Final Report

Assisted Leg Holding Device For Medical Procedures

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Abstract

The following explains how the assisted leg holding device for medical procedures can be optimally designed to aid medical personnel and patients with the use of medical stirrups. The device will allow medical personnel to adjust and lift the patient into the device with minimal effort via an anti-gravity mechanism. Additionally, minor adjustments will be accomplished using locking rotational devices that mimic the natural movement of the hips while repositioning the patient for optimal alignment during a given procedure. Current devices on the market lack the adjustability and flexibility required for many of the RERC patients.

Several specific patient populations are targeted in the RERC competition. All of the clients that must be accommodated using the assisted leg-holding device have some form of disability. The most difficult clients to consider are the two with amputated legs. Many traditional leg holding devices rely on supporting only the foot of the patient. The proposed device must allow for support in other areas of the leg as well as the foot so that these patient’s limbs can be positioned. One client has a spinal cord injury, causing difficulties for the practitioner who has to position the patient’s legs without any help from the patient. Several of the clients have joint pain, which may be exacerbated if they are placed in leg holding devices. The device detailed below will have controlled range of motion and ample padding in order to secure the most comfortable position for the patient, and will adjust from a comfortable sitting position so that it is not difficult to get these patients into the device. The patient with Parkinson’s has tremors as well as weak joints, so straps will be included in the design to prevent him from moving too much during a procedure. Finally, the device will be adjustable so that even the patient with very short stature can use it comfortably.

This device will allow medical personnel to sit the patient on the examination table, position the patient’s feet into the assisted leg holding device and make the necessary adjustments with minimal gravity forces against the medical personnel. Then while the patient lies back, the practitioner can use the anti-gravity device, a combination of an adjustable spring with a crank, to move the patient’s legs against gravity with minimal effort. The patient can be locked at the level required for the medical procedure. Additional modifications of positioning can be made to the foot and knee/thigh holders at this time. Finally, the practitioner can adjust the fine angle of the patient’s leg using the long handle and the fine adjustment clamp and locking mechanism attached to the table.
1. Introduction

Contained within these pages is a detailed outline for the creation of an assisted leg holding device for medical procedures. The use of such device is required for many medical procedures for both sexes. Such devices currently available today cannot be adjusted to accommodate patients outside of the “normal” range. In these devices, it is difficult for a medical practitioner to position patients who have muscle weakness or disease, Parkinson’s disease, arthritis, or those who are very overweight. Therefore, a modification to existing technology is required that opposes gravity, in order to simplify the positioning process.

1.1 Background

In the United States, about 51.2 million people are disabled where one-third; about 15 million people, are of age 65 or older. Arthritis and other rheumatic conditions are a leading cause of disability in the United States. Also, about 13.4 million Americans have serious physical disabilities such as back problems, arthritis and orthopedic injuries. Patients with the physical disabilities stated above in combination to paralysis, amputation, muscle atrophy, or obesity often has problems with traditional leg-holding devices. These problems stem from the lack of adjustability of such devices. The use of an assisted leg holding device is required for many medical procedures; such as knee surgery and physical check-ups. Such devices currently cannot be adjusted to accommodate patients outside of the “normal” range. In these devices, it is difficult for a medical practitioner to position patients who have muscle weakness or disability, Parkinson’s disease, arthritis, spinal injuries, or those overweight. Therefore, a modification to existing technology is desired by the medical society that opposes gravity, in order to simplify the positioning process. Finally, current models lack padding and coating to increase comfort for people in the populations mentioned above.

1.2 Purpose

It is important for the patient to have a positive experience to increase likelihood of completing a screening test. Where traditional devices are used, patients often experience anxiety in addition to physical pain caused by the supports. Part of this anxiety could be alleviated by creating a device that is comfortable to sit in, and does not require difficult or awkward positioning by the patient. The proposed clients require an anti-gravity device that will allow positioning of the legs either by the patient themselves or the practitioner. The device should be comfortable, versatile enough to be used by a wide variety of patients, and should adhere to medical standards.

Patients with physical disabilities such as paralysis, amputation, arthritis, muscle atrophy, or obesity often has problems with traditional leg-holding devices. These problems stem from the lack of adjustability of such devices. The main purpose of this project, therefore, is to produce an alternative leg-holding device that is low in cost and easily adjustable, as well as reduces strain on the patient and practitioner. The proposed device should be compact and easy to relocate so as not to hinder other examinations. It must meet medical sterilization requirements, and must be easy to clean in between examinations. In order to improve a patient’s
experience with this type of procedure, the device should not be imposing or intimidating, and should look and feel as comfortable as possible. Finally, the device should be durable and reliable so that it can withstand many examinations.

1.3 Previous work done by others

Drs. Tariq Rahman, Rungun Ramanathan, Rahamim Seliktar, William Harwin have conducted research on simple techniques for anti-gravity articulated mechanism. According to the article, kinematics and linear springs were used to produce a non-linear restoring force to oppose the gravitational moment. The researchers examined two of their experimental techniques. One of the techniques was done by using passive balance system where one could add a counterweight so that the mass center was coincident with the pivot point and the other was done using stored energy in springs to counter the effects of gravity. In conclusion, they found that the easiest method for anti gravity mechanism was to use spring system because no undue energy was added to the device which provided a non linear spring system.

The second research paper was also done by Dr. Tariq Rahman and his groups where they researched on the development and preliminary testing of a functional upper limb orthosis for people with physical disabilities. In this article, they used linear elastic techniques to counter effect the gravity and four degrees of freedom at two links for better movement and stability. According to their report, they developed a prototype that would assist disabled people for their daily routines such as eating, reading and doing simple house activities unassisted. Hence, although the research was done for the hand orthosis, similar mechanism would be taken in consideration to our design.

1.3.1 Products Research

Current designs for leg holders for medical procedures vary only slightly in positioning techniques. Most competitors offer an anti-gravity system that can be adjusted by the physician, however, current models offer limited supports built into the system for the comfort of the patient. Additionally, many systems are designed to only meet a limited range of operations and are not flexible enough to accommodate the variety of medical needs to leg holders.

Shown in figure 1.1 below are Allen Yellofin™ Lithotomy Stirrups. This innovative design allows for intra-operative re-positing of patients and is ideal for laparoscopy. Additionally, the Yellofin™ uses a Biotrac Joing Technology™ that mimics natural motion of the hip. Ergonomic boot design helps eliminate pressure under the fossa where the peroneous nerve is superficial. The slip boot clamp prevents excessive pressure on the calf. The system accommodates patients up to 350lbs and is available in a 500lb. version.
Figure 1.1 Allen Yellofin™ Lithotomy Stirrups [1]

Figure 1.2 shows the PAL Pro Power Assisted Lithotomy Stirrups. Power assisted for controllable level of lithomo and abduction, these stirrups come with a self adjusting floating boat to minimize pressure on the calf. The Feather Lift™ hand allows control of the stirrups through the lithotomy safe zone. The power-assist mechanism is protected by a rigid, durable cover. Abduction adjustments are made quickly from the end of the boot.

Figure 1.2 PAL Pro Power Assisted Lithotomy Stirrups [2]

Shown in figure 1.3 below are the Candy Cane Stirrups by AliMed. A viscoelastic gel with the same density of adipose tissue is used to support the malleolus and lateral portion of the knee with this simple and convenient device.
Allen R Deluxe Arthroscopic Legholder System for Knee Surgery are shown in figure 1.4 below. The hinged upper brace accommodates all patients seizing with this uni-directional locking mechanism that ensures a rigid fixation. The structurally enhanced design enables staff to apply pressure both medially and laterally. The straps allow for easy adjustment for the precise amount of compression.

1.3.2 Patent Search Results

Before undertaking the design of any new invention, it is important to understand any devices that have already been created and patented, so as not to infringe upon these designs. Patents can be very helpful when trying to invent a new device such as the assisted leg holders, as most patent authors admit that those with knowledge of their designs should be able to come up with adjustments and improvements. Many of the patents that were found incorporated some component of what should be accomplished with the proposed device, and these can be combined and then modified in order to create an optimum design.

One of the earliest patents found pertaining to leg holding devices was patent number 2714541, approved in August, 1955. This patent describes a design for the improvement of stirrups used in operating procedures. These are the simplest type of leg holding devices, which only support the
patient’s foot. The benefit of this design is that it is extremely compact and can be easily stored to maximize space within the operating room.

Patent 3833211, approved in September of 1974, describes a clamping device that can be used for attaching the leg holding device to an operating table. This is an important consideration, as a sturdy connection must be made in order to prevent movement or slipping during a procedure.

In September, 1976, patent number 3982742 was approved. This patent is similar to 2714541 in that only the foot of the patient is supported. However, it suggests that a curvilinear rod should be used that extends from the edge of the operating table. This support system is supposed to enhance safety and comfort of the patient, as well as isolate the patient from any electrical shocks that might occur by making the device non-conductive.

Patent 4809687, which was approved in September 1989, is one of the first to suggest the use of a complete, cushioned shell that supports a patient’s foot, as well as a support for the patient’s upper leg. This is an important development, as it accommodates for patients with joint or muscle disease, similar to those who will be served by this most recent proposed invention.

The assisted leg holding device was again improved in 1990 with patent 4958816. This proposal introduces a compact mechanism for adjusting the leg holding device both laterally and longitudinally. In this way, patients who are not within the normal leg size range can be accommodated for, again something that is being considered in the design of this most recent proposed invention.

Patent 5369827 was a unique contribution to the field because it suggests a leg holding device that can be adjusted in three dimensions. This patent, approved in December 1994, also includes a stopping mechanism, so that a patient’s leg will not be over extended to an uncomfortable position.

In September 1998, patent 5802641 became one of the first to suggest a leg holding device that can be adjusted to support a patient against gravity. This design uses a motorized system to oppose gravity and raise a patient’s legs.

Finally, approved in July 1999, patent 5918830 proposes an alternative gravity opposing, leg holding device. Instead of using a motor, this design incorporates a ratchet system for adjusting a patient’s legs for a procedure.

1.4 Map for the rest of the report

The report will continue with a brief synopsis of the three design alternatives that were proposed throughout the semester. Following the alternative designs will be a detailed description, including calculations and figures, to outline the production of the optimal design. Each subunit will also be described individually in great detail. The final design, showing changes from the optimal design within each of the subunit sections follows. The prototype section with description and photos of each section of the device along with testing results from the prototype. The last few sections of the report will summarize the realistic constraints, safety issues, the impact of the design solution of the greater community associated with this project, as well as what the group has learned from this design. The budget, timeline and member contributions will follow in order to explain the plan for implantation of
the design. Finally, the conclusion will summarize the report in total and include the projects acknowledgements and resources.

2. Project Design

2.1 Design Alternatives

2.1.1 Alternative Design One

The purpose of alternative design one was to create a basic idea of the assisted leg holding device for medical procedures that can assist medical personnel and patients with the placements and adjustment of patients in medical stirrups. In this case, a spring will be used to oppose the patient’s weight and assist the medical practitioner in lifting the patient’s legs with minimal effort. As part of the design, the patient can be locked at the level required for the medical procedure, allowing additional modifications of positioning can be made to the foot and knee/thigh holders. Finally, the practitioner can adjust the fine angle of the patient’s leg using the long handle and the fine adjustment clamp and locking mechanism attached to the table. When not in use, the leg holding device proposed in this design can be easily stored out of the way of other medical procedures.

2.1.1.1 Subunits

2.1.1.1.1 Spring

For this alternative design proposal, the feature that has been changed significantly is the method used for lifting the device and the patient’s legs to the proper position for a medical procedure. Here, a series of springs will be used as the lifting component for the leg-holding device. There are both advantages and disadvantages to this method, which must be considered when conceiving an optimal design. Some of the advantages of using springs are that they are common and inexpensive to purchase. Unless a custom spring is required, the total cost for the four springs proposed for this design could be less than ten dollars.

By using springs, this device becomes completely mechanical, with no electrical components. Therefore, there is no need for a battery or voltage source, which makes this device smaller and less bulky, and also reduces any chance of electrocution of either the patient or the practitioner. Since there are fewer components using this method than if an electrical device was designed, there is less chance that a failure will occur. At the same time, if one of the springs were to fail or surpasses its lifespan, this is a very simple problem to fix. The springs in this design will be detachable, so that they can be easily replaced, and as mentioned above, replacement springs are inexpensive.

There are, however, some significant disadvantages to using springs rather than other designs. One of the most important disadvantages of this design is that it is very difficult to position the patient’s legs accurately in the exact position necessary for an examination or procedure. While it is possible to perform the calculations necessary based on a patient’s size and weight and the angle that is needed, this becomes time consuming and would be difficult for a practitioner to implement during an appointment. Even if a program was included that could perform the necessary calculations based on some inputs from the practitioner, this would still require that the springs be changed to customize for every patient,
causing unnecessary trouble for the practitioner. Luckily, it is shown later in this section that this problem can be overcome by choosing an acceptable range of angles for the device to allow after the patient is initially loaded, and then having the practitioner make the necessary adjustments based on the angles needed for each procedure. This will still greatly reduce strain on the practitioner by performing most of the lifting work, and the practitioner will only have to make fine adjustments in height, as well as adjust the degree of abduction/adduction and internal/external rotation.

Based on the evaluation of advantages and disadvantages of using springs in the design of the assisted leg-holding device, it can be concluded that this is a viable method of design. Below, figure 2.1.1 shows a diagram of how the spring component of the device can be incorporated into a general design of an assisted leg-holding device.

![Figure 2.1.1 General design of the assisted leg holding device, with the addition of the spring for lifting](image)

Before going into the mechanics of how the assisted leg holding device will work, there are several external features that should first be mentioned. The diagrams above show a view of the side of one of the leg holding devices. In order for the system to work, a pair of these devices are needed, one for each leg. In this way, a practitioner can adjust each of the patient’s legs individually if necessary. This will accommodate for surgeries in which one leg must be positioned out of the way, while focusing on the other leg. It will also accommodate for patients who may have more trouble with one leg, and might require a specific positioning.

As mentioned above, figure 2.1.1 shows only the side view of one of the leg holding devices. The leg holding device, which is attached to the operating table at its origin, is also attached by a spring that runs along the outside of the foundation support. This design is mirrored on the other side of the device, which would be the interior of the patient’s leg.

There are several advantages to the design described above. By having two springs, the weight of the patient’s leg is distributed more evenly. Less force is required by each spring, which, as will be described below, will cause less stretching of the spring and therefore less displacement of the leg. By placing the springs along the side of the device, they are kept out of the way and are unlikely to cause any pinching of the patient or practitioner. This problem could also be avoided by placing a casing around the springs as a part of the design.

The type of spring that has been chosen for this application is a constant force extension spring. Likely, it will be made out of stainless steel. This type of spring is inexpensive and easy to purchase or replace.
An extension spring is required because the device must be able to stretch across a variety of positions so that the patient can go from sitting to a supine position, and this type of spring accommodates for this requirement. The fact that the spring is made of stainless steel means that it is both sturdy and durable, and will not be likely to fail. A stainless steel spring is also corrosion resistant, and can be sterilized easily after each examination.

While it is not shown in detail in the diagram, each spring will be attached by a hook at both its origin and insertion. It is necessary to have the springs be detachable, since springs will receive wear over time and eventually will become stretched and cease to work properly. Since it is the spring that produces the force to lift the leg-holding device, the hooks that attach the springs to the device are potentially weak points, where failure could most likely occur. However, if this is taken into consideration, care can be taken to reinforce the hooks and to choose strong materials to ensure the safety of the device.

Upon referring back to figure 2.1.1, readers may realize one problem with the proposed spring design. As mentioned at the beginning of this proposal, the goal of this device’s design was to start patients from a sitting position. Allowing the patients to start in a sitting position reduces stress on both the patients and the practitioner, who might have trouble positioning the patients from a supine position. The spring design as described above does not allow for easy positioning of the assisted leg-holding device in such a position. Without any amendments, this design forces the practitioner to physically push down the device into sitting position, which causes several problems. First, although the pushing motion is easier to perform than an upwards pulling motion, the practitioner would still be required to exert enough force to overcome the upwards force produced by the spring, and hold the device in place for the patient. Essentially, this would defeat the purpose of the assistance feature of the leg holding device, as the practitioner would still experience a considerable amount of strain. Second, because the practitioner would have to hold the device, he would not be available to help position the patient in the device. This would cause inconvenience to both the practitioner and the patient, who may not be able to position himself independently.

In order to overcome this shortcoming, a crank mechanism was designed. Figure 2.1.2 shows the incorporation of this mechanism into the final assisted-leg holding device design. The crank will attach to the table and will contain a chain or cord that can extend and hook a designated area of the assisted leg-holding device. Considerations must be made when choosing the material to ensure that it will be strong enough to oppose the spring without stretching or failing.
To release...

Cord

Handle

Figure 2.1.2 Proposed design of the assisted leg-holding device with the inclusion of a crank mechanism.

The crank will include a handle, which the practitioner will simply have to turn to wind in the cord and adjust the leg-holding device. In order for this design to be useful, a ratcheting mechanism must also be included. This way, the device can be adjusted to any angle, based on the needs of the patient, and then locked into this position so that the practitioner is free to help the patient load into the device. Once the patient is safely adjusted in the device, the practitioner can unlock the crank and allow the spring to lift the patient to the proper position.

2.1.1.1.2 Attachment of the device to the table

Careful considerations must be made when designing the attachment of the device to the table, in order to accommodate all of the features described above. The attachment must allow translational movement in the x direction in order to allow the device to swing into storage position. It must not disrupt or interact with the springs. It also must allow adjustment of the device when the practitioner uses the handle system. The ideal system must be extremely flexible, while still allowing the device to be firmly attached to the table.

One way to accomplish this is diagrammed in figure 2.1.3 below. This figure shows the attachment mechanism via a cross sectional view. The attachment is inspired by the human hip joint, and by using similar principles allows for all of the same movements as the hip.
Figure 2.1.3 Cross-sectional view of the mechanism to attach the assisted leg-holding device to the leg of an examination table

The attachment system will include two parts. The outer part, labeled as “a” in figure 2.1.3, will be welded to the table leg and will consist of a solid hemispherical piece of metal with a hollow center. Part “b” of figure 2.1.3 is a ball that will be attached directly to the bar of the leg-holding device. This will be able to articulate within part “a”, much like the ball and socket design of the hip joint. Like synovial fluid is used in the hip joint, lubrication is a concern for this design, and steps must be taken to ensure that the surfaces between “a” and “b” remain well lubricated.

2.1.1.1.3 Bar and Associated Locking Mechanisms

From figure 2.1.1, part D shows the bar that will be the foundation of the device, which helps to position the patient’s leg as desired. This type of design was chosen after much consideration of the different methods currently used and available. Part D will be used as an attachment for the other parts of the device, and will support the whole device. Making D a rigid bar will allow for fewer joints, which means that less of the device will be subjected to torques and stress concentrations. A handle, part F, will be attached to the end of part D. This handle will make it easy for the practitioner to move and adjust the leg holding device to the proper position.

A locking mechanism will be applied to the design. The dotted line, labeled as part b in figure 2.1.3 above, shows the small rod used inside part D which helps to lock the device at desired position in x-y plane. The proposed bar will be cylindrical in shape and be slightly longer and about half the diameter than part D in order to withstand the pressure caused by the patient’s body weight. The cylindrical rod will have to be made out of metal because of good corrosion and mechanical properties. Stainless steel is one of the material to fit our need as it is widely used on medical field because of its high mechanical properties and as well as easy to sterilize if needed.

The main reason to have locking-unlocking mechanism for this proposed design is to provide security for the patient and the practitioners. In the medical field, safety and injuries related to the medical device is the key issue as it could cost someone’s life and could potentially put the hospital on safety violation. Above is the circular shape plate that is designated to hold the cylindrical shaped rods in order to lock-unlock the device at desired position. This material also needs to highly corrosion resistance and probably durable and heavier than the cylindrical rod itself, in order to withstand the stress during medical procedures. From the above figure, it is visible that different holding options are available to
hold the rod to meet the patient’s comfortable position. Having different holders in both x and y axis of the plate increases the options to have people with different heights and weights in different directions.

![Diagram A]

![Diagram B]

Figure 2.1.4 Detailed schematic image of the proposed locking-unlocking mechanism

This figure above shows the detailed picture of the lock-unlock mechanism. Above, part c refers to the knob that will be used to either lock the bar on desired position or unlock the cylindrical bar to reset the position. Part A shows schematic figure of the bar when the device is unlocked for movements and Part B shows schematic image of the bar when it’s locked on desired lock holder. In order to use this mechanism, the health care professional has to pull the knob from its original position and move the foundation bar (part D) on the desired x-y plane until a comfortable position is reached. The practitioner then pushes the handle back into the foundation bar to lock the device into one of the holes shown in the above figure.

2.1.1.1.4 Patient Support Devices and Attachments

While other medical stirrups on the market only have knee/lower thigh holders for knee surgeries, this design will include an extra support on the device as an additional comfort piece and to increase the range of patient who could use this device. The knee holders will attach using an adjustable bar system to the main bar of the device. Since alternative design one uses springs, which attach to the outside of the bar, the attachment piece and the other competent of the bar should clamp on to the inside of the bar. A groove will be created as to fit the attachment component into the inside of the grove. This will require lubrication and corrosion resistance; however, the attachment components must not interfere with the springs used to control the movement of the device from the resting position to the position required for the medical procedure. Design 1 proposes that the location, height and angle of the knee supports will be adjustable by the practitioner at any point. To adjust the height of the knee support, a two pole system will be used which will allow the inner pole to which the knee support is attached to slide up and down within a slightly larger pole which will be attached to the base of the device. The practitioner could slide the device up and down by removing the locking key and sliding the key back in when the correct height is reached. The key should have a locking mechanism such that it could not be knocked out of place during a procedure. A rough estimate has holes placed every half inch as to be adjustable for a large range of patients. Figure 2.1.5 is a sketch of the two pole system.
On the lower pole where the device is attached to the main device bar, a sliding locking device will be used to move the knee support along the pole. For added safety, two points of contact should be included to balance the knee support and ensure proper alignment. To make adjustments easier for the practitioner who may need one hand to hold the patient and use the other for adjustments, a handle should be included to adjust both pins on one fluid motion. Springs within the prefabricated device will ensure a tight, rigid, lock when slid back into place. A sketch of the proposed locking device, Figure 2.1.6, is labeled for further understanding.

