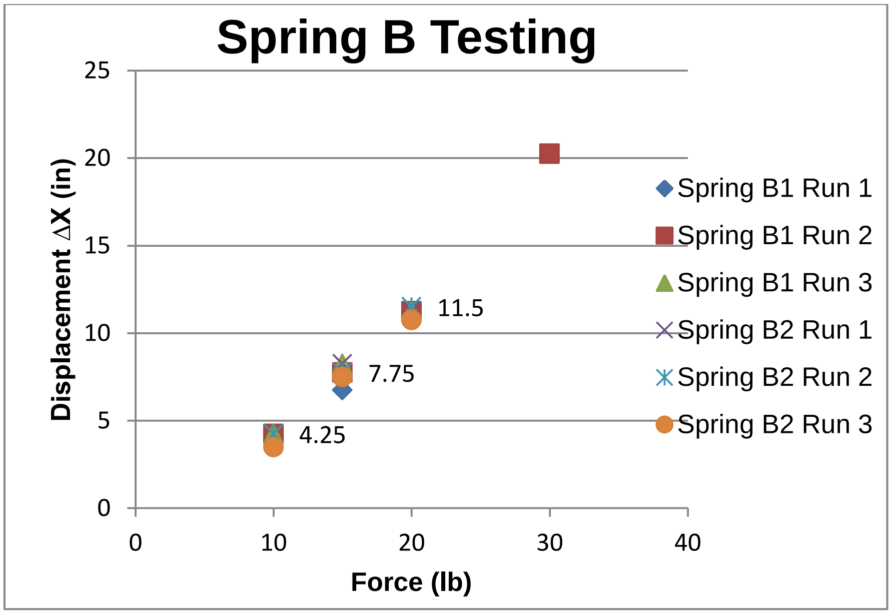


Figure 13: Spring B had a maximum load of 9.75 lb. The data on the left was gathered by individually testing how much force was felt by the spring as well as the corresponding displacement. This test was run a total of three times on two different springs.

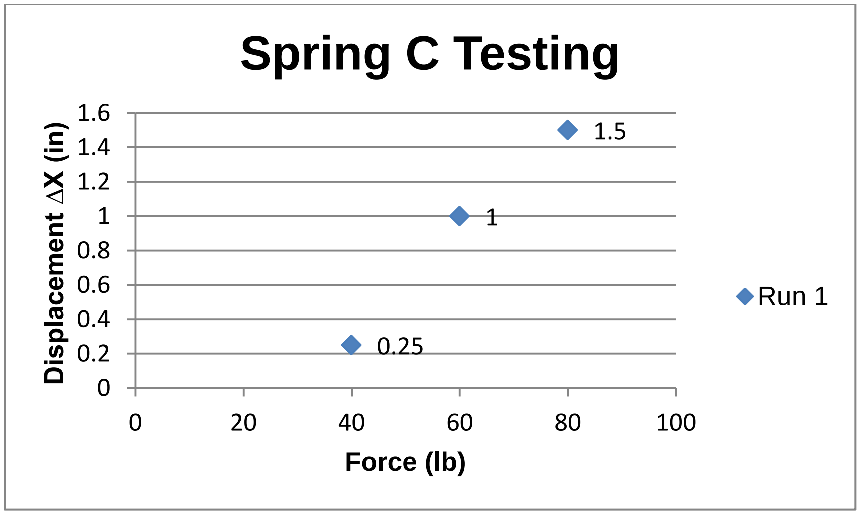


Figure 14: Spring C had a maximum load of 44.12 lb. This data was gathered by individually testing how much force was felt by the spring as well as the corresponding displacement.

Once this displacement is reached the desired additive load will be achieved. It can be shown from our tests that with increasing displacement the overall load increases. It will be useful for rehabilitation to know when certain loads are reached. These specific values are located on the graphs created from the spring testing data (Figure 11 and 12).

Figure 15: Entire testing setup displayed including the clamp, spring, weight scale, and winch.