**Figure 2.1.5** Two pole system for adjustment of support components

**Figure 2.1.6** Proposed locking and adjustment device for bar to pole connection
The final location where the prefabricated knee support will be modified is in its attachment to the adjustable height pole system. For added comfort of the patient, at the point of attachment from the top pole, the knee support will be able to tilt in a one directional plane such that patients who have longer or shorter legs will be able to achieve the correct leg posture (angle of leg in device) without having to use adjustments in other areas that might cause additional discomfort but obtain the same results. This will have a lower overall strain on the patient, both physical and the anxiety often caused by the associated medical for this device. Figure 2.1.7 shows the capabilities of the rotation of the knee support component.

![Rotation of knee support component](image)

**Figure 2.1.7 Rotation of knee support component**

Much like the knee support, the boot, or foot holder will be purchased as a prefabricated component and then modified to increase the range of patients that can be accommodated by the device. A similar, yet shorter two pole system will be used to adjust the height of the boot. The two pole sets, each with an adjustable height setting, will still maintain an overall height relation difference by having the overall height change available in the boot pole set smaller then in the larger knee support pole system. Similarly, the attachment to the main bar will be the same in that all attachment components will have to be on the inside of the bar as to avoid contact with the springs.

Unlike the knee attachment, the angle at which the boot attaches to the pole should not change. The reason behind this is that angling the boot will actually cause more pressure on the calf and associated nerves if it is tilt slightly off of the normal alignment. The boot will fasten directly to the pole system.

Finally, both components will have straps placed at intervals to help secure patients legs into the device when needed.

### 2.1.2 Alternative Design Two

Alternative design two differs from the first design in several ways. First, instead of using a system of springs and pulleys to lift a patient’s legs, a motor is incorporated into this design. This allows the device to have more precise adjustment, as the motor will be able to lift the device to any position with no assistance from the practitioner, leaving his hands free to assist the patient when loading into the device. By changing the lifting component, the attachment of the device to the table, as well as the way that the device moves with respect to the table, were both altered. Also, a different type of pole system for the knee and foot supports was suggested, allowing these components to lock into place more securely.
2.1.2.1 Subunits

2.1.2.1.1 Motor

Figure 2.1.8 shows how the motor can be incorporated into the general design of the assisted leg-holding device.

![Diagram of motor incorporation](image)

**Figure 2.1.8** Incorporation of a motor into the assisted leg-holding device

Although not shown in detail in figure 2.1.8, the type of motor that will be used in this design is a stepper motor. This type of motor was chosen for this alternative design due to its increased accuracy during rotation. For the purposes of the assisted leg-holding device, the practitioner would be able to control the rotation of the stepper motor in the vertical direction and would be able to precisely adjust the leg-holding device to the proper position simply by pressing a button.

Below, figure 2.1.9 shows a block diagram of the basic steps needed to control the movement of the assisted leg-holding device using a motor.
Figure 2.1.9 Block diagram showing the steps that must be taken in order for the practitioner to program the motor to perform the desired movement of the assisted leg-holding device

For this design, the practitioner will be able to control the device using a user interface on a computer. However, it is important to consider the fact that not all examination rooms have the space or funding for a computer. Therefore, a personal digital assistant (PDA) will be included in the total cost of this design. The computer program that controls the movement of the device can then be loaded onto this PDA, so that the practitioner will be able to move the assisted leg-holder up or down wirelessly from the PDA. Using a wireless controller decreases the amount of wiring needed, which will make the device safer, and using a PDA, technology that most professionals are comfortable with, allows the device to be user friendly and simple to operate. A package that includes the microcontroller, one stepper motor, and computer program needed is available for $50 from Images Scientific Instruments, Inc. Because two motors, one for each leg of the device, will be needed, some alterations will be necessary in order network the motors allow movement of the entire device, and a second motor also must be purchased. A UCN 5804 microchip can be used to network the two motors so that they can be run and controlled using the same software. The computer program is designed for a Microsoft Windows operating system, so this must be taken into consideration when purchasing the PDA.

2.1.2.1.2 Attachment of the device to the table

For this alternative design, an actuator was proposed as part of the lifting mechanism. When activated, this component will lift the bar vertically, keeping it parallel to the ground at all times. The proposed actuator is shown in figure 2.1.10 below.
Figure 2.1.10 Image of the proposed actuators to position the foundation bar to position patient’s leg in vertical direction. [5]

After the position is established using the motor mechanism, the practitioner has to use the locking and unlocking mechanism of the bar in order to find the correct angle on the x-y plane using the small bar inside the foundation bar which can be seen as Figure 2.1.11 below.

![Figure 2.1.10](image)

Figure 2.1.11 Side schematic view of locking mechanism with attached actuator and lock holder to the table.

On the above image, part a refers to the examination table while part b refers to the actuators welded to the table using bolted joints; part c refers to the lock bar holder that slides in between the two actuators to be attached to the table as well. Finally, part d refers to the foundation bar that needs to be lifted; part e refers to the cylindrical rod to be placed inside part d for locking-unlocking mechanism and part f refers to the knob that will allow the push and pull mechanism of the cylindrical rod. Lubrication is a concern for this design, and steps must be taken to ensure that the surfaces between “c” and “e” remain well lubricated during mechanical tune up.
2.1.2.1.3 Patient Support Devices and Attachments

The attachment mechanism described in the second alternative design was chosen for the optimal design. For more information about this mechanism, refer to the “Components” section later in this report.

2.1.3 Alternative Design Three

Alternative design three used a hydraulic system for lifting the device and the patient’s legs to the proper position for a medical procedure. For this design, the most important change was the lifting mechanism. Here, hydraulics will be used as the lifting component for the leg-holding device. A hydraulic system retains the accuracy of a motor design, while at the same time this method does not involve any electricity, reducing the problems associated with this. The device’s attachment and movement with respect to the foundation bar was exactly the same as in alternative design one, and is not explained again here. However, another attachment method for the knee and foot supports is also described in this design. The mechanism described in this section allows for a finer degree of adjustment of the supports compared with the other two designs.

2.1.3.1 Subunits

2.1.3.1.1 Hydraulic System

![Figure 2.1.12 Incorporation of hydraulic lifting system into general assisted leg-holding device design](image)

Figure 2.1.12 shows the schematic side (labeled A) and front (labeled B) view of the proposed design with hydraulic mechanism. As seen in figure 2.1.12 above, the hydraulic system incorporated into this design will consist of a foot pump, a tube, and a movable cylinder that will be attached to the device. The practitioner will simply have to compress the foot pump to make the device work.

Figure 2.1.13 below shows a more detailed schematic of the hydraulic circuit required for this application.
As can be seen in Figure 2.1.13 the hydraulic system required for this design consists of all of the components described above, including a foot pedal, hosing, valves, connectors, and moveable cylinders. Specifically, three pieces of hosing, four valves, and two cylinders are needed to make this project successful, as well as one manifold and several connecting pieces. The main subcomponents that would be needed for this design are described in more detail below. All of these components can be purchased from the Enerpac: Hydraulic Technology Worldwide Company.

Foot pedal: Enerpac Lightweight Hydraulic Foot Pump, model number P392FP, has been chosen for this design project. It is made of a combination of steel for stability and aluminum for decreased weight. The foot pad is large, so that the practitioner will have no difficulties using it.

Hosing: The hosing chosen for this application will be the 900-series heavy-duty rubber hoses offered by Enerpac. Some features of these hoses are that they rubber coated and made of two layers of steel braiding. These hoses can transmit pressures of up to 10,000 pounds per square inch (psi), and can be purchased in any length from 2-50 feet. The Enerpac hoses are small and flexible, so that they will not be difficult to manage by the practitioner.

Manifold: The purpose of using a manifold in the hydraulic circuit is to allow pressure to be transmitted simultaneously to both cylinders of the assisted leg-holding device. Basically, the manifold incorporated into this system will act as a connecting valve, transmitting the pressure created by the foot pump and traveling through the single hose connected to this pump into each of the hoses leading to the two cylinders. The manifold that will be used is AM-21 by Enerpac.

Valve: In general, the purpose of valves is to give the operator of a hydraulic system control over the flow of air and fluid through the system. Valve model number V-182 will be used for this application, because this has 3/8 inch couplings to match the requirements of the hose. The purpose of the needle valve is to control flow to each cylinder, and therefore control the speed of each cylinder. The manual valve model number V-66 will be used for this application to stop flow completely. When this valve is closed, the cylinders will maintain their respective heights, and when it is open the cylinders will be able to increase or decrease in length, changing the height of each of the patient’s legs within the device.

Moveable cylinders: The cylinders chosen for this application are from the model number RC-50’s series. The internal area of all of these cylinders is .99 square inches. This series of cylinders has a weight range of 2.2 to 6.1 pounds per cylinder, and can extend from .63 to 9.3 inches. Although any of
these cylinders could be used in this application, the RC-57, which extends in a range of 10.25 inches to 17.25 inches and weighs 5.3 pounds, will likely be chosen. All Enerpac cylinders are made from a high-strength metal alloy for durability, with a baked enamel finish to prevent corrosion.

Because the base of the cylinder and the foundation bar of the device are made from metal, it is possible to weld one end of the cylinder directly to the device. The attachment of the cylinder to the table requires slightly more consideration. For this project, the device has to move outwards and inwards along a horizontal plane, as well as up and down on a vertical plane. Therefore, the cylinder cannot restrict movement as it is attached to the table. Figure 2.14 shows how the attachment of the cylinder to the device and table can be accomplished.

![Figure 2.14 Method to attach the cylinder and device to the examination table](image)

2.1.3.1.2 Patient Support Devices and Attachments

For design three, a prefabricated attachment system with a locking attachment that slides along the pole will be used. In this way, the components of the device can be adjusted freely at any point along the foundation bar, allowing for accommodation of more patients. This will require lubrication and corrosion resistance, however, the attachment components must not interfere with the area of access required for the physician. Additionally, the support components should not interfere with the control of the movement of the device from the resting position to the position required for the medical procedure. Design three proposes that the location, height and angle of the knee support will be adjustable by the practitioner at any point. To adjust the height of this support, a telescoping system will be used which will allow the inner pole (attached to the support) to slide up and down within a slightly larger pole which will be attached to the base of the device. The practitioner will slide the device to proper position, and then lock it into place. Figure 2.1.14 is a sketch of the two pole system.
Figure 2.1.14 Two pole system for adjustment of support components with boot attachment

This system is similar to those seen on tripods used in civil engineering or photography. The ease of unlocking or locking, combined with the sliding effect, will allow for adjustment of the height of the knee or foot by the practitioner. As compared to previous alternative designs, by using a sliding mechanism rather than drilling holes at set intervals, the range of motion of the device is increased.

On the lower pole, where the device is attached to the main device bar, a sliding locking device will be used to move the knee support along the pole. The telescoping pole system shown in figure 2.1.14 will have a mechanism to prevent pull-out of the smaller pole. However, in order to prevent either the knee or foot supports from sliding off of the foundation bar entirely, a removable stop gate must be attached to the end of the pole, using a spring-loaded pin. This gate will only be removed if a component must be replaced. The prefabricated pole with stop gate is shown in Figure 2.1.15.

Figure 2.1.15 Prefabricated pole shown with and without stop gate.

A pre-grooved pole will provide for faster and easier adjustment by the practitioner compared to the spring loaded handle proposed in the first and second alternative designs. A handle will be used to
adjust the height of the knee or foot supports and to lock them into place. A sketch of the proposed locking device between the bar and support pole system is shown in figure 2.1.16 below.

**Figure 2.16** Proposed locking and adjustment device for bar to pole connection

### 2.2 Optimal Design

#### 2.2.1 Objective

The proposed optimal design is a low-cost, reliable and user-friendly leg orthosis that is more comfortable than the existing models and will improve the patient’s experience during medical procedures. It should also assist the medical practitioner in positioning a patient’s legs, and then use lock-unlock mechanism to prevent movement or slipping during medical procedures, and also prevent hyper-extension of the patients’ limbs. This device should be adjustable over the average range of heights and weights for both men and women. We intend to use the principles of dynamics to design a device that opposes gravity, allowing for easy positioning of a patient’s legs for medical procedures. By incorporating springs specifically calculated for their spring constants, we should be able to accommodate for a wide range of heights and weights. The device should be able to accommodate people in between 4’10” to 6’ 5” and up to 500 lbs. We also intend to use medical foam padding in order to make this device comfortable, especially for patients with serious physical disabilities. Overall, the device should have good fatigue strength and be able to reduce stress to both the practitioner and patient during the procedure. Thus, the device must be light-weight and compact, to allow easy movement by the practitioner and it should be easy to sterilize. Hence, the overall objective of this project is to build a leg holding device with anti-gravity and lock-unlock mechanism in order to assist the disabled individuals for medical purposes.

The main goal of the proposed device is to oppose gravity and lift a patient’s leg as he moves from a sitting to a supine position, so that a medical procedure can be performed. Allowing the patient to start in a sitting position is useful for those patients who cannot position themselves independently and
require the help of the practitioner. Without assistance, this can cause difficulties for the practitioner, but these difficulties can be alleviated by the anti-gravity capabilities of the proposed device. The foundation of the device will be a solid metal bar, which will be attached to the operating table near the hip joint. Supports for the knee and foot will also be attached to the bar. These supports help to achieve another goal of the device: to make the patient as comfortable as possible during what can be a lengthy medical procedure. Patients who are disabled and who have severe muscle weakness are very susceptible to this type of discomfort, as many of the current devices on the market lack sufficient support, and leg holding devices that lack a knee support isolate those patients who are amputees and cannot make use of the traditional foot support. To maximize comfort, each support will be well padded. The padding, as well as a sliding and locking capability for each support, also allows the device to be adjustable so that it can be customized to fit patients of nearly any size, a third objective to this project.

In completion of this optimal design, this device will be able to accommodate a large range of patients both with and without disabilities. In the methods section below, the features that will allow this device to work and achieve the project’s goals are described in further detail. Overall, this device is designed to be efficient and cost effective in order to be competitive in the field of medical technology.

2.2.2 Subunits

2.2.2.1: Lifting Mechanism

The final design selected for the assisted leg-holding device incorporates springs as the lifting mechanism. This idea was first proposed in alternative design number one, but is shown in much greater detail in this section.

One of the biggest advantages of using springs in the optimal design is that these parts are very inexpensive compared to the other alternatives. Although four springs will be used, the total price for all of these components will be just over $40.00. Compared to a stepper motor or hydraulic system, this choice is much more affordable. Since this project has a limited budget and requires many components, by spending less money on the lifting device more of the funding can be directed towards improving other parts of the project.

Compared to the motor or hydraulic lifting systems, the spring system has fewer components. This is advantageous because it decreases the chances of failure of any of the components. At the same time, if one of the springs were to fail or to surpass its lifespan, the repair would be very inexpensive compared to purchasing, for instance, a new hydraulic cylinder or stepper motor. As will be explained below, the springs will be detachable so that they can be easily replaced.

A final advantage of using springs is that this design incorporates only mechanical parts, and does not require an electric power source. Therefore, there is no chance that the patient or practitioner could be electrocuted during the medical procedure. This is significant, because the leg-holding device will be made mostly of metal, which is very conductive to electricity.

Below, figure 2.2.1 shows a diagram of how the spring component of the device can be incorporated into the general design of the assisted leg-holding device.
Before going into the mechanics of how the assisted leg holding device will work, there are several external features that should first be mentioned. The diagrams above show a view of the side of one of the leg holding devices. In order for the system to work, a pair of these devices are needed, one for each leg. In this way, a practitioner can adjust each of the patient’s legs individually if necessary. This will accommodate for surgeries in which one leg must be positioned out of the way, while focusing on the other leg. It will also accommodate for patients who may have more trouble with one leg, and might require a specific positioning.

In the following subsections, every component of the general leg-lifting design will be explained in minute detail.

2.2.2.1 Spring

As mentioned above, figure 2.2.1 shows only the side view of one of the leg holding devices. Each support of the leg holding device, which is attached to the operating table at its origin, is also attached by two springs, one that runs along the outside of the foundation support and a second that runs along the inside of the foundation support. Figure 2.2.2 below shows a diagram of the entire device, including both leg supports and all springs, from a front view.
There are several advantages to the design described above. By having two springs for each support, the weight of the patient’s leg is distributed more evenly. This will cause less stress on the point of attachment of the device to the medical table by creating a system of opposing torques. At the same time, the dual springs ensure the safety of this device by creating a back-up system. If either of the springs were to fail, the second spring will create enough force to prevent the device from crashing to the ground, potentially causing injury to the patient or practitioner.

Placing the springs along the side of the device keeps these components out of the way of the practitioner and patient, in order to avoid injury. As can be seen in figures 2.2.1 and 2.2.2, this risk is further reduced by the placement of a plastic casing around each spring.

Figure 2.2.3 shows a more detailed diagram of one spring and its casing.
Figure 2.2.3 Relationship between spring and casing that protects the patient and practitioner from injury by spring. The sliding mechanism allows the spring to be interchanged.

As can be seen in the figure, the casing will be able to slide out in order to reveal the spring. This feature is in place because over time, the springs will receive wear and begin to show signs of fatigue. At this time, it is essential for the springs to be changed in order to ensure the safety and integrity of the device, and for this to be possible the casing must be shifted. Therefore, the casing must have good friction properties and durability. Ultra high molecular weight polyethylene, a self-lubricating polymer which is known to have very good wear resistance and little friction, will be the material chosen for this application, and the protective casing pieces will be custom designed in the University of Connecticut machine shop in order to best fit the constraints of the beam and spring. Rochling Engineered Plastics, a leader in the production of quality polymer products, will be the supplier of this material, which will be used for its excellent friction properties in several parts of this design.

The type of spring that has been chosen for this application is a constant force extension spring. Because of its low cost and good mechanical properties and corrosion resistance, stainless steel will be the material chosen for this application. An extension spring is required because the spring must be able to stretch across a variety of positions so that the device will allow the patient to move from a sitting to a supine position, and this type of spring accommodates for this constraint.

Figure 2.2.4 shows an example of the type of extension spring that will be used in this design.
As can be seen in figure 2.2.4, as well as figure 2.2.3, the extension spring chosen for this application will be manufactured with hooks on each end. This feature allows easy interchanging of springs whenever necessary. One end of the spring will be attached to a metal hook welded to the foundation bar. The other end of the spring, closest to the examination table, will be soldered to a piece of nylon-coated stainless steel cording. In this way, when the device is in use and the spring becomes stretched, the cord will slide, allowing movement of the device. Using a cord instead of a wire extension from the spring allows for better flexibility and movement of the device. The end of the cord not attached to the spring will be soldered to a small caliper, which can be attached to a third hook welded to each leg of the examination table. This system is shown pictorially in figure 2.2.5 below.

By allowing the springs chosen to be both detachable and extendable, a simple storage method becomes possible. Since it is likely that the assisted leg holding device will not be needed for every procedure in a doctor’s office, a way to store the device between applications becomes necessary. Figure 2.2.6 shows a diagram of the proposed storage method.
The proposed assisted leg-holding device is designed to swing out horizontally, and lock into place along the side of the examination table. This conserves space and moves the device conveniently out of the way. The device will be held in place by hooks so that it will stay put and not move to hinder the practitioner. It is necessary to detach each of the springs in order to allow for this type of movement and prevent over-extension of the springs. This can be done simply by releasing the caliper attached to each cord from the leg of the examination table.

Now that the external parts of this design have been explained, it is necessary to analyze and explain the forces that allow this system to work properly. Figure 1.2.7 shows a free body diagram of the spring apparatus and the forces involved in lifting one support of the assisted leg-holding device. This diagram was borrowed from an analysis by Rahman et al. in the paper “A Simple Technique to Passively Gravity-Balance Articulated Mechanisms” [7].
The only forces that affect this system are the combined weights of the patient’s leg and the device, and the spring force that opposes this weight. It is assumed that after a patient is loaded into this device, the system will settle into equilibrium in the vertical direction, so that no movement occurs upwards or downwards. Therefore, according to the equations of static equilibrium, the weight of the patient’s leg and the device must be exactly balanced by an equal force in the opposite direction. This is shown in equation 1 below.

\[ \sum F_y = 0 = F_{y,+} - W_{device} - W_{leg} \]  

(1)

In this equation, the term “\( F_{y,+} \)” refers to the upwards force that must be applied in order to oppose the combined weight of the leg and the device. This force can be applied by either the practitioner, or in this case, the springs. Since there are two springs for each leg support, “\( F_{y,+} \)” refers to the combined force of both of these springs and therefore each identical spring supplies half of this force.

The force created by a spring is equal to the value of its spring constant, usually denoted as the term “\( k \)” multiplied by the distance that the spring is stretched from its resting position, which can be described as “\( \Delta x \)” In this system, the spring force is directed along the line described by measurement “\( c \)” in figure 2.2.5. In order to find the amount of force in the vertical direction, the total spring force must be broken into its vertical and horizontal components. By examining the geometry of this system, it is possible to conclude that the upwards force exerted by the spring is equal to the spring force, \( k \Delta x \), multiplied by the sine of the angle formed between measurements “\( b \)” and “\( c \)” in figure 2.2.7, which can be calculated as 180 degrees minus \( \phi \) minus \( \theta \). This is shown in equation 2 below:
\[ F_{y,x} = k \Delta x \sin(180 - \Phi - \Theta) \]  

(2)

By combining equations 1 and 2 and solving, equation 3 is formed:

\[ k \Delta x \sin(180 - \Phi - \Theta) = W_{\text{device}} + W_{\text{leg}} \]  

(3)

It can be observed from equation 3 that the stretching distance “\( \Delta x \)” is directly related to the weight exerted on the device, and that the spring will increase its length as the weight applied to the device is increased.