Figure 16: Spring A attached to weight scale and winch prior to being stretched

Figure 17: Three Spring A attached to weight scale and winch prior to being stretched for the additive testing.

VIII. Conclusion

Working in collaboration with the UW Madison Physical Therapy Department, we were successful in designing and fabricating a device that will be used at CRILA for the rehabilitation of the lower extremities. The device can also be easily replicated in Honduras using materials that can be obtained locally. Provided in the appendix is a materials list that will serve as a guide for replication of the device. Tests on the resistance mechanisms were done to ensure that the device was producing the proper amount of force thus validating it as an effective closed chain exercise.

IX. Future Work

Although our device is complete, there are places for improvement and future work. An element of our design that requires modification is the shoulder supports. Currently, they do not optimize patient comfort due to inefficient distribution of force along the patient’s shoulders. Solutions to this problem include: forming additional padding or creating new supports out of a material other than steel. Additionally, incorporating handles onto the carriage is another aspect of the design that we would like to modify. Providing handles for the patient to use would increase patient stability and safety when performing the exercises.

In addition to design modifications, we also plan to implement the device at CRILA in the spring of 2013. Traveling to Honduras and hosting a workshop in Le Ceiba to teach women engineering and physical therapy skills is essential. This workshop would include training the women in developing additional models of the device, which will correspond to improving the healthcare of the community. Through this process we hope to provide the women of Honduras with knowledge, skills, and opportunities for economic and social advancements.

In conclusion, this is not simply a BME300/200 design project for us; we have an overarching intention to influence and empower women to pursue careers and opportunities in engineering and science.

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Appendix

Product Design Specifications

Lower Extremity Rehabilitation Device for the Use in Developing Countries

Product Design Specification Report

Team Members
Hannah Meyer: Team Leader
Maria Maza: Bwig
Andrea Schuster: Bsac
Amy Slawson: Communicator
Alenna Beroza

6/28/12

5:30- 7:00 PM

Product Design Specifications

Function: The device will aid the patient in strengthening their lower extremities by allowing the patient to lie on their back with their knees at a ninety-degree angle and feet pressed against a static solid plate. The patient can then move by extending their knees. Six elastic bands will be used to attain increasing resistance, which will aid in strengthening of the lower extremities throughout a patient's treatment plan.

Client requirements:

CRILA's requirements for the design include that the device be cost effective, portable within the clinic, and easily replicable in Honduras with local materials. Additionally the design should be constructed in a multiple part assembly for ease of transportation and require low maintenance.

Design requirements:

1. Physical and Operational Characteristics

a. *Performance requirements*:

The device will be used as part of a treatment plan to strengthen the lower extremities of patients undergoing rehabilitation.

b. *Safety*:

The device should not put the patient at risk of injury from the treatment and the device itself should not cause the patient harm. The height of the device should not exceed two feet and should incorporate a safety belt to secure the patient while the device is in use.

c. *Accuracy and Reliability*:

The device must be able to withstand a high frequency of use by a variety of different patients. Each elastic band on the device should provide the same amount of resistance with each use.

d. *Life in Service*:

Under frequent use and humid conditions, the device itself should last for approximately ten years with the elastic bands lasting for three to five years.

e. *Shelf Life*:

The device must be portable within the clinic and easily replicable in Honduras. The device should be able to withstand a hot and humid environment.

f. *Operating Environment*:

The device will be used in a hot and humid environment and thus must be built of corrosive resistant materials. It must also be compact enough to fit in a small rehabilitation center. Due to high frequency of use by patients of different skill level, the device must be durable.

g. *Ergonomics*:

The device is intended for use by young adults to elderly. It is not intended for use by children, people with back problems, or pregnant women. The device should be solely used for the rehabilitation of lower extremities. For patient comfort the device will include a back cushion and shoulder pads. The device will allow the patient to lie flat with no incline angle, such that the hips and torso are at a 90 degree angle with respect to the knees. In order to accommodate a variety of patients the static plate must be vertically adjustable and include a space at the bottom to allow ankle and calve rehabilitation. For the ease and convenience of the staff working with the patient, the device will be raised to a height not exceeding two feet.

h. *Size*:

The length of the device must be long and wide enough for the average person to comfortably lie back. The dimensions of the device must be X by X feet. The device should be easily portable and assembled within the clinic by two people.

i. *Weight*:

The weight of the device should not exceed 200 pounds. Wheels may be incorporated for ease of transport.

j. *Materials*:

All the materials used to develop the device should be locally available and affordable in Honduras.

k. *Aesthetics*, *Appearance, and Finish*:

The device should be aesthetically pleasing and if possible include UW Badger reference.

2. Production Characteristics

a. *Quantity*:

One device should be constructed in Madison, WI while the others will be replicated in Honduras.

b*. Target Product Cost*:

The target cost of production needs to be less than $500.

3. Miscellaneous

a. *Standards and Specifications*:

Currently, there are no standards and regulations in place for the use of the device in Honduras.

b. *Customer*:

The device will be implemented at the CRILA rehabilitation center in Honduras. The customer requires that the device be low cost, portable, replicable, durable, and manufactured with local materials.

c. *Patient-related concerns*:

Due to the low staff to patient ratio, the device must be safely operated by the patient with minimal assistance.

d. *Competition*:

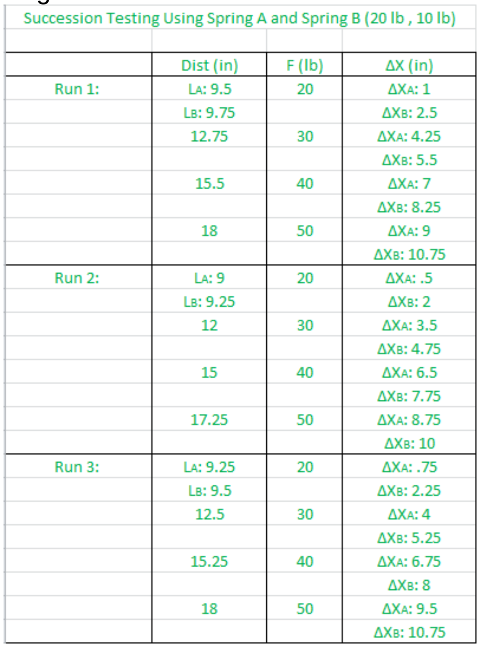
The following devices are currently used for strengthening lower extremities shuttle, leg press,

Project Timeline

Week	**6/10-6/16**	**6/17-6/23**	**6/24-6/30**	**7/01-7/07**	**7/08-7/14**	**7/15-7/21**
Task						
Introduction of Product	X					
Questions for client	X					
Meeting with client		X				
Problem Statement		X				
Design Requirements		X				
Product Design Specifications			X			
Research on patents			X			
Research papers on similar devices				X		
Research on commercial products				X	X	
Meeting with Chet Hermansen					X	
Fundraising					X	X
Rough Draft of fundraising pamphlet and letter						X
	7/22-7/28	**7/29-8/04**	**8/05-8/11**	**8/12-8/18**	**8/19-8/25**	**9/02-9/08**
Site visit with client	X					
Extensive research on commercial products	X					
Brainstorming	X					
Preliminary design	X					
Woodworking Pass	X					
Decision Matrix		X				
Original Design		X				
Solidworks of original design			X			
Presentation for client				X		
Revised problem statement				X		
Meeting with Physical Therapy graduate students					X	
Fundraising	X	X	X	X	X	X
	9/09-9/15	**9/16-9/22**	**9/23-9/29**	**9/30-10/06**	**10/07-10/13**	**10/14/10/20**
Meeting with client	X					
Design Modifications from feedback	X	X	X	X		
Meeting with Kendra Zimmerman	X					
Meeting with Wally Block about fundraising		X				
Medical Regulations from Tiffani Diage	X	X				
Site visit to Chet's shop			X			
Final Design and Solidworks			X			
Fundraising	X	X	X	X	X	X
Presentation for design class			X			
Presentation for Hackett Hemwall Foundation				X		
Presentation for EGR 160					X	
Mid-semester presentation					X	
Mid-semester report						X
	10/21-1027	**10/28-11/03**	**11/04-11/10**	**11/11-11/17**	**11/25-12/01**	**12/02-12/08**
Cut legs to size	X					
Design modifications of track	X					
Fabrication of mortise and tendons	X	X				
Cut wood of base to size and plastic track	X					
Fabrication of footplate	X					
Base frame squared		X				
Fitted legs with base		X				
Gussets and plastic sliders cut		X				
Design modifications			X	X	X	X
Frame painted			X			
Designed testing mechanism for resistance			X			
Band Testing				X		
Meeting with Physical Therapy students and input on design				X		
Fabrication of carriage component				X	X	X
Testing of Bands				X		
Testing of Springs						X
Completion of device						X
	12/02-12/08	**12/09-12/15**	**1/06-1/12**	**03/09-03/16**		
Final presentation	X					
Prepare device to be shipped		X				
Device sent to Honduras			X			
Device implemented in Honduras				X		
Training of fabrication and use of device in Honduras				X		
Fundraising	X	X	X	X		