It is now necessary to analyze the effect that changing the “\( x \)” value has on the height of the assisted leg holding device. In order to do this, several more terms must be examined.

For the purposes of this analysis, both the lengths “\( a \)” and “\( b \)” in figure 2.2.7 are considered to be constant. These lengths are solely based on the design of the spring and placement of its attachments to the device. However, the length “\( c \)” is completely dependent on the stretching distance “\( \Delta x \)” of the spring caused by an applied force, and as x stretches, “\( c \)” increases. As “\( c \)” increases, the angles \( \phi \) and \( \theta \) are altered, and the leg-holding device drops to a lower position. The angles \( \phi \) and \( \theta \) can be determined from the values of “\( a \)” , “\( b \)” , and “\( c \)” using the law of cosines, and are calculated as equations 4 and 5 below.

\[ \cos(\Phi) = (((a^2 + (c + \Delta x)^2 - b^2)/(2a(c + \Delta x)))) \]  

(4)

\[ \cos(\Theta) = (((a^2 + b^2 - (c + \Delta x)^2)/(2ab))) \]  

(5)

By understanding the relations between the values described above, it is possible to manipulate the assisted leg-holding device to position any patient’s leg within an acceptable range of angles. Figure 2.2.8 shows the relationship between the angle \( \theta \) and the amount that the device will drop.

![Figure 2.2.8](image)

**Figure 2.2.8** Relationship between the angle \( \theta \) formed between the device and the examination table and the height of the device.

Referring to equation 5, the angle \( \theta \) will increase as “\( c \)” increases, meaning that the weight applied to the system will also increase and the spring will stretch to accommodate for this weight. As \( \theta \) increases, the angle formed between the device and the horizontal, \( 90-\theta \), will decrease. Using
trigonometry, it is possible to calculate the vertical distance of the device from the horizontal, shown in equation 6.

\[ d_y = l_{device} \sin(90 - \Theta) \quad (6) \]

From equation 6, as 90-\(\theta\) decreases, \(\sin(90-\theta)\) also decreases and the device drops closer to the horizontal.

Based on the observations summarized in equations 1-6 above, it is possible to calculate a spring constant for this device and to determine the corresponding range of motion allowed by the device. In order to do this, the first step is to determine the range of weights that must be accommodated by the device. The specifications for this project require that the device must withstand a patient weight of up to 500 pounds. According to an anthropomorphic table found in [8], each leg makes up approximately 16% of the total body weight, so each support of the assisted leg-holding device must accommodate 40 pounds. Therefore, since each support will be held by two springs, each spring will be responsible for supporting 20 pounds of force from the patient’s leg.

The next step in calculating the required spring constant is to determine the initial weight of the device before patient loading. As will be explained below, this will include several components such as the metal foundation bar, knee support, and foot holder. Together, these components will be estimated at approximately 40 pounds, meaning that each spring must be able to accommodate a combined total of 40 pounds of force due to both the patient’s and the device’s weights.

Next, the parameters “a”, “b”, and “c” from figure 1.2.7 must be determined. In order to fit the physical constraints of this design, the values for “a” and “b” will be set at 3 inches and 8 inches, respectively. Both of these parameters will remain unchanged for any position of the device. The value of “c”, however, can be set at any initial length, but will change as the spring is stretched or compressed. For the purposes of this analysis, “c” will be initially set at 5 inches. In this way, when the device is completely unloaded, it will be held completely vertically, as can be confirmed using equation 5, as shown below:

\[
\cos(\Theta) = (3^2 + 8^2 - (5 + 0)^2)/(2 * 3 * 8) \\
\cos(\Theta) = 1 \\
\Theta = 0 degrees
\]

Because this calculation demonstrates the “worst case” scenario for the angle \(\theta\), or the smallest possible value of this angle, it can be concluded that the device is safe and will not overextend a patient’s legs. According to [9], the maximum safe extension of the human leg is 120 degrees, which is much greater than the capabilities of this device.

Figure 2.2.9 below shows this design, with parameters determined.
As can be seen from the figure, the device will be incapable of moving to a position greater than 90 degrees from the horizontal, due to the constraints of the table. Figure 2.2.9 shows the case of no loading, meaning that this is the position when the device is not being used by a patient, and the spring is not stretched at all. A weight exerted by any patient’s leg will cause the device to move to a position closer to the horizontal.

The device can be adjusted to a range of angles based on the change in length of the spring, “Δx”. For this project, the maximum angle $\theta$ that the device will form with the vertical, corresponding with the lowest equilibrium position of the device with a 500 pound patient, will be set at 45 degrees. Patients weighing less than this maximum will have their legs initially positioned at a higher incline. For fine adjustment, the practitioner will be able to move each leg of the device using a handle attached to the end of the device, and then lock each position into place. This system will be explained in detail in a subsequent section.

When the device has settled into equilibrium at a certain position, this will cause a corresponding stretch in the spring. When the device reaches the specified angle using the parameters mentioned above, the amount of stretch can be calculated using equation 5, and this analysis is shown below:
\[
\cos(\Theta) = \frac{(a^2 + b^2 - (c + \Delta x)^2)}{(2ab)} \\
\Theta = 90 - 45 = 45\text{ degrees} \\
\cos(45) = \frac{(3^2 + 8^2 - (5 + \Delta x)^2)}{(2 \times 3 \times 8)} \\
(5 + \Delta x)^2 = 73 - 33.9 = 39.1 \\
5 + \Delta x = \sqrt{39.1} = 6.25\text{ inches} \\
\Delta x = 1.25\text{ inches}
\]

Thus, it can be concluded that, for the specifications listed above, the spring must stretch 1.25 inches from its resting length when a 500 pound patient is using this device.

Using the information above, the angle \( \phi \) can also be calculated from equation 4:

\[
\cos(\Phi) = \frac{(a^2 + (c + \Delta x)^2 - b^2)}{(2a(c + \Delta x))} \\
\cos(\Phi) = \frac{(3^2 + (5 + 1.25)^2 - 8^2)}{(2 \times 3 \times (5 + 1.25))} \\
\cos(\Phi) = -.425 \\
\Phi = 115.2
\]

At this time, all of the variables have been accounted for, and can be used to solve equation 2. This analysis is shown below:

\[
F_{spring} = k \times \Delta x \times \sin(180 - \Phi - \Theta) \\
40 = k \times 1.25 \times \sin(180 - 115.2 - 45) \\
k = \frac{40}{.423} = 94.6\text{ lb/in}
\]

This analysis has shown all of the requirements for both the spring and the rigging of the spring to the table. In summary, the required spring must be able to extend at least 1.25 inches past its free length, and it must have a spring constant of 94.6 pounds per inch.

The supplier of the desired springs will be W.B. Jones Spring Company. The spring closest to the specifications listed above is part number 331. This particular spring has a spring constant of 109.83, with a free length of 7.25 inches and a maximum safe loading of 139.87 pounds, higher than the expected loading. [10]

Figure 2.2.10 below shows a profile view of one support of the assisted leg-holding device, with all dimensions of the springs and their attachments specified. This figure summarizes all of the calculations explained above, and therefore uses the assumption that the maximum patient weight will be applied to the device. Although only one spring is shown in this figure, an identical spring can be found on the inside of the support bar, and the numbers shown are for both springs combined.
Upon referring back to figure 2.1.1, readers may realize one problem with the proposed spring design. As mentioned at the beginning of this proposal, the goal of this device’s design was to load patients starting in a sitting position. Allowing the patients to start in a sitting position reduces stress on both the patients and the practitioner, who might have trouble positioning the patients from a supine position. The spring design as described above does not allow for easy positioning of the assisted leg-holding device in such a position. Without any amendments, this design forces the practitioner to push down the device into sitting position, which causes several problems. First, although the pushing motion is easier to perform than an upwards pulling motion, the practitioner would still be required to exert enough force to overcome the upwards force produced by the spring, and hold the device in place for the patient. Essentially, this would defeat the purpose of the assistance feature of the leg holding device, as the practitioner would still experience a considerable amount of strain. Second, because the practitioner would have to hold the device, he would not be available to help position the patient in the device. This would cause inconvenience to both the practitioner and the patient, who may not be able to position himself independently.

In order to overcome this shortcoming, a crank mechanism was designed. Figure 2.2.11 shows the basic purpose of the crank mechanism.

**Figure 2.2.10** Diagram of the spring component of the assisted leg-holding device, with all features labeled and specified

### 2.2.2.2 Crank

Upon referring back to figure 2.1.1, readers may realize one problem with the proposed spring design. As mentioned at the beginning of this proposal, the goal of this device’s design was to load patients starting in a sitting position. Allowing the patients to start in a sitting position reduces stress on both the patients and the practitioner, who might have trouble positioning the patients from a supine position. The spring design as described above does not allow for easy positioning of the assisted leg-holding device in such a position. Without any amendments, this design forces the practitioner to push down the device into sitting position, which causes several problems. First, although the pushing motion is easier to perform than an upwards pulling motion, the practitioner would still be required to exert enough force to overcome the upwards force produced by the spring, and hold the device in place for the patient. Essentially, this would defeat the purpose of the assistance feature of the leg holding device, as the practitioner would still experience a considerable amount of strain. Second, because the practitioner would have to hold the device, he would not be available to help position the patient in the device. This would cause inconvenience to both the practitioner and the patient, who may not be able to position himself independently.

In order to overcome this shortcoming, a crank mechanism was designed. Figure 2.2.11 shows the basic purpose of the crank mechanism.
As can be seen in the figure, the crank mechanism is responsible for opposing the force exerted by the spring and moving the assisted leg-holding device into a position other than the equilibrium spring position, especially into a position convenient for patient loading.

The type of crank chosen for this application will be a manual hand crank. Figure 2.2.12 shows a diagram of the proposed crank. As can be seen from the figure, the proposed crank will consist of a reel, handle, and cording.

**Figure 2.2.11** Proposed design of the assisted leg-holding device with the inclusion of a crank mechanism
The reel used for this application will be custom-made. Since winch systems are extremely expensive to purchase, this method will allow it to maintain all of the required specifications for this project without straining the budget. This reel must be durable, so that it can withstand many cycles of cranking and loading/unloading of the cord. Ideally, the proposed reel must small enough to fit within a leg of an examination table. The inner diameter of the tubing will therefore be set at 1 inch, and the diameter of the flange will be 2 inches. The crank will be .25 inches wide. In this way, the reel and cord can placed within the leg of the examination table, and will not get in the way of a medical procedure or cause injury to the patient or practitioner. Figure 2.2.13 shows the proposed reel and its incorporation into the leg of the examination table, using a cross-sectional view directly through the center of the reel.

Figure 1.2.13 Cross sectional view of the hand crank’s incorporation into the leg of an examination table.
As can be seen in figures 2.2.12 and 2.2.13, one of the requirements of the custom reel is that it must be toothed, to allow a locking and unlocking feature of the crank. Figure 2.2.14 shows a detailed diagram of this locking and unlocking mechanism.

![Schematic of the crank mechanism to adjust the position of the assisted leg-holding device](image)

**Figure 2.2.14** Schematic of the crank mechanism to adjust the position of the assisted leg-holding device

As the practitioner rotates the handle clockwise, after each 1/4 turn of the reel a tooth will articulate with a spring-loaded metal pin. Therefore, if the practitioner releases the handle, the pin will prevent counterclockwise rotation of the reel, which would cause release of the cord and sudden elevation of the leg-holding device. This is the locking feature of the crank. In order to unlock the device and allow release of the cord, the practitioner must simply press a button to compress the spring-loaded pin. This motion will unlatch the device so that the practitioner can rotate the handle and release the cord, increasing the device’s height. As soon as the practitioner stops compressing the pin, the reel will again lock, ensuring that the device will not be forced upwards. Because of the forces that will be applied to this pin, it must be made of a material such as stainless steel, which has very good mechanical properties. This pin must also be firmly welded to the table leg.

Figure 2.2.15 shows a free body diagram of the spring-loaded pin for two conditions.
In order for this component to work correctly, the pin will be inserted between two compression springs. The pin will be able to slide freely, so that it will only interact with one spring at any time. The spring near the pin’s head will have a low spring constant, so that it can be compressed easily each time it interacts with the tooth of the reel. However, the spring on the right must be able to resist compression at any force applied by the rotating reel. Since these forces are caused by tension in the cord due to the assisted leg-holding device, the maximum force that must be resisted by the compression spring can be calculated. The practitioner must overcome this force in order to move the pin and release the locking mechanism. A complete analysis of these forces will be made later in this report.

Based on figure 2.2.15, an equation can be written that relates the forces produced when the pin is unlocked by the practitioner:

\[ \sum F = m \cdot a = F_{s2} - F_{\text{reel}} - F_{\text{practitioner}} \]

where \( F_{s2} = k_{s2} \cdot \Delta x_{s2} \) \( F_{\text{reel}} = T_{\text{cord}} \)

As can be seen in this equation, in order for the device to unlock, the forces applied by both the reel and the practitioner must be able to overcome the force applied by the spring.

In order for this mechanism to work correctly, the cord used in this procedure must be able to resist high loads without breaking or stretching. The cord chosen for this application must also be flexible, so that it can be easily wound around the reel. Therefore, a nylon-coated stainless steel cord will be purchased (model number MCX-125). The stainless steel ensures the good mechanical properties of this cord, while the nylon prevents abrasion and increases the cord’s flexibility. The model chosen has a breaking strength of 920 pounds, which is much greater than the maximum tension that will be created in the cord during this application. It has a diameter of only .125 inches, which is ideal for this situation because
this allows the cord to be inconspicuous and lightweight, and also allows for easy storage within the reel. A picture of the desired cord is shown in figure 2.2.16 below.

![Figure 2.2.16](image)

**Figure 2.2.16** Nylon coated stainless steel rope. [11]

Of course, each leg support of the assisted leg-holding device must have its own cord running to it. However, it would be inconvenient for the practitioner if there was an individual crank for the cord running to each support of the device. Therefore, this current device proposes only one crank capable of controlling the descent of both legs supports. Figure 2.2.17 demonstrates how this system will work in 3-D.

![Figure 2.2.17](image)

**Figure 2.2.17** Three dimensional rendering of the cord system.

As can be seen from the figure, one cord will run underneath the examination table from the crank to the table’s center. This same cord will be inserted into a hollow metal bar attached between the legs of the
table. Here, the cord will split into two secondary cords, so that the three cords are attached within the metal insert. Each of the secondary cords will run through the insert and feed into each leg of the table. They will emerge from the table near the ground, where they will extend and connect to the leg supports. A diagram of the attachment of one cord to the leg support is shown as figure 2.2.18, as well as all of the forces that will be applied to this system. As can be seen in this figure, the cord will be welded to a caliper at its end. This will be used to attach to a ring attached directly to the leg support, but the caliper will also prevent the cord from becoming lost within the legs of the examination table.

**Figure 2.2.18** Diagram of the interaction between the crank and spring systems, with forces and dimension variables shown

As can be seen in figure 2.2.18, the purpose of having the cords exit the table as low to the ground as possible is to increase the angle $\theta$ that the cord forms with the horizontal. By increasing this angle, more of the force exerted by the cord is directed downwards, as opposed to inwards towards the table.

Using Newton’s second law, equation 8 relates all of the forces that occur in the y direction of the assisted leg-holding system when a tension is applied to the cord.

$$\sum F_y = m \cdot a = F_{spring} \cdot \sin(180 - \Phi - \Theta) - m \cdot g - T_{cord} \cdot \sin(\beta) \quad (8)$$

At equilibrium, according to equation 2, the $F_{spring}$ term must be equivalent to the weight terms in equation 8. Therefore, applying any tension to the cord will cause the device to descend. Since the tension applied to the cord is due to rotation of the hand crank by the practitioner, the practitioner will be able to move the device very easily by turning the crank to reel in the cord. However, as the assisted leg-holding device begins to descend, the spring will be stretched and therefore the force opposing the descent will increase. In this case, more force will be required from the hand crank.
Referring back to figure 2.2.18, the first parameters that must be defined in order to complete the force analysis for the crank system are the dimensions “a” and “h” that correspond to the horizontal and vertical lengths of the attachment to the cord. For consistency, the dimension “a” will be the same as defined previously for the spring attachment, three inches from the table leg. As was explained above, it is desirable to have the angle $\beta$ be as large as possible, and in order to do this the value of the parameter “h” must be large. For this analysis, “h” will be set at 36 inches, a typical table leg height. Finally, in order to determine the minimum length required of the cord, a maximum value for $\theta$ below the horizontal must be chosen. In this case, $\theta$ will be chosen as a maximum of 45 degrees below the horizontal. This position will allow easy loading of a patient from a sitting position, without causing additional strain on the crank system.

Figure 2.2.19 below shows the crank system with all of these dimensions defined.

![Figure 2.2.19 Assisted leg-holding device with dimensions](image)

The triangle formed between the table leg, assisted leg-holding device, and cord is shown below as figure 2.2.20.
Using the law of cosines, it is possible to determine the length “l” of the cord, and this is shown below.

\[(l_{cord})^2 = a^2 + d^2 - 2* a*d * \cos(45)\]
\[(l_{cord})^2 = 3^2 + 36^2 - 2 \times 3 \times 36 \times \cos(45)\]
\[l_{cord} = 33.9 \text{ inches}\]

With this information and using the law of sines, the angle \(\beta\) can be determined.

\[\frac{l_{cord}}{\sin(45)} = \frac{3}{\sin(90 - \beta)}\]
\[33.9 \times 45 = \frac{3}{\sin(90 - \beta)}\]
\[\sin(90 - \beta) = 0.06249\]
\[90 - \beta = 3.58 \text{ degrees}\]
\[\beta = 86.4 \text{ degrees}\]

Now that a value for \(\beta\) has been decided, the next step is to determine the maximum stretch in the springs when the device is at the position 45 degrees below the horizontal. This can be done using equation 5:

\[\cos(\Theta) = ((a^2 + b^2 - (c + \Delta x)^2)/(2ab))\]
\[\cos(135) = ((3^2 + 8^2 - (5 + \Delta x)^2)/(2 \times 3 \times 8))\]
\[(5 + \Delta x) = 10.34 \text{ inches}\]
\[\Delta x = 5.34 \text{ inches}\]
This calculation has shown that, contrary to the previous assumption that the chosen springs must be able to stretch 1.25 inches, each spring must actually be able to extend 5.34 inches past its initial resting length without any deformation.

The next step to determine the tension in the cord of each support of the assisted leg-holding device is to calculate the angle $\phi$ between the spring and the device, using equation 4.

$$
\cos(\Phi) = \frac{(a^2 + (c + \Delta x)^2 - b^2) / (2a(c + \Delta x))}{(3^2 + (10.34)^2 - 8^2) / (2 \times 3 \times (10.34))}
$$

$$
\cos(\Phi) = \frac{.837}{\Phi = 33.2 degrees}
$$

Having calculated the spring’s maximum deflection, it is now possible to determine the force that will be exerted by each spring when the assisted leg-holding device is in its lowest position, 45 degrees below the horizontal, using the spring constant rate determined above for the extension spring chosen.

$$
F_{spring} = k \times x = 109.83 \times 5.34 = 586.5 \text{ lbs}
$$

This value is within the acceptable loading range for this spring model, 298,015 pounds. In order to convert the spring force to tension in the cord, first, it must be noted that because there are two springs for each leg of the assisted leg-holding device, the total spring force will be 1173 pounds. Now, equation 8 can be used to calculate the tension in cord that is required in order to overcome the spring force, and this analysis is shown below:

$$
\sum F_y = m \times a = F_{spring} \times \sin(180 - \Phi - \Theta) - W_{leg} - W_{device} - T_{cord} \times \sin(\beta)
$$

$$
\sum F_y = 0 = 1173 \times \sin(180 - 33.2 - 135) - (40) - T_{cord} \times \sin(86.4)
$$

$$
T_{cord} = 200.2 \text{ lbs}
$$

However, since this tension is calculated for only one of the springs, and the crank controls both supports simultaneously for a total for four springs, the total tension that must be opposed by the crank and practitioner will be four times as large as the tension calculated above. It should be noted that this value, 801 pounds, is much less than the maximum tension that can be withstood by the chosen stainless steel cord, which has a value of 920 pounds.

Now that the maximum tension in the cord has been calculated, the rest of this section will be devoted to the calculation of the maximum force that must be applied to the hand crank in order to adjust the assisted leg-holding device to an appropriate position. The maximum force must be within a reasonable range of forces for a practitioner. For these calculations, a female practitioner will be considered, because females typically have less upper body strength than males, and this device must be accessible to all practitioners. A measure of mean average arm strength for females was found to be 127 pounds, according to one study. [12]
Before the force calculations can be carried out, however, the properties of a lever or crank handle must first be explained. Figure 2.2.21 shows a side view of a free body diagram for the proposed crank for this design.

![Crank free body diagram](image)

**Figure 2.2.21** Crank free body diagram

As can be seen in this figure, the only two forces that are being applied to the crank are the force that the practitioner applies to the handle, and the responding force caused by tension in the cord. The relation between these two forces can be calculated by finding the moment of each force about the center reel, and this is shown in equation 9 below:

\[
\sum M_o = F_{\text{practitioner}} * d_1 - T_{\text{cord}} * d_2
\]

(9)

If the system is at equilibrium, so that there is no moment occurring at point “o”, then the following relationship exists:

\[
F_{\text{practitioner}} * d_1 = T_{\text{cord}} * d_2
\]

(10)

And therefore:

\[
T_{\text{cord}} = F_{\text{practitioner}} \frac{d_1}{d_2}
\]

(11)

As can be seen from this equation, the force applied by the practitioner is multiplied by the ratio of the distance from this force to the reel’s center and the distance from the cord to the reel’s center. Therefore, the length of the handle can be manipulated to control the maximum force exerted by the practitioner.