Spring Testing

Table 3: Succession testing was also done using springs of varying maximum loading values. Springs A and B, with maximum loads of approx. 20 and 10 lb respectively, were used to confirm that springs of varying length and stiffness would also have an additive effect when used together.



Succession Testing Using Spring A and Spring B (20 lb , 10 lb)

	Dist (in)	F (lb)	ΔX (in)
Run 1:	L_A: 9.5	20	ΔX_A: 1
	L_B: 9.75		ΔX_B: 2.5
	12.75	30	ΔX_A: 4.25
			ΔX_B: 5.5
	15.5	40	ΔX_A: 7
			ΔX_B: 8.25
	18	50	ΔX_A: 9
			ΔX_B: 10.75
Run 2:	L_A: 9	20	ΔX_A: .5
	L_B: 9.25		ΔX_B: 2
	12	30	ΔX_A: 3.5
			ΔX_B: 4.75
	15	40	ΔX_A: 6.5
			ΔX_B: 7.75
	17.25	50	ΔX_A: 8.75
			ΔX_B: 10
Run 3:	L_A: 9.25	20	ΔX_A: .75
	L_B: 9.5		ΔX_B: 2.25
	12.5	30	ΔX_A: 4
			ΔX_B: 5.25
	15.25	40	ΔX_A: 6.75
			ΔX_B: 8
	18	50	ΔX_A: 9.5
			ΔX_B: 10.75

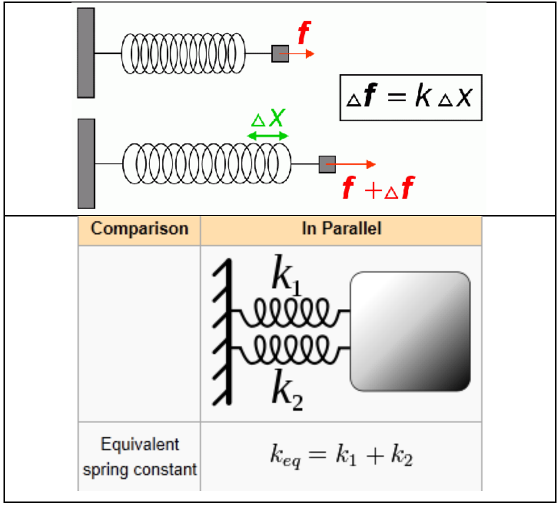


Figure 18: Spring force manipulation calculation for springs in parallel (10).

Equation 1: $\varepsilon_{max} = (M_{max}\ C) / IE$
Equation 2: [F= k Δx] where F is the force in lbs, Δx is the displacements, and k is the spring constant.
Equation 3: $F=k\Delta X$
Equation 4: $F_1=k\Delta X_1$
Equation 5: $F_2=k\Delta X_2$
Equation 6: $F= F_1+F_2= k_2(\Delta X)\ F_1=k\Delta X_1$

Costs and Fundraising

Thus far, we have been awarded $3644 from the Kemper K. Knapp Bequest Committee of UW Madison for the research and development of our device. Roughly only $500 of this grant is issued to us for the fabrication of the device, while the rest is for the travel funds of the PT Department. It has been estimated by Chet and others who have gone to Honduras in the past through the Hackett Hemwall Foundation that the cost per person is roughly $1500-$2000. With five engineering students that puts us at a goal of $10,000 (Figure 19).

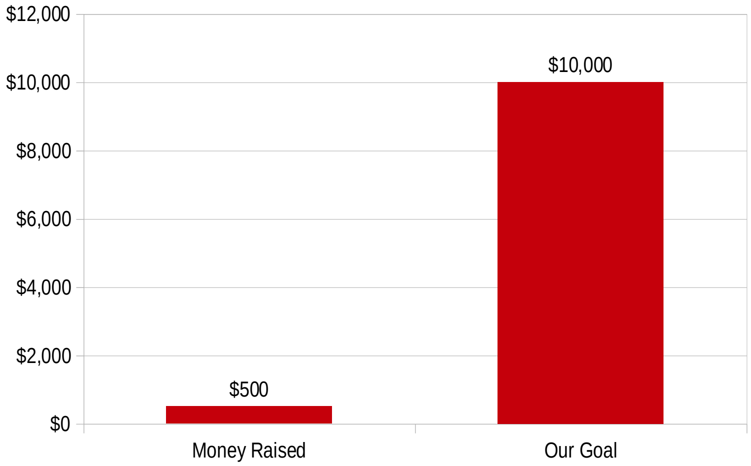


Figure 19: Bar graph of money raised and our goal for

With our timeline for traveling to Honduras quickly approaching we have been fundraising over the past few months to hopefully gain the funds for traveling to Honduras ourselves. Beginning in August we began researching and applying to additional grants we found through the Alumni Association and UW-Madison programs. On October 10th, 2012 we sent out a fundraising letter to over 150 engineering corporations and companies in the Madison area. We have also spoken on October 18th, 2012 at the Hackett Hemwall Conference for over a hundred doctors and physicians, after which we handed out our fundraising letter and a gift donation sheet. Additionally, throughout the process of our design we have been filming our progression through the design process and fabrication. Not only do we hope to use this as a media video for influencing and empowering women in science and engineering, but we also will create an instructional video for the fabrication and assembly of our device. We hope that through all of our efforts we will be able to reach our goal of $10,000 and travel with the PT students, Karen Patterson, and the Hackett Hemwall Foundation to Honduras.