Now that all of the equations and diagrams have been explained, it is possible to calculate the remaining forces acting in the crank system.
In order to determine the required handle length that will allow the practitioner to exert a sufficient force, the distance “d2” must first be calculated. This distance, as can be seen in figure 2.2.21, is based upon the number of coils of cord that will be in place on the crank’s reel when the device is at its lowest position. Therefore, the maximum length of the cord must be determined. This length will occur when the device is in a position parallel to the floor. Again referring to figure 2.2.20, but assuming that \( \theta \) is equal to 90 degrees, the law of cosines can be used to solve for the length “l”

\[
(l_{\text{cord}})^2 = a^2 + d^2 - 2 * a * d * \cos(\Theta)
\]

\[
(l_{\text{cord}})^2 = 3^2 + 36^2 - 2 * 3 * 36 * \cos(90)
\]

\[
(l_{\text{cord}})^2 = 3^2 + 36^2
\]

\[
l_{\text{cord}} = 36.1 \text{ inches}
\]

For safety, this value will be extended to 40 inches. Therefore, it can be concluded that the change in length of the cord, which is the amount that will be wrapped around the reel when the device is at its lowest position, is approximately 6 inches. As mentioned above, the diameter of the reel will be set at 1 inch, which ensures that it is small enough to fit within a leg of the table. Therefore, the circumference of the reel will be 3.14 inches, so it will take two rotations to reel in the necessary amount of cord for the device to be at its lowest position. Because the cord has a diameter of .125 inches, the distance “d2” will be the .5 inches corresponding to the radius of the reel, plus the .25 inches corresponding to the thickness of two coils of cord, for a total distance of .75 inches.

In order to ensure that any practitioner will be able to use the crank system without trouble, the maximum force exerted by the practitioner will be set at 100 pounds, much less than the average strength of a female. Figure 2.2.22 shows the free body diagram of the crank with all values filled in.

![Figure 1.2.22 Free body diagram of crank with values](attachment:image.png)
It is now possible to solve for the required distance “d_1” of the crank handle.

\[
T_{\text{cord}} = F_{\text{practitioner}} \left( \frac{d_1}{d_2} \right) \\
801 = 100 \times \left( \frac{d_1}{.75} \right) \\
d_1 = 6.00 \text{ inches}
\]

Finally, having determined the maximum force exerted by the tension in the cable, it is now possible to calculate the necessary spring constant “s_2” of the compression spring shown in figure 1.2.15, using equation 7.

\[
\sum F = m \times a = F_{s_2} - F_{\text{reel}} - F_{\text{button}} \\
F_{s_2} = F_{\text{reel}} + F_{\text{button}} \\
k_{s_2} \times \Delta x = 801 \text{ lb} + F_{\text{button}}
\]

To ensure that the device will not unlock suddenly, which would cause the device to drop and the patient to crash to the ground, it will be assumed that the force that must be applied to the button is 100 pounds. Also, the pin was designed so that it is compressed by 1 inch. Therefore, the minimum required spring constant can be calculated:

\[
k_{s_2} = 901 \text{ lb/lin} = 901 \text{ lb/in}
\]

W.B. Jones Spring Company carries a spring model number C64-375-128 that has a free length of 4 inches and an outer diameter of 1.945 inches. [10] The spring rate of this compression spring is 1150 pounds per inch, which means that the spring would only have to be compressed by .78 inches in order to release the reel, a more ideal situation as it requires less space.

Figure 2.2.23a summarizes all of the components making up the lifting system for the assisted leg-holding device in 3D, and figure 2.2.23b shows a profile view of one leg of the device with all of the angles, heights, and distances specified. As can be seen from the figure, the device is capable of movement in both the x and y directions. In subsequent sections, other components of this device will be explained and incorporated into this basic design.
Figure 2.2.23 Summary of the lifting component of the assisted leg-holding device (a) from a front view (b) from a profile view
2.2.2.2: Foundation Bar

The next component that will be discussed is part D from figure 2.1.2, the foundation bar of the device. As the foundation of the device, this component will be used as an attachment for the knee and foot supports, which will also be explained in detail later in this report. The foundation bar must also be attached to the examination table, and the mechanism behind this attachment will be explained as well.

The purpose of designing part D as a rigid bar is to reduce the number of joints within the assisted leg-holding device. In this way, the amount of area subjected to stress concentrations is reduced. Therefore, as long as cautions are taken to strengthen the attachment joint, the device will remain durable and sustainable, so that it can be used many times without failure.

As mentioned above, it is important to make the foundation bar as strong and durable as possible, while at the same time allowing the device to be lightweight. Due to its exceptional mechanical properties and ease of sterilization, a metal will be used for this application. Aluminum, which is extremely strong and also lightweight, is the metal that will be used. The modulus of elasticity of this material is 10,200,000 pounds per inch, showing that this is an extremely strong metal.

The supplier of the foundation bar that has been chosen for this application is 80/20 The Industrial Erector Set. This company specializes in providing innovative, creative components, especially metal bars in different styles and designs. The bar chosen for this application is the 15 Series T-Slotted Profile, model number 1501. Figure 2.2.24 below shows a diagram of this product.
However, there are some problems with a single-bar design that must be considered in order to ensure that this system will be adequate. One of the most important considerations is the deflection that will occur when weight is added to the foundation bar due to the patient’s leg, knee or foot supports, and from the bar itself. The 80/20 website provides a deflection calculation for different methods of loading. In this application, the bar will be secured at one end, with no support at its other end. A diagram of this attachment method is shown as figure 2.2.25 below.
The equation corresponding to this loading is shown as equation 12 below:

\[ \text{Deflection} = \frac{L^3 \cdot w}{3 \cdot E \cdot I} \quad (12) \]

Equation 12 shows the worst-case deflection amount, when all force is applied at the end of the beam. In this situation, the foundation bars of the assisted leg-holding device will not have to withstand all weight from the end opposite of the attachment, so the expected deflection of the beam will actually be less than this calculated value.

For the T-1501 beam, the moment of inertia is given as .1660, and again, the maximum weight is assumed to be 80 pounds and the length of the device three feet. Therefore, the deflection for this case can be calculated as:

\[ \text{Deflection} = \frac{36 \text{in}^3 \cdot 80}{3 \cdot 10,200,000 \cdot .1726} = .707 \text{ inches} \]

As can be seen from this calculation, the beam should be able to withstand the maximum force with little deflection.

A handle will be inserted at the end of the bar not attached to the table. In this way, the practitioner can have greater control over movement and adjustment of the device. The handle will be made from ultra high molecular weight polyethylene, which will be attached to the bar using a screw. Figure 2.2.26 shows a diagram of the bar and handle, with all dimensions labeled.
1.2.3: Attachment of the device to the table

Careful considerations must be made when designing the attachment of the device to the table, in order to accommodate all of the features described above. The attachment must allow translational movement in the x direction in order to allow the device to swing into storage position. It must not disrupt or interact with the springs. It must allow the system to adjust to a wide range of positions, while at the same time be able to lock into each position securely. The ideal system must be extremely flexible, while still allowing the device to be firmly attached to the table.

One way to accomplish this is diagrammed in figure 2.2.27 below. This figure shows the attachment mechanism from an overhead view.

Figure 2.2.27 Overhead view of the mechanism to attach one support of the assisted leg-holding device to the leg of an examination table
As can be seen in the figure, the attachment and movement mechanism consists of several parts. Each foundation bar will be directly attached to a pivoting component piece. This joint allows 180 degrees of movement in the x plane, so that the foundation bar can swing into storage position as described in figure 2.2.6. The piece that will be used is also supplied by 80/20 The Industrial Erector Set, and can be found as part of a pivot system in the online catalog as part number 4452. This pivot is shown in detail in figure 2.2.28 below.

![Figure 2.2.28](image)

**Figure 2.2.28** (a) Photograph of the pivot as attached to a metal bar (b) schematic of pivot with dimensions shown [13]

Like the foundation bar, the pivot joint is also made of aluminum so that it is strong and also lightweight. However, the pivot joint also has permanently lubricated bronze bushings lining the articulating parts, so that friction becomes negligible. The pivot joint also has a braking system, so that the device can be positioned at any position in the 180 degree range. This braking system works simply by allowing the practitioner to tighten a screw, putting pressure on the joint and preventing the bar from
slipping. When the screw is loosened, the device can move freely so that the practitioner can adjust it to any point. Because there should not be many forces in the x direction other than the force exerted by the practitioner, this braking mechanism will be sufficient to prevent movement of the device.

As can be seen in the previous figures, the pivot joint must attach to two separate bars. Therefore, another small 1501 T-Slotted Profile will be used as an attachment piece, as shown in figure 2.2.27.

Having described this mechanism, it is possible to draw a free body diagram of the foundation bar, showing the approximate forces and moments that the attachment piece must oppose. This is shown as figure 2.2.29 below.

As can be seen from the figure, forces are applied at different points along the foundation bar corresponding to the locations of the knee and foot holding components. It is assumed that the weight of the leg is distributed evenly for both of these components, and that each component is approximately the same weight. The force from the knee component is located at the bar’s center point, and the force from the foot is located at the bar’s end. Therefore, the force and moment equations can be written as equations 13 and 14.

\[
\sum F = F_{\text{pivot}} + F_{\text{spring},y} - T_{\text{cord},y} - (W_{\text{knee}} + W_{\text{foot}}) \quad (13)
\]

\[
\sum M_o = M_{\text{pivot}} + F_{\text{spring},y} * 3\text{ in} - T_{\text{cord},y} * 3\text{ in} - (W_{\text{knee}} * l/2 + W_{\text{foot}} * l) \quad (14)
\]

At the equilibrium position, the force applied by the spring exactly balances out the combined weights of the patient’s leg and foot supports, and there is no tension in the cord. In this case, no forces are exerted on the pivot. When the device is moved to any other position there will be a tension in the cord. However, as was shown in equation 8 above, the y-component of this tension, added to the weights of the supports and patient legs, will exactly balance the force applied by the spring for any position. Therefore, the force applied by the pivot will be zero for any position of the device.
The moment applied to the device, in contrast, will not be zero. The maximum moment will occur when there is the greatest tension in the cord. This value was calculated in a previous section, and was found to be 801 pounds at an angle $\beta$ of 86.4 degrees. In this case, the y-component of tension is 799 pounds. Recall from above that this value was determined for the situation in which there is no patient using the device, and it is positioned at its lowest point, 45 degrees below the horizontal. Therefore, the only weight to take into consideration is the combined weight of the device, 40 pounds, and the force applied by the spring in the y-direction must be equal to 839 pounds, again from equation 8. The maximum moment can now be calculated using equation 14:

$$
\sum M = M_{pivot} + F_{spring,y} \times 3 \text{ in} - T_{cord,y} \times 3 \text{ in} - (W_{knee} \times l/2 + W_{foot} \times l) = 0
$$

$$
M_{pivot} = -839 \times 3 + 799 \times 3 + (20 \times 18 + 20 \times 36)
$$

$$
M_{pivot} = 960 \text{ pounds} \times \text{ in}
$$

[] estimates the values of the maximum forces and moments that different joining methods can withstand. According to this source, a joint similar to the one described above can withstand 200 pounds of force from one end, and can withstand 1,100 pounds*inches of torque. From these statistics and the calculations above, it can be concluded that the described joint fits within the practical specifications of these materials.

While the pivot joint allows each support of the assisted leg-holding device to move along the x axis, the natural movement of the hip and leg is in both the x and y planes. Therefore, a component must be incorporated that allows for vertical movement of the leg within the device to the proper position. This can be done by including a zero degree pivot nub, also available from the 80/20 Industrial Erector Set online catalog as part of a pivoting system, model number 4397. Figure 2.2.30 below shows a diagram of this component, along with a schematic of its dimensions.
In order for the pivot nub to work properly, it will be permanently attached to the leg of the examination table using a screw through the center hole. Two joining plates will be attached to the end of the secondary bar of the leg-holding device, which must also be attached to the main foundation bar by the pivot piece. These plates will connect the pivot nub with the support bar system, and allow for articulation between the bar and pivot nub. Having described the entire attachment system, figure 2.2.27 can be redrawn to include all dimensions, and is shown as figure 2.2.31 below.

**Figure 2.2.30** The zero degree pivot nub allowing for vertical movement of the leg (a) a picture (b) with dimensions

**Figure 2.2.31** Diagram of the method of attaching the foundation bar to the examination table while allowing movement of the device in the x and y directions, with dimensions labeled
Unlike the pivot piece, which has a brake system to lock the device at any position in the x direction, the pivot nub has no brake system. The device will be allowed to move freely along the y axis until it reaches its equilibrium position, determined by the spring. Then, if the practitioner must move the device to another position, he can simply use the crank to make these fine height adjustments.

1.2.4: Patient Support Devices and Attachments

Since the basic designs for the traditional parts of the leg stirrups have not changed entirely since their creation, this proposal suggests ordering used medical equipment, the foot and knee holders, and then engineering ways to attach them to the device. Figure 2.2.32 shows examples of available support devices that can be purchased through used medical supply companies.

Figure 1.2.32 Boots and knee holders available from medical supply companies. [14]
Ordering preexisting parts from a supply company instead of molding the pieces from scratch allows more time and money to be spent on modifying these components to fit the various types of patients and changing the way these components attach to the overall device, the assisted leg holding device for medical procedures. Current cost estimations are $375 for the stirrups and an additional $375 for the knee supports, for a total of $750. Figure 1.2.33 shows the overall layout of the device, emphasizing the location of the knee and foot holders.

![Figure 2.2.33 Knee and foot supports](image)

While other medical stirrups on the market only have knee/lower thigh holders, this design is different in that it will include an extra support as an additional comfort piece and to increase the range of patients who could use this device.

### 2.2.2.2.1 Linear Bearing

Both the knee and foot supports must attach securely to the foundation bar. In order to accommodate the widest range of patients, who may have legs of various sizes and dimensions, each of these supports must be able to slide along the foundation bar to any position, and then lock firmly into place when the proper adjustments have been made. In order to slide smoothly and decrease wear on the components, the attachment pieces must be well lubricated. However, an oil-based lubrication would wear off quickly and could damage clothing or property of the patient or practitioner. Finally, the attachment pieces must not interfere with or damage the springs.

The 80/20 Industrial Erector Set online catalog offers a solution that works for all of these constraints in their line of single flange linear bearings, model number 6515. Intended for linear motion as part of a T-slot series, these products are made of lightweight aluminum lined with ultra high molecular weight polyethylene. Figure 2.2.34 below shows diagrams of this product.
As can be seen from figure 2.2.34, the linear bearing is designed so that the ultra high molecular weight polyethylene articulates with the aluminum T-slotted profile. This particular polymer is extremely strong and durable, has good wear resistance, and, most importantly, has an extremely low coefficient of kinetic friction of 0.016 on aluminum. [13] In this way, the support acts as though it is lubricated while at the same time avoiding the problems of oil lubrication.

Figure 2.2.35 shows a free body diagram for the bearing/foundation bar system for one of the linear bearings during adjustment by the practitioner. Since it is assumed that the weight of the patient’s legs will be distributed evenly over both the knee and foot supports, and that each support will be similar in weight, the free body diagram shown in figure 2.2.35 could represent either of the supports.
As can be seen in figure 2.2.35, the only force that will oppose adjustment of the linear bearing along the foundation bar is the friction force between the aluminum and ultra high molecular weight polyethylene, and this force is equal to the coefficient of friction multiplied by the normal force that the bar exerts on the bearing. Also, since the only forces in the y direction are the combined weight of the patient’s leg and the support, the normal force must equal the sum of these weights to allow static equilibrium. These conclusions are summarized in equations 15 and 16 below.

\[
\begin{align*}
\sum F_x &= F_{\text{practitioner}} - u_k \times N \quad (15) \\
\sum F_y &= N - (W_{\text{leg}} + W_{\text{support}}) \quad (16)
\end{align*}
\]

By assuming the maximum patient leg weight of 40 pounds, the maximum friction resistance can be calculated:

\[
\begin{align*}
N &= (20\text{ lbs} + 40\text{ lbs}) = 60\text{ lbs} \\
F_{\text{practitioner}} &= .016 \times 60 = .96\text{ lbs}
\end{align*}
\]

This calculation shows that the practitioner will have to exert a force of less than one pound in order to move either support for even the heaviest patient. This will be beneficial to the practitioner, but it will also increase the lifetime of the device by reducing wear on the bearing.
Referring back to figure 2.2.34, a brake system is also incorporated into the linear bearing component. Similar to the pivot part, the linear bearings can be fastened into place at any position simply by rotating the handle of the brake, which will cause the screw to tighten and exert force on the foundation bar, stopping any motion.

The final specification that must be accommodated for is that the linear bearings must not interfere with or damage the springs. The springs will be attached along the foundation bar near the examination table, in a way that ensures that it would be very unlikely that the knee or foot support would have to be positioned so close to the patient. Therefore, a simple obstruction gate can be placed between the location of the spring and the knee support linear bearing, to prevent the bearing from accidentally becoming jammed into the spring. Such an obstruction is shown in figure 2.2.35 below.

![Diagram of gate preventing the knee support from interfering with the spring of the assisted leg-holding device](image)

**Figure 1.2.35** Gate preventing the knee support from interfering with the spring of the assisted leg-holding device

### 2.2.2.2 Telescoping Bar

While adjustment in the x direction is controlled by the linear bearings, the height each knee or foot support must also be able to change depending on an individual patient’s dimensions. Therefore, the linear bearings will be attached to an adjustable, telescoping bar system, and then the knee and foot supports. This telescoping system can be manufactured from a series of two hollow poles for each knee or foot support, for a total of eight individual outer or inner poles.

The outer, larger pole of the telescoping system will be attached to the linear bearing described above. As was mentioned above, the linear bearing that will be used for this application has a length slightly larger than two inches, and it also has two holes drilled into its flange that are 1.5 inches apart. From 80/20 *The Industrial Erector Set*, part number 8120 describes a rectangular, hollow, aluminum tube that will be used as the outer pole. This tube will be attached to the linear bearing using screws inserted into each of the drilled holes on the bearing’s flange. Allowing these screws to be inserted completely
through the pole and firmly attached with nuts on the opposite side ensures that the pole will be securely fastened to the linear bearing. Figure 2.2.36 below shows a diagram of this part and how it will be attached to the linear bearing.

![Diagram of attachment](image)

**Figure 1.2.36** Attachment of outer pole to linear bearing, cross sectional view

Unlike the outer pole, the inner bar will be made of solid aluminum. As is shown in Figure 2.2.36, the dimensions of the outer pole are 3 inches by 1.5 inches. Therefore, the inner pole must be smaller in both length and width, so that it can fit and slide easily within the outer layer. The model chosen for this application, again from the 80/20 *Industrial Erector Set* online catalog will be number 8710. With dimensions of 2.060 inches by 1.260 inches, this component will easily fit within the outer pole, ensuring that the telescoping system can work correctly. Figure 2.2.37 shows the foundation bar, telescoping pole system, and linear bearing from two different views, with all dimensions labeled.
Figure 2.2.37 (a) Front view (b) side view of linear bearing system, with dimensions labeled

From figure 2.2.37, it is clear that the solid, inner pole is significantly smaller than the hollow, outer pole. This ensures that the smaller pole will be able to fit within the larger one, and also that there will not be too much friction due to excess rubbing of the smaller pole against the larger one. However, this would make an inconvenient telescoping system for the practitioner and patient, as the inner pole would undoubtedly “wobble” within the extra room and the patient’s leg would not remain steady for an operation. Figure 2.2.38 shows a solution to this problem.
As can be seen in the figure, blocks of ultra high molecular weight polyethylene will be attached to each pole. A 3 inch by 1.5 inch block of this polymer will be screwed into the inner pole’s base, so that the ultra high molecular weight polyethylene block can constantly articulate with the inside of the hollow, outer pole. As mentioned above, because the coefficient of friction is so low between the polyethylene and aluminum, this will act as a lubricant and allow the poles to slide easily along each other.

Another block of ultra high molecular weight polyethylene will be attached at the top of the outer pole. A square large enough to allow the smaller pole through will be cut from the center of this piece. This design ensures that the practitioner will never accidentally pull the telescoping system apart, because the hollow block will not allow the solid block past. Another advantage of having this second block is that, as another space filler, it will further prevent motion of the inner bar, reducing strain on the bottom block and the screw attaching it to the inner pole. Again, the ultra high molecular weight polyethylene reduces friction, so that with this system, the practitioner can adjust the device smoothly and easily.

A spring-loaded pin will be used to adjust the height of the telescoping system. In order to fit the specifications required for this project, this pin will be custom designed in the University of Connecticut machine shop. A diagram of the required pin is shown as figure 2.2.39 below.
As can be seen in the figure, a compression spring will be used in the pin’s design. As the practitioner pulls on the pin, the spring will become more compressed, storing energy so that if the pin is released, it will move back into its original position.

The spring-loaded pin will be attached to the telescoping system through a hole drilled into the outer pole of the system. Holes will also be drilled through the inner, solid pole in increments of 1 inch. As the practitioner pulls upon the pin, it will be removed from the inner pole, causing the support to slide up or down freely. When the support reaches a proper height, the practitioner can release the pin, which will move back towards and into the inner pole, securing the support. This is shown in detail in figure 2.2.40 below.
Having the pin be spring-loaded ensures safety of the device, because if the practitioner were to release the pin unintentionally, the spring would force it inwards and stop the support from collapsing completely, preventing injury to the patient or practitioner.