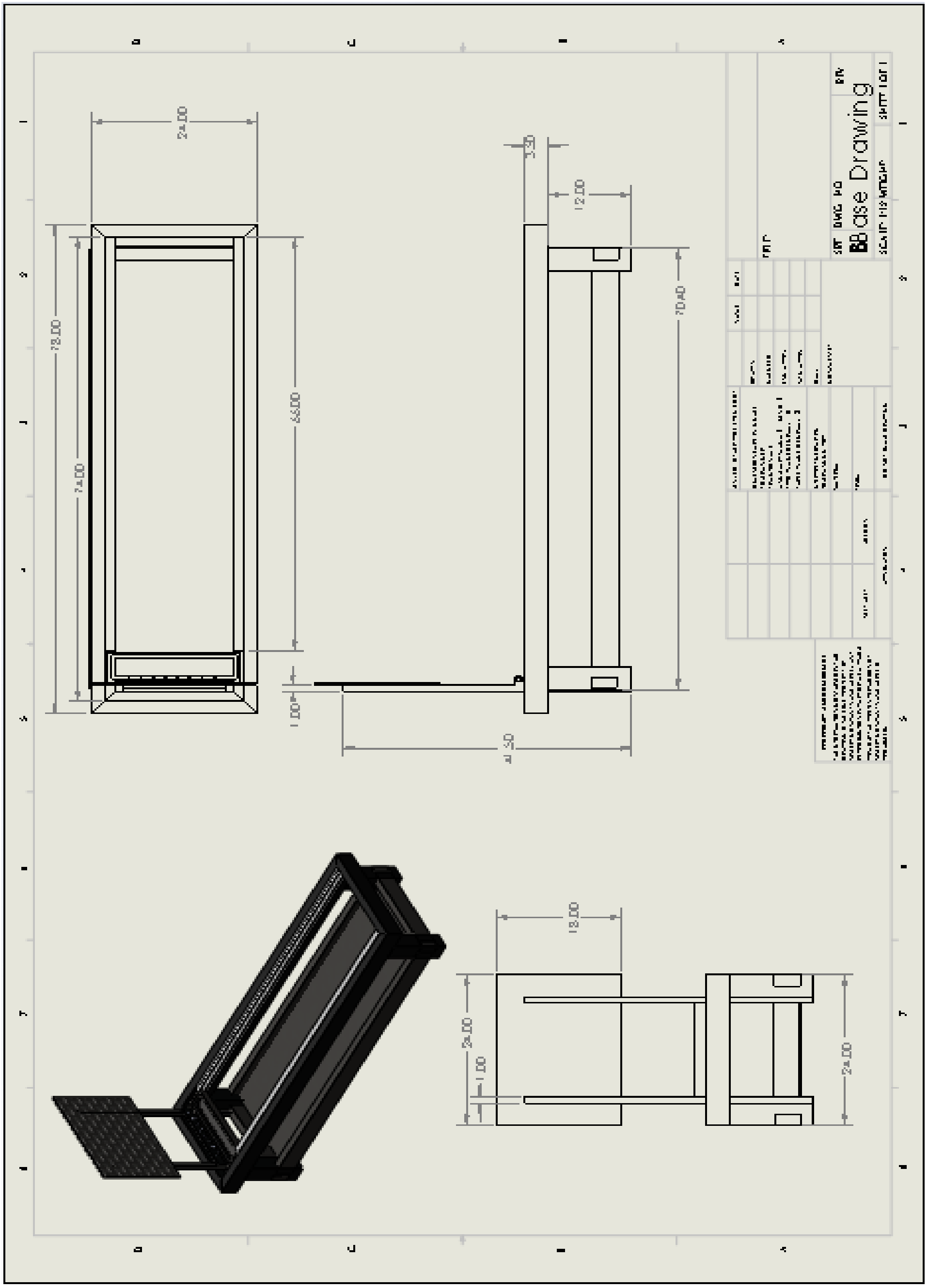


Figure 20: Final SolidWorks schematics for the frame, track, and footplate.