In choosing a material for the pin, cautions must be taken to ensure that the pin will be able to support a large shear stress. The equation for shear stress is shown below:

$$
\tau_{shear} = \frac{\text{Force}}{\text{Area}}
$$

(17)

For a maximum patient weight of 40 pounds per leg, the force that would be applied to the pin would be approximately 60 pounds. If the pin is also .25 inches in diameter, the shear stress is approximately 1,200 pounds per square inch. A metal such as aluminum will be able to support such stress easily without failure.

Although the pin system decreases the flexibility of adjustment of the device by allowing for only a set number of holes to be drilled within the telescoping poles, the added safety of the pin outweighs this drawback.
2.2.2.2.3 Knee Support

As mentioned above, the knee support is one design feature of this device that differs from others on the market. However, as was seen in figure 2.2.32, knee supports do exist on the market, and can be purchased and modified to fit the constraints of this assisted leg-holding device. Below, figure 2.2.41 shows a schematic of how the knee support will be attached to the telescoping pole.

![Knee Support Diagram](image)

**Figure 2.2.41** Attachment of the knee support to the inner pole (a) profile view (b) view from inner side of device

As can be seen from the figure, the knee support will be welded to a 90 degree bent metal piece, which can be ordered from 80/20 *The Industrial Erector Set*. This piece will be attached to the telescoping pole so that it can pivot around a central point. It will also be fabricated to have holes drilled in an arc along its side, and a spring-loaded pin that fits into these holes. The practitioner will be able to control the motion of the knee support by manipulating the spring loaded pin, and then maneuvering the support to the proper position, similar to the movement of the telescoping pole system.

It is essential for the knee support to be adjustable, in order to ensure maximum comfort for each patient. Also, one of the purposes of the knee support is to allow the device to accommodate amputees, who
could not use a traditional leg-holding device that consists only of stirrups. By providing a knee support, these patients can also use the device for medical procedures.

As can be seen from figure 2.2.41, the range of motion for the knee support is 25 degrees forwards or backwards from the vertical, for a total range of motion of 50 degrees. The support will be adjustable in increments of 5 degrees, which should be sufficient for this purpose. Like the telescoping pole system, this adjustment method ensures that the device will be safe and not fail, which could cause the patient injury, while only compromising sensitivity of adjustment slightly.

The telescoping system for the knee supports will be adjustable in increments of 1 inch, as mentioned above. The maximum height capability of the telescoping system controlling the knee support will be 1.5 feet above the foundation bar. Therefore, the outer pole will be 1 foot long, and the inner pole will be .75 feet long, in order to ensure that this height specification can be reached without compromising the integrity of the system. In this way, a practitioner will be able to position any patient’s leg at any height that might be required.

As mentioned above, it is important to consider the types of patients that must be accommodated by this device. The main focus of this design project is to create an assisted leg-holding device that is accessible to the handicapped or disabled. Special considerations must be made for this group. As mentioned above, the knee support has been added to the design in order to increase support and stability of a patient’s legs, especially for those patients with weak muscles or amputations. Another important feature of this design will be the addition of Velcro straps, to keep the patient’s legs securely fastened within the device. This will reduce anxiety by ensuring that the patient feels comfortable. It will also be useful for patients with Parkinson’s or other diseases that might cause tremors, as extra precautions must be made to ensure that these individuals do not move or disrupt a delicate procedure. Figure 2.2.42 below shows possible locations for strap attachment.
2.2.2.4 Foot Support

Much like the knee support, the boot or foot holder will be purchased as a prefabricated component and then modified to increase the range of patients that can be accommodated by the device. A similar, yet shorter two pole system will be used to adjust the height of the boot. This component will be able to adjust to a maximum height of 1 foot above the foundation bar. Therefore, the larger pole will be .67 feet, and the smaller pole will be .5 feet in length.

The attachment to the main bar will use the same moveable linear bearing system as the knee support. However, unlike the knee support, which could potentially slide too far and disrupt the spring component, the ultra high molecular weight polyethylene handle, described in a previous section, will prevent the boot from sliding off of the device. If a part must be changed or replaced on either the boot or knee support, the handle can be removed by unscrewing it from the foundation bar, and each of the support components can then be removed or replaced.
Like the knee support, the boot will also be able to pivot about the telescoping bar system, using the same technology as described in figure 2.2.41 in the previous section. Figure 2.2.43 below shows the capabilities of rotation of the foot support component.

The boot attachments will rotate at the point of contact on the pole, however, the range of rotation will be smaller than on the knee. The boot must allow less rotation because there is an optimal range of foot angles that prevent damage due to pressure on nerves of the lower leg. The boot will be able to rotate on 5 degree intervals, but only for a maximum rotation of 15 degrees from the vertical. The need for alignment with the knee rotation must be balanced with the requirement not to create nerve or tissue damage.

Figure 2.2.44 below summarizes the knee and foot support components, their dimensions, and the relationships among them.
The assisted leg-holding device described in this design report has many features allowing it to be user friendly for the practitioner, and comfortable and accessible to patients having many different requirements. The design of this device is simple in that it is fully mechanical and therefore does not require additional components such as a battery or outlet. Each piece is designed to work successfully and for a long time without failure, as is proven by the technical analysis distributed throughout the report. Allowing so many components of the device to be adjustable, such as the height of the foundation bar, and the range of motion as well as the heights of the foot and knee supports, guarantees that the device can be customized for the needs of each practitioner and patient, as well as for individual procedures. The final schematics below show this device, its components, and its capabilities.

Due to the constraints of the final two diagrams, the final pages of the “Components” section of this report will be in “landscape” format. In this way, all of the details of the assisted leg-holding device, which is much longer than it is wide, can be shown vividly.

Figure 2.2.45 shows a comprehensive view of one leg support of the assisted leg-holding device, looking along the length of the bar. In this diagram, every subcomponent is shown and labeled, and the movement of each piece is described.

Finally, figure 2.2.46 shows the assisted leg-holding device system in three dimensions, again with all components labeled.
Figure 2.44 Comprehensive view of one leg support of the assisted leg-holding device.
Figure 2.46 Three dimensional drawing of assisted leg-holding device, with major parts labeled.
2.3 Final Design

2.3.1 Link System

The most important aspect of this device is the link system. Based on the math and calculations provided in the spring section of this report, the links are just smaller, repeating units of the original design. Each link is identical except for link length. Here the two links which hold the support devices are 12 inches and the middle two links without attachments are 10 inches. The reason the team went to a link system is that the system allows for greater movement and adjustment of the device overall and its associated support pieces. Not only can the device extent to 44 inches in length for patients who are six feet in height but having four links means the middle two can bend into each other so that the shortest available length is 24 inches. Further testing with the motors attached reviled that the actual shortest length is longer due to the motors not allowing the links to bend all the way into each other. The four links can also be set at different heights which can be used to change both length and the height angle of the support components which are attached. While 44 inches may seem long, the length is required so that the location of the support components along the bar can be changed.

It is important to make the links as strong and durable as possible, while at the same time allowing the device to be lightweight. Due to its exceptional mechanical properties and ease of sterilization, a metal will be used for this application. Aluminum, which is extremely strong and also lightweight, is the metal that will be used. The modulus of elasticity of this material is 10,200,000 pounds per inch, showing that this is an extremely strong metal.

The supplier of the links that has been chosen for this application is 80/20 The Industrial Erector Set. This company specializes in providing innovative, creative components, especially metal bars in different styles and designs. The bar chosen for this application is the 15 Series T-Slotted Profile, model number 1501. Figure 2.3.1 below shows a diagram of this product.
While the upper horizontal bar will be made of the 15 series, the vertical bars onto which the motors attach will be made 10 series which is simply smaller in size but has the same profile. The image of the 10 series is provided below in figure 2.3.2.

**Figure 2.3.1** T-Slotted Profile (a) photograph (b) with dimensions shown [13]
The link system avoids the issue of deflection which is outlined in the optimal design.

The final consideration with the link system was the bottom horizontal bar which was made from aluminum scrap metal found at the machine shop. This metal was used because it reduces the cost of the overall project and need to hold no significant weight from the device. One issue that arrows was in which order to attach the links and the horizontal bars. The order was important because the thigh and foot support must be aligned and for electrical reasons it would be nice if all the motors were on the same face. This cuts down on the possibility of an electrical interaction with either the patient or the practitioner. Additionally, because the 15 and 10 series are different sizes, there was going to be a small difference no matter how the links were laid, ideally it could be made minimal. The layout shown below in figure 2.3.3. is the final layout with left a .5 inches difference between the first and final link.

2.3.2 Spring Theory

As explained in previous sections, we will be using anti-gravity technology for the leg supports of our assisted leg-holding device. The theory behind this technology is based on the paper “A Simple
As explained in this paper, it is possible to use springs to create a situation of weightlessness by understanding and manipulating the forces that are being applied to the system.

Although our device is relatively complicated, with multiple links, the theory behind the anti-gravity concept is best understood by considering a simplified version of our design. Figure 2.3.2.1, which is borrowed from (1), shows only one link of our design. Having explained the theory based on this model, it is possible to apply this same concept into our multi-link system.

**Figure 2.3.2.1** One link of the assisted leg-holding device, from (1)

Figure 2.3.2.2 below shows a free body diagram of figure 2.3.1.1, with all forces drawn in place.
Figure 2.3.2.2 Free body diagram of one link of the assisted leg-holding device, from (1)

One way to determine that the system in figure 2.3.2.2 is in equilibrium is to ensure that its total potential energy is zero. Because there are only two forces acting on this single-link system, the determination of the total potential energy is easily determined:

**Gravitational Potential Energy**

\[ GPE = -m_n g l_n \cos \Theta_n \]  

**Spring Potential Energy**

\[ SPE = \frac{1}{2} K_n x_n^2 \]

**Total Potential Energy**

\[ TPE = -m_n g l_n \cos \Theta_n + \frac{1}{2} K_n x_n^2 = 0 \]

A problem arises when we attempt to determine the value of \( x_n \). However, using the law of cosines, it is possible to replace this term with using the values for “\( a_n \)” and “\( b_n \)”, and this derivation is shown below:

\[ x_n^2 = a_n^2 + b_n^2 + 2 \cdot a_n \cdot b_n \cdot \cos(\Theta_n) \]

By substituting (4) into (3), it is possible to solve for \( K_n \), the spring constant required for the link to be in equilibrium:

\[ K_n = \frac{m_n g l_n}{(a_n \cdot b_n)} \]

Using this formula to determine the spring constant for each link based on the weight of the link as well as “\( a \)” and “\( b \)” ensures that the link will be in equilibrium and therefore feel complete weightlessness.
This same theory can be expanded to accommodate the four-link system found in our device. Below, figure 2.3.2.3 shows the free body diagram extended to the entire system.

![Free body diagram of four-bar system](image)

**Figure 2.3.2.3** Free body diagram of four-bar system

The derivation for the appropriate spring constant shown in (5) can be applied to the “n\textsuperscript{th}”, or specifically the fourth bar of our system. For the other three links, however, the forces for each preceding link must be taken into account. Therefore, for the third link, the total potential energy is as shown in equation (9).

**Gravitational Potential Energy**:

\[
GPE(\text{link} D) = -m_D \cdot g \cdot l_D \cdot \cos \Theta_D \\
GPE(\text{link} C) = -2 \cdot m_C \cdot g \cdot l_C \cdot \cos \Theta_C
\]  

(6)  

(7)

**Spring Potential Energy**:

\[
SPE = (K_C / 2) \cdot (a_C^2 + b_C^2 + 2 \cdot a_C \cdot b_C \cdot \cos \Theta_C)
\]  

(8)

**Total Potential Energy**:

\[
TPE = -m_D \cdot g \cdot l_D \cdot \cos \Theta_D - 2 \cdot m_C \cdot g \cdot l_C \cdot \cos \Theta_C + (K_C / 2) \cdot (a_C^2 + b_C^2 + 2 \cdot a_C \cdot b_C \cdot \cos \Theta_C)
\]

(9)

Again, solving for the spring constant for the third link:

\[
K_C = \left[ \frac{g}{(a_C \cdot b_C)} \right] \cdot \left[ m_C \cdot l_C + 2 \cdot m_D \cdot l_D \right]
\]  

(10)

This same method can be used to solve for each link’s spring constant, and equation 10 can be generalized for all four links of our system, as shown in equation 11 below.
The theory explained here was applied to our project directly, and as a result our device can be adjusted by a practitioner with little force exerted. We did, however, have to make some adjustments before using these ideas in our device. The largest problem that we encountered was that all of the calculations carried out in (1) were based on the assumption that the weight exerted on the device, or the m*g term in figure 2, was constant. In our case, we had to make the device adjustable for a wide range of patients with different heights and dimensions. Therefore, we were left with two choices: either the practitioner would have to change the springs used for each patient, or else we would have to come up with a way to keep the spring constant the same, even as the weight exerted on the device differed. Due to the inconvenience associated with the former, we chose the latter situation, and thus had to find a way to compensate for changing weight.

In order to do this, we went back and re-examined equation 11. How could we keep the spring constant “Kt” the same even when patients of very different weights needed to use the device? After some thought, we realized that the easiest way to manipulate equation 11 to keep the Kt term constant would be to alter the “a*b” dimension term. From figures 1 and 2, recall that “a” refers to the distance that the spring is from each link’s point of attachment in the horizontal direction, and “b” is the distance that the spring is from each link’s point of attachment in the vertical direction. We realized that if we were to change these two dimensions, then we could keep the spring constant ratio constant.

In order to do this, we first had to put equation 11 into terms of “a*b” for each of the four links A-D, and these calculations are shown as equations 12-15 below:

\[
K_t = \frac{g}{(a_i \cdot b_i)} \cdot m_i \cdot l_i + \sum_{i=1}^{n} 2 \cdot m_s \cdot l_s
\]  

Where \( m \) is mass, \( g \) is the gravitational constant, 386.4 in/s\(^2\) 1 is the distance to the center of mass, and \( K \) is each link’s spring constant. For clarification, the link labeling system is shown as figure 2.3.2.4 below.
Obviously, in order to calculate these “a*b” terms, many variables must be defined. Table 2.3.2.1 below shows the weight and center of mass specifications for our device.

<table>
<thead>
<tr>
<th>Link</th>
<th>Structural Weight</th>
<th>Center of Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5 pounds</td>
<td>inches</td>
</tr>
<tr>
<td>B</td>
<td>pounds</td>
<td>inches</td>
</tr>
<tr>
<td>C</td>
<td>pounds</td>
<td>inches</td>
</tr>
<tr>
<td>D</td>
<td>5 pounds</td>
<td>inches</td>
</tr>
</tbody>
</table>

Table 2.3.2.1 Specifications of weight and center of mass for each link of the device

The center of mass terms shown in table 1 were calculated assuming that all of each link’s weight was directed in the center of each link. In actuality, this is not the case, because different parts of the device are mounted asymmetrically, and the position of both the foot and the knee supports can be adjusted on links A and D. However, to reduce calculations and allow for a general design, these facts were ignored and the weight was assumed central. Perhaps a future improvement for this device could be to take these factors into account. This would allow the calculations to be more accurate, and thus allow the anti-gravity ability of the device to be more precise.

The weights shown above were calculated based on the combined weights of all of the components that make up each link of the system, including motors, springs, and supporting linkage. Each patient’s weight is then added to this term to find the final combined link weights. To make the device more user-friendly, we divided the total range of weights for which this device is rated, 75 pounds to 300 pounds, into 25 pound sub-categories (75-100 pounds, 100-125 pounds, etc). We then further divided these categories into weight exerted by the upper leg, which will be exerted through the thigh support onto link A, and weight exerted by the lower leg and foot, which will be exerted through the foot support onto link D. In order to calculate the amount of weight of both the upper and lower legs, an anthropomorphic table was used. (2) According to this table, a person’s upper leg comprises 10% of his total body weight (each leg), and each lower leg and foot makes up another 6.1% of his total body weight. Therefore, a 100-pound person using our device would be assumed to
have an upper leg weighing 10 pounds, and a lower leg weighing 6.1 pounds, and these weights were added to the weight of the device without a patient in order to calculate the final link weights and thus the “a*b” terms. Values for the weights of each link for each category are shown in table 2.3.2.2 below.

<table>
<thead>
<tr>
<th>Weight Category</th>
<th>Link A</th>
<th>Link B</th>
<th>Link C</th>
<th>Link D</th>
</tr>
</thead>
<tbody>
<tr>
<td>75-100 pounds</td>
<td>14.75</td>
<td>3</td>
<td>3</td>
<td>11.825 pounds</td>
</tr>
<tr>
<td>100-125 pounds</td>
<td>17.25</td>
<td>3</td>
<td>3</td>
<td>13.35 pounds</td>
</tr>
<tr>
<td>125-150 pounds</td>
<td>19.75</td>
<td>3</td>
<td>3</td>
<td>14.875 pounds</td>
</tr>
<tr>
<td>150-175 pounds</td>
<td>22.25</td>
<td>3</td>
<td>3</td>
<td>16.4 pounds</td>
</tr>
<tr>
<td>175-200 pounds</td>
<td>24.75</td>
<td>3</td>
<td>3</td>
<td>17.925 pounds</td>
</tr>
<tr>
<td>200-225 pounds</td>
<td>27.25</td>
<td>3</td>
<td>3</td>
<td>19.45 pounds</td>
</tr>
<tr>
<td>225-250 pounds</td>
<td>29.75</td>
<td>3</td>
<td>3</td>
<td>20.975 pounds</td>
</tr>
<tr>
<td>250-275 pounds</td>
<td>32.25</td>
<td>3</td>
<td>3</td>
<td>22.5 pounds</td>
</tr>
<tr>
<td>275-300 pounds</td>
<td>34.75</td>
<td>3</td>
<td>3</td>
<td>24.025 pounds</td>
</tr>
</tbody>
</table>

**Table 2.3.2.2** Summary of link weights (combined structural and patient) for each patient weight category

Because each weight sub-category changed the weight variable in equations 12-15 above, nine “a*b” terms were determined for each link A-D. However, as can be seen in these equations, the final variables needed to calculate each “a*b” term are the spring constants $K_A$, $K_B$, $K_C$, and $K_D$.

After much calculation and research into available options for springs, we decided that the simplest and most cost-effective solution for ordering springs for this device would be to order stock springs, as it would be extremely expensive and time-consuming to order custom-designed springs for our project. We also decided to order eight identical springs, so that all four links on each of the two leg supports of the leg-holding device were the same. The dimensions and requirements of all four links were able to tolerate this consistency, and it greatly simplified the project. The spring constant for these springs is 46.9, and the springs will be explained in greater detail in the next section. With this information, it is now possible to calculate the “a*b” terms for each patient weight category for each link, and this information is given in table 2.3.2.3 below.

<table>
<thead>
<tr>
<th>Weight Category</th>
<th>Link A</th>
<th>Link B</th>
<th>Link C</th>
<th>Link D</th>
</tr>
</thead>
<tbody>
<tr>
<td>75-100 pounds</td>
<td>6.191897655</td>
<td>3.985074627</td>
<td>3.34515778</td>
<td>1.512793177</td>
</tr>
<tr>
<td>100-125 pounds</td>
<td>6.901918977</td>
<td>4.375266525</td>
<td>3.735607676</td>
<td>1.707889126</td>
</tr>
<tr>
<td>125-150 pounds</td>
<td>7.611940299</td>
<td>4.765458422</td>
<td>4.125799574</td>
<td>1.902985075</td>
</tr>
<tr>
<td>150-175 pounds</td>
<td>8.32196162</td>
<td>5.15565032</td>
<td>4.515991471</td>
<td>2.098081023</td>
</tr>
<tr>
<td>175-200 pounds</td>
<td>9.031982942</td>
<td>5.545842217</td>
<td>4.906183369</td>
<td>2.293176972</td>
</tr>
<tr>
<td>200-225 pounds</td>
<td>9.742004264</td>
<td>5.936034115</td>
<td>5.296375267</td>
<td>2.488272921</td>
</tr>
<tr>
<td>225-250 pounds</td>
<td>10.45202559</td>
<td>6.326226013</td>
<td>5.686567164</td>
<td>2.68336887</td>
</tr>
<tr>
<td>250-275 pounds</td>
<td>11.16204691</td>
<td>6.71641791</td>
<td>6.07659062</td>
<td>2.878464819</td>
</tr>
<tr>
<td>275-300 pounds</td>
<td>11.87206823</td>
<td>7.106609808</td>
<td>6.466950959</td>
<td>3.073560768</td>
</tr>
</tbody>
</table>

**Table 2.3.2.3** Summary of “a*b” terms for each link of each patient weight category (all terms in inches squared)
Recall that the “a*b” term corresponds to multiplying the “a” and “b” dimensions from the set-up for each link (refer back to figure 2), and therefore is meaningless in itself. However, this term was used to calculate the appropriate measurements of “a” and “b” so that the device can be balanced for every patient. This is done using stepper motors controlled by a microprocessor, but will be explained in detail in a later section.

As explained above, in order for the device to create an anti-gravity situation for each individual patient, the product of the “a” and “b” dimensions must match with the number given in table 3 for that patient’s weight subcategory. Still, we must determine each term “a” and “b” separately in order for the device to succeed.

Figure 2.3.2.5 shows the actual set-up of a link from one of the leg supports of the device. Again, the “a” and “b” sections are highlighted. As can be seen in this figure, a cord is used as an extension of the spring, and it is this component that is being adjusted when the “a” and “b” terms are altered. This cord will be described in greater detail in another section. For now, its’ mention will be limited to its relevance to “a” and “b” adjustment.

It would be inconvenient if this device required that the practitioner adjust the length of the cord each time he or she wanted to alter the “a” and “b” dimensions for patient accommodation. Therefore, one of the requirements of this project was to ensure that the cord length remained constant throughout all device adjustments. In order for this to happen, based on the simple geometric relationship between the dimensions “a” and “b”, for every “b” adjustment, an identical “a” adjustment must be made. This rule can be broken only in the case that the cord controlling “a”’s movement is looped so that the “a” dimension moves in proportion to the number of loops that are made. In our device, three of four links on each leg support had the simple 1:1 ratio between “a” and “b”, and because of space limitations we created a 1:2 ratio of “a” to “b” by double-looping the cord.
for the other link (Link A on each support). Figure 2.3.2.6 shows the double-loop set-up that was used for link A, and again the rationale for changing the set-up for this link was because due to the nature of the system link A feels weight from all other links because it is closest to the table (calculations in equations 1-11), and this forces its “a” and “b” terms to be substantially larger. Therefore, because we are limited in space by the dimensions of each link, the double-loop was necessary.

![Photograph of spring and cord set-up for link A (double loop)](image)

**Figure 2.3.2. 6** Photograph of spring and cord set-up for link A (double loop)

For links B, C, and D, in order to keep the 1:1 ratio, the square root of each “a*b” term was taken, and therefore the “a” and “b” dimensions can remain identical for each adjustment. For link A, the square root of the “a*b” term was also taken, and divided by 2 to obtain the “a” value. The “b” dimension was determined by dividing the “a*b” term by the newly-found “a” term, and again, the 2:1 ratio was ensured and thus cord length kept constant. Table 2.3.2.4 below shows the “a” and “b” values for each link A-D for each sub-category.
<table>
<thead>
<tr>
<th>Model Number</th>
<th>LE177L02M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring Constant</td>
<td>46.9 pounds/inch</td>
</tr>
<tr>
<td>Resting Length</td>
<td>5 inches</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>7.345 inches</td>
</tr>
<tr>
<td>Change in Length</td>
<td>2.345 inches</td>
</tr>
<tr>
<td>Outside Diameter</td>
<td>1.5 inches</td>
</tr>
<tr>
<td>Wire Diameter</td>
<td>.177 inches</td>
</tr>
<tr>
<td>Maximum Load</td>
<td>161.2 pounds</td>
</tr>
<tr>
<td>Initial Tension</td>
<td>10.97 pounds</td>
</tr>
</tbody>
</table>

Table 2.3.3.1 Spring specifications
As can be seen in table 2.3.3.1, there are many things to consider when choosing a spring for any application, and due to time and budget constraints, we had to compromise on several items. One of the most important things to consider when choosing the spring for this application was the maximum allowable load. Table 2 shows the maximum weight that will be exerted on any of our springs, as link A will see a combination of structural and patient weight from all four links for a total of 64.76 pounds. Thus the factor of safety for the springs in this device can be calculated by dividing the rated spring rate by the maximum weight that the spring will feel, and this calculation is shown as equation 16 below.

\[
\text{Factor of Safety} = \frac{161.2}{64.76} = 2.49
\]  

As can be seen from this calculation, our design is conservative with respect to the springs that were selected. However, there are other parameters to consider as well. Because we want this device to be compatible with both light patients as well as heavier patients, the initial tension must not be greater than the minimum weight exerted on any of the springs, again a combination of structural and patient weight for only link D, determined in table 2 as 11.825 pounds. Again, the spring chosen for this application can accommodate this factor.

A third important consideration to be made when choosing our spring was the spring’s ability to change length, calculated based on the resting and maximum safe extension ratings. For our device, the “a” and “b” dimensions are set when each link is placed into its highest position, in order to ensure that the device will support the patient’s weight for the full necessary range of motion. At this time, the “a” and “b” positions are locked into place, and since the cord does not change length throughout any movement, any change in height of the device comes from changing the length of the spring. Therefore, in order to ensure that the device can move through the necessary range, the spring must be able to stretch sufficiently.

When choosing a spring with sufficient stretch, we were limited by the fact that the spring must also have a relatively high spring constant and a high maximum load rating. Ideally, if we could order custom springs, we would choose a spring with a resting length much smaller than 5 inches, and with a maximum extension greater than 2.345 inches, so that we would not be limited by the spring’s length when determining the “a” and “b” adjustments (see explanation of “double-loop”) and so that we could adjust the device through a wider range of heights. However, to accommodate the limitations of our springs, we decided that the maximum heights of links A and C would be 45 degrees above the horizontal, and the maximum heights of links B and D would be horizontal. In this way, the device could reach a maximum extension when all four links were horizontal, and a minimum extension when links A and C were at their full heights, and links B and D were at their lowest heights, approximately 45 degrees below the horizontal.

The calculations for determining the device height based on spring extension were made by considering the triangle made between “a,” “b,” and the linear distance between these two points, which we called “c”. Figure 2.3.3.1 shows a photograph of one link from our leg-holding device, with the triangle highlighted.
Figure 2.3.3.1 Triangle formed between “a”, “b”, and the linear distance between these points

We were able to calculate the “c” distance using the geometric relation known as the “Law of Cosines”, which is shown as equation 17 below.

\[ c = \sqrt{a^2 + b^2 - 2ab \cos(\Theta)} \] (17)

As can be seen from equation 17, the “c” distance is based on “a” and “b”, as well as the angle formed between these two values. This angle, \( \theta \), is equal to the angle that the links of the device form with the horizontal.

The change in “c” when each link goes from its highest to its lowest position is directly equivalent to the change in spring length. Also, the change in “c” will be greatest when the maximum patient weight of 300 pounds is loaded into the device, because at this point the “a” and “b” terms will be greatest, as can be seen in table 4. Therefore, in order to calculate the maximum change in “c”, and therefore the maximum needed spring stretch, the maximum “a” and “b” values for each link were inserted into equation 17, along with the maximum and minimum required \( \theta \) terms. Table 2.3.3.2 shows the parameters used to calculate maximum required spring stretch for each of the four links, as well as the corresponding stretch values.

<table>
<thead>
<tr>
<th>Link</th>
<th>Maximum ( \theta )</th>
<th>Minimum ( \theta )</th>
<th>Maximum “a”</th>
<th>Maximum “b”</th>
<th>Required stretch</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>45 degrees</td>
<td>0 degrees</td>
<td>1.72 inches</td>
<td>6.89 inches</td>
<td>.63 inches</td>
</tr>
<tr>
<td>B</td>
<td>135 degrees</td>
<td>90 degrees</td>
<td>2.66 inches</td>
<td>2.66 inches</td>
<td>1.15 inches</td>
</tr>
<tr>
<td>C</td>
<td>45 degrees</td>
<td>0 degrees</td>
<td>2.54 inches</td>
<td>2.54 inches</td>
<td>1.94 inches</td>
</tr>
<tr>
<td>D</td>
<td>135 degrees</td>
<td>90 degrees</td>
<td>1.75 inches</td>
<td>1.75 inches</td>
<td>.76 inches</td>
</tr>
</tbody>
</table>

Table 2.3.3.2 Summary of parameters determining required spring stretch

As can be seen from table 2.3.2.3, the springs chosen for this application have sufficient stretch to accommodate the required change in height of all four links. With this final calculation, we agreed that this spring would work sufficiently for the purposes of our device. Again, by creating a custom
spring with a greater stretch than what was available to us, we could have a greater range of motion for this device, and perhaps this could be a future improvement to our project.

Each of the eight springs ordered cost $17.01, for a total of $136.08. Because we ordered less than ten springs, there was also a $20 shipping charge, so that the total cost of springs came to $156.08.

2.3.4 Spring Attachment

In order to attach the springs to the assisted leg-holding device, custom metal plates were designed at the University of Connecticut Engineering Machine Shop. Scrap metal (aluminum and tempered steel) was used to make a total of eight of these plates, one for each spring. Each plate was cut to a length of 3 inches, and then each side was milled to a width of .75 inches. With these dimensions, the plate could be inserted onto the back of each of the eight 15-series 8020 pieces that make up the top horizontal framework of the device. Because each of these extruded aluminum bars has a width of 1.5 inches, the plates did not extend past the bars, which could have prevented articulation of the bars with each other. Because the bars are square, they each also have a height of 1.5 inches, and therefore the metal plates hang down past each bar by 1.5 inches so that the spring can be inserted.

Having finished cutting each plate to the proper dimension, two holes were drilled into each plate. The first hole was centered at .75 inches from the top of the plate, and at .375 inches from each side. In this way, the hole matches up with the hole in the center of each extruded aluminum bar, and the plate is centered on the bar’s width. A 3/8 inch clearance drill was used to make each hole.

The same drill bit was used to make a second hole in the plate, again centered at .375 inches from each side of the plate, but at approximately 1.75 inches from the first hole. The ends of the springs are inserted into these holes, and in this way the springs are attached to the plates. Figure 2.3.4.1 shows the dimensions of the metal plates, with a ruler for comparison.

![Dimensions of the metal plates used for spring attachment](image)

In order to attach the plates to the device, the hole at the end of each 15-series extruded aluminum bar was threaded using a 5/16-18 inch-threads/inch end tap. A matching bolt was inserted through the plate and threaded into the bar to keep the plate in place on the device. Figure 2.3.4.2 shows this set-up.
Having explained each part of the plate set-up, figure 2.3.4.3 shows a comprehensive photograph of the spring’s attachment to the device.

**Figure 2.3.4.3** Attachment of spring to device
2.3.5 Cord

As mentioned above, a cord was used to attach the spring to the vertical supports of the device. The cord chosen for this application was purchased from Mansfield Supply Company in Storrs, CT for $0.39 per foot. 20 feet of cord were purchased to ensure that there was sufficient cord available for every link of the device, for a total cost of $7.80. The cord that was chosen is made of uncoated stainless steel to prevent slipping. To increase strength and further prevent slipping, the cord is made up of seven groups of seven smaller cords twisted together in the pattern shown in figure 2.3.5.1 below.

![7x7 Stainless Steel cord](image)

Figure 2.3.5.1 7x7 Stainless Steel cord

Due to this design, the 1/16\textsuperscript{th} inch diameter cord has a breaking strength of 94 pounds. The factor of safety can again be calculated for this part if we use table 2 to determine the maximum weight that the cord will feel, and this calculation is shown as equation 18 below.

\[
\text{Factor of Safety} = \frac{94}{61.775 \text{lbs}} = 1.52 \quad (18)
\]

Again, this cord is safe to use for our design.

2.3.6 Cord Lock

In order to attach the cord to the spring as explained above, cord locks were purchased from Mansfield Supply. Sixteen of these locks were purchased at $0.49 each, for a total of $7.84. Figure 2.3.6.1 shows a photograph of one of these cord locks.
As can be seen in figure 2.3.6.1, the cord locks are relatively small (approximately 1 inch by .5 inches), and consist of a hooked, threaded rod, a sliding piece, and two nuts. Cord is inserted into the cord lock and then the nuts are tightened using a wrench until the cord stays firmly in place. For further safety, we tied off each cord with a self-tightening knot looped around the hooked rod, so that as tension is exerted onto the lock, the cord simply pulls itself into a tighter knot. The knot that was used is shown in figure 2.3.6.2 below.

Enough space was left in one of the loops of the knot to allow the cord to slip over the end of the spring, thus creating an attachment point.

The locks were also used to attach the other end of the cord, to the platform that controls the “b” dimension for each link. This platform will be described in greater detail in a later section, but a hole
was drilled into each platform so that the cord could be inserted through the hole with the lock on the bottom to prevent the cord from sliding when tension is applied.

2.3.7 Welded I-Hook (for “a” adjustment)

As described above, both the “a” and “b” dimensions must be adjusted based on the weight of the patient using the device. However, because the “a” dimension is horizontal and the “b” dimension is vertical, different systems are used to adjust each dimension. Also as explained above, because of the 1:1 ratio between the “a” and “b” dimensions, if one of these two dimensions is changed, the other must be adjusted accordingly.

In order to ensure accurate adjustment within this system, we decided that it would be a good idea for the “a” and “b” distances to be adjusted automatically rather than manually by the practitioner. However, as mentioned above, when one of these dimensions is changed the other will follow automatically, and therefore only one of the dimensions need be motorized. For our system, we decided that it would ultimately be simpler to change “b”, the vertical dimension, and the method for changing “b” will be explained in great detail in further sections.

Because the “b” dimension is being changed automatically, “a” will be forced to re-align itself simultaneously within the 1:1 ratio. In order to do this, the component that is in charge of “a” adjustment must be able to move readily into position to keep the cord in tension. Once “a” reaches the correct position, which is when “a” and “b” remain within the 1:1 ratio and thus the cord remains tight, “a” must also be locked into place so that no further movement can occur to take the cord out of tension, which would prevent the anti-gravity mechanism from working.

In order for the “a” adjustment component to perform all of these tasks, we created a custom-made welded I-hook, which is shown in figure 2.3.7.1 below.
Figure 2.3.7.1 Custom made welded I-hook for “a” adjustment

As can be seen in the photograph, this welded I-hook is inserted into the horizontal 8020 support piece of each link. Several components were placed together in order to create a working support, including bolts that can be ordered from the 8020 website to fit into the extrusions of the 8020 aluminum. Also from the 8020 website, the ultra high molecular weight polyethylene slides that fit into the extrusions assure that the bolt slides smoothly and does not catch within the aluminum. The wing nuts and I-hooks also seen in the photograph were purchased from the machine shop, and Serge was hired to weld the system together.

As can be inferred from the picture, the cord is strung from where it is looped around the spring, through the I-hook, and finally into the “b” adjustment linear slide. When the “b” position is adjusted, the “a” system slides into place along the horizontal support. Then, after “b” positioning has concluded, the practitioner tightens the wing-nut to secure the “a” dimension into its position.

2.3.8 Linear Slide System (for “b” adjustment)

Like the welded I-hook, the linear slide system for “b” adjustment is made up of several components, which include a sliding platform and a threaded rod coupled to a stepper motor. This section will describe the sliding platform, threaded rod, and motor coupler. However, the stepper motor will be described within its own subsection.

In order to adjust the “b” height for each link automatically, we had to convert the rotational motion that we could get from a motor into linear motion. To do this, we decided to couple the motor to a threaded rod, which was also attached to a threaded hole within the platform that runs up and down
the vertical 8020 supports. Therefore, as the motor rotates, the threaded rod spins, and because it is threaded into the hole in the platform, this drives the platform up or down the vertical support, thus adjusting the height “b” of the cord.

In order to couple the motor to the threaded rod, a custom-made piece was designed at the University of Connecticut Machine Shop. We started by purchasing eight 1 inch long by 5/8 inch diameter rods. Using a lathe with a ¼ inch drill bit, we bored a ¼ inch hole through each rod. Next, we used a miller to drill 2 tapped holes, centered and approximately .375 inches apart, into one side of each rod. These rods are used as the couplers between the motor’s shafts and the threaded rods, which were both sanded so that they had flat surfaces. The flat surfaces of each part were inserted into the couplers, and Allen-head screws were inserted and tightened using an Allen-wrench. Below, figure 2.3.8.1 shows one of these couplers attached to a motor and threaded rod.

![Coupler between motor shaft and threaded rod](image)

**Figure 2.3.8.1** Coupler between motor shaft and threaded rod

The threaded rods used for this application were ¼”-20x12”. Therefore, for every 20 rotations of the motor, the linear platform will move 1 inch.

The linear platform used for “b” adjustment was also custom-made in the University of Connecticut Machine Shop, and again this piece was made from several components. 24 1 inch pieces of aluminum with a 90 degree bend were purchased, as well as eight 4”x3” rectangular aluminum pieces. A 1.5 inch by 1.5 inch rectangular piece was removed from one of the 3” sides of the larger rectangular piece. Perpendicular to each side of this rectangular hole, sets of two ¼ inch tapped holes were drilled using the miller with ½ inch spacing in between them. Holes were also drilled and tapped as described above for the threaded rod driving the linear motion. Next, the bent aluminum pieces were milled so that each piece had a ¼ inch by ¼ inch hole in the center.
The purpose of this procedure was to create linear slides with supports that fit snugly around the vertical 8020 supports. ½ inch bolts were inserted through the bent aluminum pieces and threaded through each of the two holes in the platform. The bent aluminum pieces could then be adjusted to fit exactly around the 8020 supports, to allow a fluid movement of the platform when driven by the motor and threaded rod. This entire set-up, including the threaded rod, is shown in figure 2.3.8.2 below.

![Figure 2.3.8.2 Linear platform for adjusting “b” dimension](image)

The black bolt seen in figure 2.3.8.2 was purchased from the 8020 website, and like the bolt that fits into the extrusions of the horizontal supports, this bolt fits into the vertical 8020 support to ensure proper alignment and sliding.

Figure 2.3.8.3 below shows the entire assembly for “b” adjustment, including a motor, threaded rod, and linear platform.
Figure 2.3.8.3 Assembly for “b” adjustment

One final hole was drilled into the linear platform, and as explained above, this is where the cord and cord lock were inserted. Figure 2.3.8.4 shows the linear platform with the cord inserted.
2.3.9 Locking Mechanism

Based on the anti-gravity theory described in a previous section, the assisted leg-holding device should support its own weight, and therefore no locking mechanism should be required. However, because we decided to make some assumptions such as putting patients into weight categories instead of customizing for each patient and assuming that all weight of each link is concentrated at the center of each link, our device is unable to support its own weight perfectly and therefore we decided to add a locking mechanism. This is actually helpful even if the device could function perfectly, because the device should be able to lock into place during surgery to prevent accidental bumping or patient movement.

As in other parts of our device, time and budget constraints forces us to make concessions on the locking mechanism that we chose for our device. Ideally, we hoped to attach motors at the bottom joints of each of the links of the leg holding device, in the positions highlighted in figure 2.3.9.1.
The purpose of these motors would be to exert torque to tighten the nuts located at every support of the leg-holding device to such an extent that no articulation could occur within the joints. However, after testing, we realized that the amount of torque required to keep each joint in place exceeded 75 pounds/inch, and motors capable of this amount of torque were extremely expensive. So, we decided instead that, for our device, the nuts would simply be tightened by hand once the ideal position is reached, and that this would be a sufficient locking mechanism for this project. A motorize locking system can be added to the list of improvements that could be used to alter the leg-holding device in the future.

2.3.10 Motor Mounts

In order to keep a uniform appearance to the device, all motors will be mounted on the front face (outward facing) on each leg. This will allow more space between the each leg of the device for the practitioner as the motors will not be on the inside. Each motor has four screws holes placed 2 inches apart along the square body of the motor. Each motor is 1.2 lbs in weight and requires 3 inches in each direction to clear a space. The mounts which were created for the motors are L brackets which were made in the machine shop from the scrap in creating the L brackets for the attachment of the device to the table. The mounts were drilled using C&C milling for accurate hole placement. Then, two holes were drilled and milled measuring $\frac{1}{4}$ 20”. While both are for attachment to the vertical support bar, one will go the entire length, that is go through the bar and be used in locking the link and the other is simply used to counter rotation of the mount due to gravity. Figure 2.3.10.1 below, shows a completed motor mount.
2.3.11 Motor

Since our final design included having a motor system to adjust the length of the cord based upon the patient’s weight, as a team, we looked for a stepper motor with drivers. We considered stepper motors to be the best option for our design because microsteps played a major role in our design. A small error in the steps could jeopardize the patient’s safety by unbalancing the leg holding device.

We could not accommodate to have a motor that was embedded with encoder and driver although position played an important role for the motor. The main reason for us to have an encoder was so that the motor could realize its position in comparison to the original position. This would eliminate any hazardous movement of the motor and also send the motor back to original position after the movement.
Figure 2.3.11.1 The figure 1 above shows the adjustment of “b” required to accommodate different patient

Figure 2.3.11.1 above shows the design with required adjustment of link “b” which will be accomplished with use of motor as described below.

2.3.12 MDrive 23 PLUS Micro stepping:

MDrive 23 plus Microstepping purchased through IMS (Intelligent Motion Systems) is a high torque integrated motor + driver which is an ideal motor for our design because of its simplicity with onboard electronics. The integrated electronics of the MDrive23Plus eliminates the need to run motor cabling through the machine, reducing the potential problems due to electrical noise. Figure 2 below shows the MDrive 23 plus Microstepping motor purchased via IMS.

The smoothness and performance delivered by the MDrive23Plus Micro stepping were achieved through advanced second generation current control. By applying innovative techniques to control current flow through the motor, resonance is significantly dampened over the entire speed range and noise was reduced. Since, current flow of the motor was controlled, it seemed an ideal motor for our design as well.

In addition, the motor accepts a broad input voltage ranging from +12 to +75 VDC, delivering enhanced performance and speed. Oversized input capacitors are used to minimize power line surges, reducing problems that can occur with long runs and multiple drive systems. An extended operating range of -40° to +85°C provides long life, trouble free service in any kind of environments.

Furthermore, the MDrive23Plus uses a NEMA 23 frame size high torque brushless motor combined with a Microstepping driver, and accepts up to 20 resolution settings from full to 256 micro steps per
full step, including degrees, metric and arc minutes. Hence, MDrive23Plus is a compact, powerful and inexpensive solution that reduces system cost, design and assembly time for a large range of brushless motor applications.