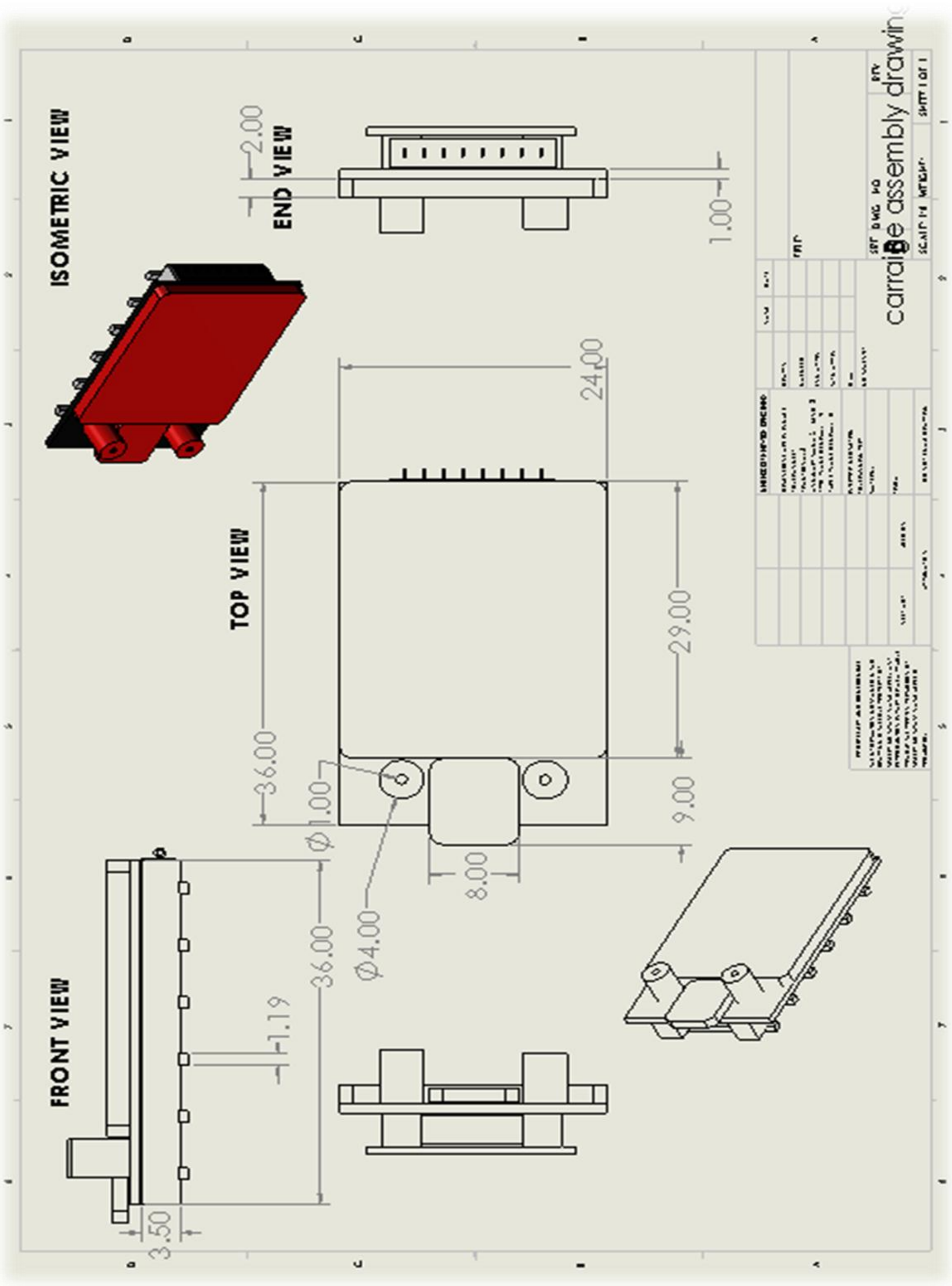


Figure 21: Final SolidWorks Schematics for the carriage component.

Materials List

Place of Purchase	Item	Price
Menards	4x4-10' Treated Wood	$11.97
	4x4-8' Treated Wood	2@ $5.97 each → $11.94
	4x4-6' Treated Wood	$5.69
	1x4-8' Treated Wood	2 @ $3.57 each → $7.14
	Fir Closet Pole WM233	$7.48
	2x4-10' Stud/#2&BTR SPF	$3.30
Hillman Spring Group	Spring #193 [9.75 lbs. max load)	4 @ $4.35 each → $17.14
	Spring #198 (20.94 lbs. max load)	8 @ $6.75 each → $54.00
	Spring #200 (44.12 lbs. max load)	2 @ $10.65 each → $21.30
	UHMW Polyethylene	
	Steel	$45.00
	Silicone	$642.94
Ace Hardware	Bolt/Nuts	$21.09

	Shoulder/Brackets	$20.00
	Glide Pads	$8.49
	Carabineers	$39.03
	Paint, Brushes, & Cleaner	$57.15
Place of Purchase	**Item**	**Price**
Ace Hardware	Spray Paint	$17.07
	Wood Glue and Screws	$31.48
	Eye Bolts	$9.45
	Vinyl Cushions and Sewing	$130.00
	4 Pillows	$75.00
Walgreens	Stamps	$45.00
		Total: $632.96