**STANDARD SPECIFICATIONS**

<table>
<thead>
<tr>
<th>INPUT VOLTAGE (V)</th>
<th>Range</th>
<th>+12 to +75 VDC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Power supply current requirements = 2A (maximum)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>per MDrive23Plus. Refer to illustration.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Actual power supply current will depend</td>
</tr>
<tr>
<td></td>
<td></td>
<td>on voltage and load.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ISOLATED INPUT</th>
<th>Step Clock, Direction and Enable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Range</td>
<td>+5 to +24 VDC Sourcing or Sinking</td>
</tr>
<tr>
<td>Clock Types</td>
<td>Step/Direction, Quadrature, Step Up/Step Down</td>
</tr>
<tr>
<td>Step Frequency</td>
<td>2 MHz Default / 5 MHz Max</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MOTION</th>
<th>Number of Settings</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>Steps Per Revolution</td>
<td>200, 400, 800, 1600, 3200, 5000, 6400, 10000, 12500, 20000, 25000, 25500, 40000, 50000, 51200, 38600 (0.01 deg/step), 21500 ([1 arc minute/step]), 25400 (0.0011 mm/step)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THERMAL</th>
<th>Operating Temperature</th>
<th>Heat Sink</th>
<th>-40°C to +85°C (non-condensing)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Motor</td>
<td></td>
<td>-40°C to +100°C (non-condensing)</td>
</tr>
</tbody>
</table>

**Figure 2.3.12.1** The above figure shows MDrive23 plus Microstepping Motor + Driver from IMS

**Figure 2.3.12.2:** Standard specification of MDrive 23 plus Micro stepping motor

According to standard specifications above, the input voltage ranged from +12 to +75 VDC. On the other hand, for the input such as step clock, direction and enable, the voltage ranged from +5 to +24 VDC sourcing or sinking. The step clock types were variables including step/direction, quadrature, and step up/step down. The default frequency was 2 MHz and the max frequency allowed was 5 MHz. In
addition, various steps per resolution were specified such as 200, 400, 800, 1000, 1600, 2000, 3200, 5000 and up to 51,200.

The main reason to choose MDrive 23 plus Microstepping motor over other motor was the low cost, high torque, good resolution; various clock steps provided and also because of the number of required wirings to the PIC.

Figure 2.3.12.3: Schematic image of the stepper motor

Figure 2.3.12.3 above shows the schematic image of the stepper motor which shows two different connectors available to be connected. The first connector is labeled as P1 and the second connector is P2. In addition, the 12-pin locking wire crimp connector at P1 eliminates the P2 connector. For our specific design, only P1 connector was used since P2 was for communication port of the motor to the computer.

Figure 2.3.12.4: Minimum required connections to drive MDrive plus 23

The above figure 2.3.12.4 shows the minimum required connections to drive the stepper motor. According to the figure above, at least five out of the seven connections were required to move the
motor. Pin 6 and Pin 7 were connected to the ground and to +12VDC respectively, while pin 3, pin 4 and pin 5 are connected to step clock, direction and enable respectively. In addition, Pin 5 (enable) was connected to +5VDC source.

According to Figure 2.3.12.5 above, seven pins are available where five should be connected in order to microstep the motor as desired. For our particular setup, only 5 ports will be connected as shown in Figure 2.3.12.4. Figure 2.3.12.6 below shows the P1 connector options which has 7-pin pluggable terminal as mentioned above. It also shows the pin numbers from pin 1- pin 7.
**P1 Plus Connector Configuration**

**Flying Lead and 7-Pin Terminal Strip**

<table>
<thead>
<tr>
<th>P1 Connector Flying Lead and Pin Configuration</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>12&quot; Flying Leads Wire Color</strong></td>
<td><strong>7-Pin Pluggable Terminal Strip</strong></td>
</tr>
<tr>
<td>White</td>
<td>Pin 1</td>
</tr>
<tr>
<td>—</td>
<td>Pin 2</td>
</tr>
<tr>
<td>Orange</td>
<td>Pin 3</td>
</tr>
<tr>
<td>Blue</td>
<td>Pin 4</td>
</tr>
<tr>
<td>Brown</td>
<td>Pin 5</td>
</tr>
<tr>
<td>Black</td>
<td>Pin 6</td>
</tr>
<tr>
<td>Red</td>
<td>Pin 7</td>
</tr>
</tbody>
</table>

**Figure 2.3.12.7: P1 Connector Configuration for 7-Pin Terminal**

The above figure, Figure 2.3.12.7 shows the connector configuration of the 7 terminal pins (P1) where Pin 1 and Pin 2 are optional and other Pins (3, 4, 5, 6, and 7) are to be connected with provided function above.

**Specifications**

**Electrical Specifications**

- **Input Voltage (+V) Range**: +12 to +75 VDC
- **Max Power Supply Current (Per MDrive23Plus)**: 2 A

*Actual Power Supply Current will depend on Voltage and Load.*

**Environmental Specifications**

- **Operating Temperature**: -40°C to +85°C
- **Heat Sink**: Motor
- **-40°C to +100°C**: IP-65 Compliant
- **Sealing (Plus2-65 Only)**: Motor

**Isolated Input Specifications**

- **Step Clock, Direction and Enable**: +5 to +24 VDC
- **Current (+5V Max)**: 8.7 mA
- **Current (+24V Max)**: 14.3 mA

**Motion Specifications**

- **Digital Filter Range**: 50 nS to 12.9 μS (10 MHz to 38.8 kHz)
- **Clock Types**: Step/Direction, Up/Down, Quadrature
- **Step Frequency (Max)**: 6 MHz
- **Step Frequency Minimum Pulse Width**: 100 nS
- **Number of Microstep Resolution Settings**: 20

| Available Microsteps Per Revolution |
|---|---|---|---|---|---|---|---|---|
| 200 | 400 | 800 | 1000 | 1600 | 2000 | 3000 | 5000 | 6000 |
| 21600 | 25600 | 40000 | 50000 | 51200 | 56000 | 216000 | 256000 |

1° = 0.01 deg/μstep, 2° = 1 arc minute/μstep, 3° = 0.001 mm/μstep

**Figure 2.3.12.8: Specification for MDrive 23 plus Microstepper**

Figure 2.3.12.8 above shows the specification of MDrive 23 plus with motor + driver which also shows electrical configuration, environmental specifications, isolated input specifications and motion specifications with available microstep per revolution.
Figure 2.3.12.9: Schematic image of MDrive 23 Plus Microstepping

The above figure shows the schematic image of the microstepping motor which shows the dimensions of the device. It also shows the length, width of all the dimensions on the motor.

2.3.13 PIC Microprocessor

For our design to work, we needed a PIC that could control 8 different motors. The main reason for having a single PIC was to avoid communications between 2 or more different PICs which would have been almost impossible given the time for our project. Nevertheless, to control all the 8 motors, we used PIC16F877 because it composed of 33 pins which could have been set either as input or output.

Basically for our design, our goal was similar as shown below (figure 2.3.13.1).

Figure 2.3.13.1: Schematic functions of PIC16F877 for our design
The above figure shows a brief schematic of our design and the purpose of the PIC that we were using. Basically, the purpose was to program the PIC in such a way that it took a patient’s weight as an input (wireless) and based upon that, it moved the motor so that part “b” of Figure 1 could be adjusted. For the design, we had to move all the motors simultaneously in order for it work according to the given weight. In addition, motor 1&5 reflects to one segment of our proposed design where motor 1 and 5 would basically move same distance and have same functions. Similarly, motor 2&6; motor 3 &7 and motor 4 &8 reflects motors placed in various segment of the leg but with similar functions. Also note that motor 1, 2, 3 and 4 were placed on one side of the leg whereas motor 5, 6, 7 and 8 were placed on the second foundation bar for the other leg.

Some of the technical features and the description of various PINS on PIC16F877 are shown below as figure 2.3.13.2.
Figure 2.3.13.2: Pin Diagram of PIC16F877
Microcontroller Core Features:

- High performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
  Up to 368 x 8 bytes of Data Memory (RAM)
  Up to 256 x 8 bytes of EEPROM Data Memory
- Pinout compatible to the PIC16C73B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and
  Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC
  oscillator for reliable operation
- Programmable code protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low power, high speed CMOS FLASH/EEPROM
  technology
- Fully static design
- In-Circuit Serial Programming™ (ICSP) via two
  pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.0V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial, Industrial and Extended temperature
  ranges
- Low-power consumption:
  - < 0.6 mA typical @ 3V, 4 MHz
  - 20 μA typical @ 3V, 32 kHz
  - < 1 μA typical standby current

Figure 2.3.13.3: Microcontroller Main Features

Figure 2.3.13.3 above shows the main features of the PIC16F877 microcontroller. The important
feature to note is the operating speed (DC-20MHz clock input); wide operating voltage range (2V to
5.5V) and High sink/source current of 25mA.
Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during SLEEP via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I²C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

Figure 2.3.13.4: Peripheral Features of PIC16F877

Figure 2.3.13.4 above shows the peripheral features of PIC16F877. According to the datasheet above, it shows that Timer0 has 8-bit timer/counter with 8-bit prescaler; Timer 1 has 16-bit timer/counter with prescaler and Timer 2 has 8-bit timer/counter with 8-bit period register, prescaler and postscaler. The important fact to note is the PWM modules (only two). Also, the PIC has 40 pins where 33 pins are I/O ports.

More importantly, the PIN description of PIC16F877 is shown below as Figure 2.3.13.5 which also describes the function of each individual port.
<table>
<thead>
<tr>
<th>Pin Name</th>
<th>DIP Pin#</th>
<th>PLCC Pin#</th>
<th>QFP Pin#</th>
<th>IO/P Type</th>
<th>Buffer Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSC1/CLKIN</td>
<td>13</td>
<td>14</td>
<td>31</td>
<td>1</td>
<td>STCMOS</td>
<td>Oscillator crystal input/external clock source input.</td>
</tr>
<tr>
<td>OSC2/CLKOUT</td>
<td>14</td>
<td>15</td>
<td>31</td>
<td>1</td>
<td>—</td>
<td>Oscillator crystal output. Connected to crystal or resonator in crystal oscillator mode. In RC mode, QG2 pin outputs CLKOUT which has 1/6 the frequency of OSC1 and denotes the instruction cycle rate.</td>
</tr>
<tr>
<td>MCLR</td>
<td>1</td>
<td>2</td>
<td>18</td>
<td>16</td>
<td>ST</td>
<td>Master Clear (Reset) input or programming voltage input. This pin is an active low RESET to the device.</td>
</tr>
<tr>
<td>RA0/AN0</td>
<td>2</td>
<td>3</td>
<td>10</td>
<td>10</td>
<td>I/O</td>
<td>TTL</td>
</tr>
<tr>
<td>RA1/AN1</td>
<td>3</td>
<td>4</td>
<td>20</td>
<td>20</td>
<td>I/O</td>
<td>TTL</td>
</tr>
<tr>
<td>RA2/AN2/REF+</td>
<td>4</td>
<td>5</td>
<td>21</td>
<td>21</td>
<td>I/O</td>
<td>TTL</td>
</tr>
<tr>
<td>RA3/AN3/REF+</td>
<td>5</td>
<td>6</td>
<td>22</td>
<td>22</td>
<td>I/O</td>
<td>TTL</td>
</tr>
<tr>
<td>RA4/T0CKI</td>
<td>6</td>
<td>7</td>
<td>23</td>
<td>23</td>
<td>I/O</td>
<td>ST</td>
</tr>
<tr>
<td>RA5/T0SCL</td>
<td>7</td>
<td>8</td>
<td>24</td>
<td>24</td>
<td>I/O</td>
<td>TTL</td>
</tr>
<tr>
<td>RB0/INT</td>
<td>33</td>
<td>32</td>
<td>9</td>
<td>9</td>
<td>I/O</td>
<td>TTL/ST(1)</td>
</tr>
<tr>
<td>RB1</td>
<td>34</td>
<td>33</td>
<td>9</td>
<td>9</td>
<td>I/O</td>
<td>TTL</td>
</tr>
<tr>
<td>RB2</td>
<td>35</td>
<td>34</td>
<td>10</td>
<td>10</td>
<td>I/O</td>
<td>TTL</td>
</tr>
<tr>
<td>RB3/PWM</td>
<td>36</td>
<td>35</td>
<td>11</td>
<td>11</td>
<td>I/O</td>
<td>TTL</td>
</tr>
<tr>
<td>RB4</td>
<td>37</td>
<td>36</td>
<td>14</td>
<td>14</td>
<td>I/O</td>
<td>TTL</td>
</tr>
<tr>
<td>RB5</td>
<td>38</td>
<td>37</td>
<td>15</td>
<td>15</td>
<td>I/O</td>
<td>TTL</td>
</tr>
<tr>
<td>RB6/PGC</td>
<td>39</td>
<td>38</td>
<td>16</td>
<td>16</td>
<td>I/O</td>
<td>TTL/ST(2)</td>
</tr>
<tr>
<td>RB7/PAD</td>
<td>40</td>
<td>41</td>
<td>17</td>
<td>17</td>
<td>I/O</td>
<td>TTL/ST(2)</td>
</tr>
</tbody>
</table>

Legend: | — | Not used | TTL | TTL input | ST | Schmitt Trigger input |

**TABLE 1-2: PIC16F874 AND PIC16F877 PINOUT DESCRIPTION (CONTINUED)**

<table>
<thead>
<tr>
<th>Pin Name</th>
<th>DIP Pin#</th>
<th>PLCC Pin#</th>
<th>QFP Pin#</th>
<th>IO/P Type</th>
<th>Buffer Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC0/TOS0/T1CKI</td>
<td>15</td>
<td>16</td>
<td>32</td>
<td>32</td>
<td>I/O</td>
<td>ST</td>
</tr>
<tr>
<td>RC1/TOS1/CCP2</td>
<td>16</td>
<td>17</td>
<td>35</td>
<td>35</td>
<td>I/O</td>
<td>ST</td>
</tr>
<tr>
<td>RC2/CCP1</td>
<td>17</td>
<td>18</td>
<td>36</td>
<td>36</td>
<td>I/O</td>
<td>ST</td>
</tr>
<tr>
<td>RC3/GOK/EXL</td>
<td>18</td>
<td>19</td>
<td>37</td>
<td>37</td>
<td>I/O</td>
<td>ST</td>
</tr>
<tr>
<td>RC4/ODI/OCA</td>
<td>23</td>
<td>24</td>
<td>42</td>
<td>42</td>
<td>I/O</td>
<td>ST</td>
</tr>
<tr>
<td>RC5/DDO</td>
<td>24</td>
<td>25</td>
<td>43</td>
<td>43</td>
<td>I/O</td>
<td>ST</td>
</tr>
<tr>
<td>RC6/TXIC</td>
<td>26</td>
<td>27</td>
<td>44</td>
<td>44</td>
<td>I/O</td>
<td>ST</td>
</tr>
<tr>
<td>RC7/RX/DT</td>
<td>26</td>
<td>27</td>
<td>45</td>
<td>45</td>
<td>I/O</td>
<td>ST</td>
</tr>
<tr>
<td>RD0/PS0</td>
<td>13</td>
<td>16</td>
<td>24</td>
<td>24</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD1/PS1</td>
<td>14</td>
<td>17</td>
<td>25</td>
<td>25</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD2/PS2</td>
<td>15</td>
<td>18</td>
<td>26</td>
<td>26</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD3/PS3</td>
<td>16</td>
<td>19</td>
<td>27</td>
<td>27</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD4/PS4</td>
<td>17</td>
<td>20</td>
<td>28</td>
<td>28</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD5/PS5</td>
<td>18</td>
<td>21</td>
<td>29</td>
<td>29</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD6/PS6</td>
<td>19</td>
<td>22</td>
<td>30</td>
<td>30</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD7/PS7</td>
<td>20</td>
<td>23</td>
<td>31</td>
<td>31</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD0/RD/AN0</td>
<td>0</td>
<td>9</td>
<td>20</td>
<td>20</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD1/RD/AN1</td>
<td>9</td>
<td>10</td>
<td>21</td>
<td>21</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD2/RD/AN2</td>
<td>10</td>
<td>11</td>
<td>22</td>
<td>22</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>RD3/RD/AN3</td>
<td>11</td>
<td>12</td>
<td>23</td>
<td>23</td>
<td>I/O</td>
<td>ST/TTL(3)</td>
</tr>
<tr>
<td>Vss</td>
<td>12</td>
<td>13</td>
<td>24</td>
<td>24</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Vcc</td>
<td>13</td>
<td>14</td>
<td>25</td>
<td>25</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>NC</td>
<td>—</td>
<td>17, 18</td>
<td>40</td>
<td>40</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Legend: | — | Not used | TTL | TTL input | ST | Schmitt Trigger input |

Figure 2.3.13.5: PIN description of PIC16F877
Figure 2.3.13.6: Circuit Design to control motors

Figure 2.3.13.6 above shows the circuit design to control the stepper motors. As seen above is PIC16F877 with 6 MHz oscillator connected to pin 13-pin15 and 1k resistor connected to pin 1 while grounding pin 12 and 31. In addition, pin 11 and 32 were connected to +5V. Also, seen above is a voltage regulator (7805) that regulates +12V as input while outputting +5V for the PIC. The schematic image to set-up a voltage regulator is seen below as Figure 2.3.13.7.
In addition, Microchip MPLAB ICD 2 (*In-Circuit Debugger*) was used to debug the program to PIC16F877. In addition, MPLAB IDE version 8.00 software was used to write the program and also debug the code to the PIC microprocessor. Also, C language was used to write the code because assembly language was proven to be hard to assemble and understand as well. The below figure shows the MPLAB In-Circuit Debugger 2 that was used during the process of our programming.
2.3.14 Patient Support Devices and Attachments

Since the basic designs for the traditional parts of the leg stirrups have not changed entirely since their creation, this proposal suggests ordering used medical equipment, the foot and thigh holders, and then engineering ways to attach them to the device. Figure 2.3.14.1 shows examples of available support devices that can be purchased through used medical supply companies.

Ordering preexisting parts from a supply company instead of molding the pieces from scratch allows more time and money to be spent on modifying these components to fit the various types of patients and changing the way these components attach to the overall device, the assisted leg holding device for medical procedures. Current cost estimations are $375 for the stirrups and an additional $375 for the thigh supports, for a total of $750. Figure 1.2.33 shows the overall layout of the device, emphasizing the location of the thigh and foot holders.
While other medical stirrups on the market only have thigh holders, this design is different in that it will include an extra support as an additional comfort piece and to increase the range of patients who could use this device. Since the most common amputation is below the thigh, changing from a thigh support to an upper thigh support means increased comfort and usability for those who have amputations.

### 2.3.15 Linear Bearing

Both the thigh and foot supports must attach securely to the foundation bar. In order to accommodate the widest range of patients, who may have legs of various sizes and dimensions, each of these supports must be able to slide along their associated link to any position, and then lock firmly into place when the proper adjustments have been made. In order to slide smoothly and decrease wear on the components, the attachment pieces must be well lubricated. However, an oil-based lubrication would wear off quickly and could damage clothing or property of the patient or practitioner. Finally, the attachment pieces must not interfere with or damage the springs.

The 80/20 Industrial Erector Set online catalog offers a solution that works for all of these constraints in their line of single flange linear bearings, model number 6515. Intended for linear motion as part of a T-
As can be seen from figure 2.3.15.1, the linear bearing is designed so that the ultra high molecular weight polyethylene articulates with the aluminum T-slotted profile. This particular polymer is extremely strong and durable, has good wear resistance, and, most importantly, has an extremely low coefficient of kinetic friction of 0.016 on aluminum. [13] In this way, the support acts as though it is lubricated while at the same time avoiding the problems of oil lubrication.
Figure 2.3.15.1 shows a free body diagram for the bearing/foundation bar system for one of the linear bearings during adjustment by the practitioner. Since it is assumed that the weight of the patient’s legs will be distributed evenly over both the thigh and foot supports, and that each support will be similar in weight, the free body diagram shown in figure 2.3.15.2 could represent either of the supports.

![Free body diagram of the bearing/foundation bar system, with forces labeled](image)

**Figure 2.3.15.2** Free body diagram of the bearing/foundation bar system, with forces labeled

As can be seen in figure 2.3.15.2, the only force that will oppose adjustment of the linear bearing along the foundation bar is the friction force between the aluminum and ultra high molecular weight polyethylene, and this force is equal to the coefficient of friction multiplied by the normal force that the bar exerts on the bearing. Also, since the only forces in the y direction are the combined weight of the patient’s leg and the support, the normal force must equal the sum of these weights to allow static equilibrium. These conclusions are summarized in equations 15 and 16 below.

\[
\begin{align*}
\sum F_x &= F_{practitioner} - u_k * N \\
\sum F_y &= N - (W_{\text{leg}} + W_{\text{support}})
\end{align*}
\]

By assuming the maximum patient leg weight of 40 pounds, the maximum friction resistance can be calculated:

\[
N = (20 \text{ lbs} + 40 \text{ lbs}) = 60 \text{ lbs}
\]

\[
F_{practitioner} = .016 * 60 = .96 \text{ lbs}
\]
This calculation shows that the practitioner will have to exert a force of less than one pound in order to move either support for even the heaviest patient. This will be beneficial to the practitioner, but it will also increase the lifetime of the device by reducing wear on the bearing.

Referring back to figure 2.2.34, a brake system is also incorporated into the linear bearing component. Similar to the pivot part, the linear bearings can be fastened into place at any position simply by rotating the handle of the brake, which will cause the screw to tighten and exert force on the foundation bar, stopping any motion.

The final specification that must be accommodated for is that the linear bearings must not interfere with or damage the springs. The springs will be attached along the underside of the link system, this ensures that it would be very unlikely that the thigh or foot support would interfere with the springs. As shown in the Figure 2.3.15.3 below, the metal used to attach the spring to the link actually keeps the linear bearings from interfering with spring motion.

**Figure 2.3.15.3- Block ending path of linear bearing.**
2.3.16 Thigh Support

As mentioned above, the thigh support is one design feature of this device that differs from others on the market. However, as was seen in figure 2.2.32, thigh supports do exist on the market, and can be purchased and modified to fit the constraints of this assisted leg-holding device. Below, figure 2.3.16.1 shows a picture of how the thigh support was attached to the linear bearings.

![Thigh support in linear bearing.](image)

Using a square piece of aluminum which was cut to a length of 4 inches and turned on its side was used as the support for attachment to the linear bearings. Due to the changes in the overall design, that is the link system, the need for a telescoping pole was reduced. Changes required in angle or height is now made to the individual link which in turn raises the height and angle of the support device. This is an
improvement to the overall design as it requires fewer adjustments by the medical professional to the device for each patient thus shortening the exam period.

It is essential for the thigh support to be adjustable, in order to ensure maximum comfort for each patient. Also, one of the purposes of the thigh support is to allow the device to accommodate amputees, who could not use a traditional leg-holding device that consists only of stirrups. By providing a thigh support, these patients can also use the device for medical procedures.

As mentioned above, it is important to consider the types of patients that must be accommodated by this device. The main focus of this design project is to create an assisted leg-holding device that is accessible to the handicapped or disabled. Special considerations must be made for this group. As mentioned above, the thigh support has been added to the design in order to increase support and stability of a patient’s legs, especially for those patients with weak muscles or amputations. Another important feature of this design will be the addition of Velcro straps, to keep the patient’s legs securely fastened within the device. This will reduce anxiety by ensuring that the patient feels comfortable. It will also be useful for patients with Parkinson’s or other diseases that might cause tremors, as extra precautions must be made to ensure that these individuals do not move or disrupt a delicate procedure. Figure 2.3.16.2 below shows the straps on the device.

![Figure 2.3.16.2- Thigh support with Velcro straps.](image)
2.3.17 Foot Support

Much like the thigh support, the boot or foot holder will be purchased as a prefabricated component and then modified to increase the range of patients that can be accommodated by the device. Again, since the updated design with the link system, the telescoping pole has been removed from the foot support. Again, a square piece of aluminum was used to raise the support so that it did not interfere with the sliding of the linear bearings. An image of a competed attachment can be seen below in figure 2.3.17.1:

Figure 2.3.17.1- Completed attachment for foot support.
The assisted leg-holding device described in this design report has many features allowing it to be user friendly for the practitioner, and comfortable and accessible to patients having many different requirements. The design of this device is simple in that it is fully mechanical and therefore does not require additional components such as a battery or outlet. Each piece is designed to work successfully and for a long time without failure, as is proven by the technical analysis distributed throughout the report.

2.2.18 Table
In order to simulate the real world environment that the device would encounter in daily use, the team ordered a simple medical table onto which the device would be attached. Table designs and prices ranges were researched and finally the team decided to order the Hausmann Hi-Line Space-Saver Treatment Table with Cabinet (4143-HAUS) whose capacity was 350 lbs. While this capacity was lower than the original capacity for our device, the cost to purchase a table that could support the larger weight would have been a waste of funds as the team does not have access to a person to test the higher end weight on. Figure 2.3.18.1, shown below shows a picture of the table from the company’s website as well as one of the team’s actual table which was ordered in navy blue and pine.

![Figure 2.3.18.1](image)

The website provided image and the team’s actual table.

The overall dimensions of the table are 52” in length when the head/foot rest is folded down and 72” when the rest is fully expanded. For attachment of the device, the team used the side of the table without the head/food support. The table was 24” wide and 31” in height with a weigh of 220 lbs. In addition to the head/foot rest, the table also featured a cabinet with one adjustable shelf. The material of which the cabinet was made of became a concern when the team started to discuss the attachment of the device. The table is made of DMF which has then been laminated to meet the buyer’s choice of wood tones. While this DMF structure as a whole could hold 220 pounds, individual surfaces cannot take a lot of strain nor can the DMF hold bolts and other screws strongly because of the compressed particle nature of the material. The team therefore would have to reinforce the table.
2.3. 19 Attachment of the device to the table

Careful considerations must be made when designing the attachment of the device to the table, in order to accommodate all of the features described above. The attachment must allow translational movement in the x direction in order to allow the device to swing into storage position. It must not disrupt or interact with the springs. It must allow the system to adjust to a wide range of positions, while at the same time be able to lock into each position securely. The ideal system must be extremely flexible, while still allowing the device to be firmly attached to the table.

This was accomplished and can be seen below in figure 2.3.19.1. This figure shows the attachment mechanism from an overhead view.

As can be seen in the figure, the attachment and movement mechanism consists of several parts. Each set of links will be attached to a shorter section of 80/20 materials which is then attached to the pivoting component. This joint allows 180 degrees of movement in the x plane, so that the links can accommodate several positions. The piece that will be used is also supplied by 80/20 The Industrial
Erector Set, and can be found as part of a pivot system in the online catalog as part number 4452. This pivot is shown in detail in figure 2.3.19.2 below.

![Figure 2.3.19.2](image)

Figure 2.3.19.2 (a) Photograph of the pivot as attached to a metal bar (b) schematic of pivot with dimensions shown [13]

Like the link bars, the pivot joint is also made of aluminum so that it is strong and also lightweight. However, the pivot joint also has permanently lubricated bronze bushings lining the articulating parts, so that friction becomes negligible. The pivot joint also has a braking system, so that the device can be positioned at any position in the 180 degree range. This braking system works simply by allowing the practitioner to tighten a screw, putting pressure on the joint and preventing the bar from slipping. When the screw is loosened, the device can move freely so that the practitioner can adjust it to any point. Because there should not be many forces in the x direction other than the force exerted by the practitioner, this braking mechanism will be sufficient to prevent movement of the device.
Finally, since the link system has both an upper and lower horizontal bar, a second rotation joint was required on the lower section to match the movement of the upper bar. Since the upper bar has a breaking mechanism and the overall design is such that the upper and lower bar move jointly, a second breaking mechanism for the lower bar is not necessary. A simple hinge joint from 80/20 will be used. An image of the joint can be seen below in figure 2.3.19.3 As with the upper link, a short piece of 80/20 15 series stock will be used to connect the joint to the lower horizontal bar.

![Image of the joint](image)

**Figure 2.3.19.3-** Image of lower joint.

### 2.3.20 Reinforcements

In order to attach the device to the table, two 6 inch aluminum L brackets were created in the machine shop to help distribute the weight over a larger area and align the start of the device with the edge of the exam surface. Additionally, ½ inch aluminum sheet metal was attached to the inside of the table to increase the strength of the table by sandwiching the DMF and to increase the safety of the device. For
the top of the links attachment to the table, two 6 inch aluminum L brackets were cut from a large H beam that was found in the machine shop. Next, holes were drilled and taped to match the holes on the 180 degree rotation bracket that was purchased from 80/20 at the beginning of the semester. A second set of holes were drilled and treded which would be placed into the table and attached to a the backing aluminum on the inside. Figure 2.3.20.1, shown below, shows an L bracket.

For the lower hinge brackets which only had one point of entry, a L bracket was not necessary to make the hinges align with the exam surface. A ½ inch aluminum backing was still used to help reinforce the DMF.

**Figure 2.3.20.1** - A picture of the L bracket.
Future Improvement

2.3.21 Bluetooth Scale
An optional feature of the device, the Bluetooth scale would allow a patient to simply stand on the scale which would relay the patient’s weight to a Bluetooth receiver and into the microprocessor. The microprocessor would then use the weight to calculate the required movement of the motors to adjust the lengths of “b” and “a” accordingly for the patient. Adding a Bluetooth scale means that the practitioner is no longer required to manually enter the patient’s weight information thus reducing steps required during step up and decreasing the time required for an exam. Additionally, it also decreases the chance of human error since the scale sends the weight directly to the program via the receiver.

A Lifesource UC-321BT, 450 pound capacity scale was purchased from Lifesource, a component of A&D Engineering, Inc. The benefit of this particular scale is that it has a 40 weight memory storage, this memory storage is marked with a time and date stamp, and the scale has its own unique serial number. The unique serial number is important since the device will most likely be used in a clinical setting where it is possible that multiple rooms will have the device in use. The serial number allows a technician to pair the scale with a particular receiver and microprocessor combination so that there is little interference with multiple exam rooms using the device. Finally, the device is a Class 2 Bluetooth
that is it can display the signal for up to 30 feet away. The average exam and operating room are smaller than 30 feet in any given direction and therefore there should not be a problem with signal receiving. A picture of the slim, sleek design can be seen below in figure 2.3.21.1, notice the large font size which would also be beneficial for clients with reduced eye sight.

![Bluetooth enabled scale](image)

**Figure- 2.3.21.1- Bluetooth enabled scale.**

A&D Engineering does not currently supply customers with the protocol manual or the specific unique serial number and corresponding service name and ID pin. In August of 2007, the Biomedical Engineering Department and A&D Engineering entered into a non-disclosure agreement which will remain into effect for 3 years after the signing date (8-3-07). Thought this non-disclosure agreement the protocol manual and specific number and pin for the scales were received. The manual also explained how the data would be set, the order and an additional commands that are related to the device. The weight is set to a Bluetooth receiver in 14 bit words. A command is sent to establish a connection, followed by the number (weight), a returned command and a live feed command.

So far, the team has been unsuccessful in connecting to the device with either our wireless receiver or a Bluetooth receiver.

### 2.3.22 Bluetooth Receiver

In order to connect the Bluetooth scale to the microprocessor to compute the changes in length required from the patient’s weight, a Bluetooth receiver was required. The eb505-SER OEM Bluetooth Serial adapter was purchased from A 7 Engineering, Inc. This module is the generic add on for making a wireless connection. The eb505 implements all components on the board so that no additional host processor code is required. A picture of the chip, along with pin connectivity, can be seen in figure 2.3.22.1, shown below:
Figure 2.3.22.1- Chip and PIN diagram.

Some special features of the eb505 include simple aerial UART communications and control, seamless connectivity over a 328 feet range, low current consumption for long battery life, and 2.4GHz FHSS to ensure a high reliability. As to date, we have not been able to connect to the wireless scale.
2.3.23 MRI Scanner

Obviously, it was not within our budget to consider the inclusion of an MRI into our system. However, such a device would yield significant advantage if combined with our assisted leg holding device.

As mentioned in previous categories, one of the limitations of our device is that it makes assumptions regarding weight distribution within a patient’s legs. Although our information on weight distribution is taken from an anthropomorphic table, we have not taken into consideration that some patients may have aberrant weight distributions, especially the disabled such as spinal-cord injured patients or those who are severely obese. In order to make our device more accurate in accommodating for patient weights, it would be helpful to take an MRI of the patient’s legs before a procedure. From this, we could gain information about the composition of each patient’s legs, such as fat, muscle, and bone mass distributions, and apply this in our center of mass calculations. Again, this is something that should be thought about as a future improvement to this project.

2.4 The Prototype

Figures 2.4.1 through 2.4.3 show the prototype in its entirety:

![View of entire prototype, with medical table and both leg supports](image)

**Figure 2.4.1** View of entire prototype, with medical table and both leg supports
Figure 2.4.2 Profile view of one leg support of the device
As can be seen in the figures, the assisted leg holding device is large, complicated, and involves the interaction of many components. To prevent injury to herself or a patient or damage of the device, a practitioner must use caution when preparing the device for use by a patient and while the device is being used for a procedure, and should be aware of the proper operating techniques before attempting to use the device.

Before the device is to be used with a patient, the practitioner should check each leg support of the device to ensure that all parts are in order, nothing has become loose, and everything is in working order. The practitioner should then loosen the wing-nuts controlling the welded I-hooks and braking system, as shown in figures 2.4.4 and 2.4.5 below.
Figure 2.4.4 Loosen wing-nuts controlling the welded I-hook by turning them in a counterclockwise direction
Next, the practitioner should ensure that all wiring is properly inserted and has not become loose or disconnected, and should turn on the power supply controlling the motors, as shown in figure 2.4.6.
Figure 2.4.6 The device is turned on by flipping the appropriate switch on the power supply.

At this point, the practitioner should turn on the PC that runs the computer program controlling the microprocessor. When the computer has loaded, the practitioner should double click on the “MPLAB” icon on the desktop (figure 2.4.7).

Figure 2.4.7 MPLAB icon
She should then click “File”→“Open”→“DESING1_FIN”→“Design1.mcw” to load the proper program, as shown in figure 8. The required program is shown as figure 9.

Figure 2.4.8 Steps to load computer program controlling motor function and movement
// Program to provide simple square wave

#include <pic.h>
#include <math.h>
#include <delay.h>

__CONFIG(HS & WDTDIS);

// Define Terms
#define PWM_output1 RD7
#define PWM_output2 RD6
#define PWM_output3 RD5
#define PWM_output4 RD4
#define Direction RD2

// Routine to obtain PWM for Port D's

int main (void)
{
    long i;
    // long j;
    // long k;
    // long l;
    // long patient_weight;
    // float foot_weight;
    // long spring_constant;
    // float total_weight;
    // long mass_center_D;
    // float mgl;
    // float ab_D;
    // int steps;
    //
/** Setting the ports */
///
TRISD = 0x00; //sets PORTD for output
PORTD = 0x00; //clear PORTD
///
/// Having user define patient weight
///
patient_weight=143;
///
/// Determining weight of foot
///
foot_weight=patient_weight*.061;
///
/// Defining known terms
///
// spring_constant=47;
// total_weight=foot_weight+7;
// mass_center_D=6;
///
/// Determine m*g*l term
///
// aml=mass_center_D*total_weight;
///
/// Determining a*b based on patient's weight
///
// ab_D=aml/spring_constant;
///
/// Determining the required number of steps for the motor
///
// steps=20*87500*ab_D;
for \(i=0; i<=205000; i++\)
{
    PWM_output1=1;
    DelayUs(1);
    PWM_output1=0;
    DelayUs(1);
}

//
// for(j=0; j<=turns; j++)
//
//    PWM_output2=1;
//    DelayUs(1);
//    PWM_output2=0;
//    DelayUs(1);
//
// for(k=0; k<=turns; k++)
//{
//    PWM_output3=1;
//    DelayUs(1);
//    PWM_output3=0;
//    DelayUs(1);
//}
//
// for(l=0; l<=turns; l++)
//{
//    PWM_output4=1;
//    DelayUs(1);
//    PWM_output4=0;
//    DelayUs(1);
//}

while(1);  //wait forever

**Figure 2.4.9** Program controlling motor function and movement (accurate as of 5/1/08)

Finally, before the patient has arrived, the practitioner should take strain off of the leg-holding device by placing a support underneath of the device. This support should cause the device to make a 45 degree angle with the horizontal, as shown in figure 2.4.10 below.
Figure 2.4.10 To reduce strain on the leg-holding device for adjustment, place a support underneath of the device so that it makes a 45 degree angle with the horizontal

After the patient arrives, he should be weighed by the practitioner. A standing scale is provided with the device, (figure 2.4.11) but the practitioner should be aware that many patients who may require the use of this device, especially disabled or very overweight patients, may be unable to use this scale and will require alternative means of weight determination, such as shown in figure 2.4.12.
Figure 2.4.11 A standing scale is provided for patients with the capabilities to use it
Figure 2.4.12 An alternative scale, such as this toilet-seat scale, can be used for disabled patients

Having determined the patient’s weight, the next step for the practitioner is to enter this value into the aforementioned computer program, as shown in figure 2.4.13.

```
Having user define patient weight

patient_weight=143;
```

Figure 2.4.13 Enter patient’s weight as commanded by the program, shown here with an example weight entered

The practitioner must then “Build,” “Program Target Device”, and “Release” the program, in this order, in order for the motors to move to their proper positions. The proper buttons to carry out this sequence are shown in figure 2.4.14.
Now, the motors should move to the appropriate positions based on the patient’s weight. If movement does not occur, the practitioner should consult the “Troubleshooting” section of the Operator’s Manual to attempt to fix the problem.

Having adjusted the motors and in turn the “b” dimension of each link, the next step for the practitioner is to adjust the “a” dimension and tighten the cord. Starting with the Link D, the practitioner must move the welded I-hook to the appropriate position for each link on both supports. Figures 15-18 show the appropriate angles that should be formed initially between each link and the horizontal. Links A and C should be adjusted at 45 degrees above the horizontal, and Links B and D should be adjusted horizontally.
Figure 2.4.15 Proper initial set-up for link A
Figure 2.4.16 Proper initial set-up for link B
Figure 2.4.17 Proper initial set-up for link C
For each link, the practitioner should slide the welded I-hook until the cord is fully tightened, and then turn the wing-nut in a clockwise direction until the welded I-hook is secured into place, as shown in figure 2.4.19 below.
Figure 2.4.19 The cord on each link should be tightened completely

After all dimensions are set on the assisted leg-holding device, it should be covered with medical draperies as shown in figure 2.4.20 to keep the device sterile and reduce intimidation of the patient, as well as to prevent injury.
At this point, the device is ready for patient loading. The device will support itself so that the practitioner is free to assist the patient in getting onto the table and into the device properly and comfortably. The practitioner should assist the patient as she moves onto the table to make sure that he does not slip off and fall to the floor. The patient should begin by standing with her back parallel to the table. From this position, she should slide onto the table so that she is sitting perpendicularly to the device and in the center of the table. This transition is shown in figure 2.4.21.

**Figure 2.4.20** Always cover the device with medical drapings before using with a patient
Next, the practitioner should assist the patient in swinging her legs over the proximal leg support, so that both of the patient’s legs are hanging off of the table in between the leg supports, as shown in figure 2.4.22.
Figure 2.4.22 Preparation of patient for loading into device

The practitioner should now slide the thigh support to an appropriate position, and help the patient lift one leg so that it rests upon this support. The device should remain in position during this time. The practitioner can then adjust the device so that the patient’s knee and thigh are secured safely and comfortably within the knee and thigh supports. The Velcro straps should be used to ensure that the patient does not slip off of the device or move during a procedure.
This process can be repeated for the patient’s other leg as well.

After the patient is safely and comfortably secured with both legs in the device, the practitioner can adjust the device to any height depending on the type of procedure that is to be performed. This device has been designed to accommodate a large variety of procedures including gynecological or urological examinations, and surgeries of the legs, so a large amount of flexibility is required.

Having reached an appropriate position for the necessary procedure, the final step that the practitioner must carry out before actually performing the procedure is to lock the device into place. This is done using the device’s braking system, which consists of a series of wing-nuts at each link’s lower joint, as shown in figure 2.4.24 below.
The practitioner should realize that it is essential to use the locking mechanism regardless of how accurately the device is able to gravity-balance the patient’s legs. During any procedure, it is possible that the patient could inadvertently move and alter her position, which could compromise the procedure. This is especially a concern when considering a patient with Parkinson’s or Alzheimer’s disease, as these patients often cannot control their movements. It is also possible that a practitioner or assistant could accidentally bump against the device during a procedure and in doing so could move the device to a different position, another reason why it is important to use the braking mechanism every time that the device is in use. Figure 2.4.25 shows the proper procedure for locking the device into place.
As can be seen from the figure, the locking mechanism can be used simply by twisting the wing-nuts in a clockwise direction until the device stays in place.

The second and final locking mechanism that must be put into place is the pivot joint used to attach the device to the medical table. This part is shown in figure 2.4.26.
To ensure that the device does not re-adjust itself medially or laterally, the practitioner must tighten the pivot’s handle by turning it in a clockwise direction until the device no longer slides through the pivot tract.

At this point, the device has been adjusted successfully and can be used for procedures.

Having finished a procedure, the practitioner can remove the patient from the device before making any other adjustments, in order to expedite the appointment. To do this, the practitioner simply releases the Velcro strips from the foot and thigh supports, and assists the patient in swinging her legs over the device until she is again sitting in a position perpendicular to the device and fully on the medical table, as shown in figure 2.4.27.
After the patient has left the procedure, the practitioner can repeat the steps listed above to release the braking system and the “a” and “b” supports. The practitioner should remove the medical drappings and place them into the laundry, and should use a sterilizing cleaner such as Clorox spray cleaner to sterilize any part of the device that may have had contact with the patient, especially the foot and thigh supports.

3. Realistic Constraints

Similar to every new design, this design also has some engineering standards as well as realistic constraints in consideration to economic; environmental; sustainability; manufacturability; ethical; health and safety; social and political. These guidelines are set in consideration of the patient’s safety and as required rules/guidelines for the engineering societies. The main function of this standard is to avoid unintentional misuse of the product and provide full safety of the society. Also, after the completion of a design, it needs to meet engineering standards such as process standards, test method standards and performance standards in order for the company to market their product. Some of the organizations that develop and maintain standards relating to the design of medical devices are the International Organization for Standardization (ISO), the International Electro technical Commission (IEC), the American Society for Testing and Materials (ASTM), the Association for the Advancement of Medical Instrumentation (AAMI), and the European Committee for Standardization (CEN).

During the process of this design, national, as well as international mechanical standards should be taken in considerations. National standard such as ASEE (American Society for Engineering Education) and ASME (American Society of Mechanical Engineers) have engineering standards for mechanical materials and design parts which should be taken into consideration before developing a device.
International organization such as International Organization of Standardization (ISO) also set standards for engineering society globally in order to provide global safety and meet international requirements. Such standards, both national and international must be taken in consideration when designing this leg holding device.

Some of the international standards to be taken on consideration for this design are: ISO 9001 which requires that the design team establish and document the product’s design requirements, evaluate potential design hazards, establish finished device specifications, and assure transfer to production. In addition, since our design project is used frequently for medical procedures, it requires sterilization with ethylene oxide which has its own international standards, ISO 11135, which describes the procedures used to validate that the sterilization conditions will render the product sterile. Also, ISO 10993-7 defines special tests to assure that the products do not contain any toxic by-products because of the sterilization method.

Some of other standards that should be taken in account for this design is EN 4600, which contains special requirements for managing a medical device manufacturing business such as maintenance of sterility. Also, in consideration is EN 1441 which specifies that the design project to be investigated for the safety of a medical device by identifying hazards and estimating the risks associated with the hazards. In addition, EN 980 provides a set of international symbols that eliminate the need to provide multilingual product information on medical device package labels. EN 868-1 standard assures that packaging is compatible with the sterilization process and effective at maintaining sterility throughout the product’s shelf life. Finally, EN 104 standard which specifies the device is safe and effective to use in the market.

Economic
The funding for this project should be enough in completion of the proposed project. Economically, this design will require purchasing of table, springs, boots and other proposed materials which would be of high quality products with good material properties for long term use and manufacturability.

Environmental
Since this device will be used at clinical settings, it would not render a lot of environmental issues because most health care institutes are daily sterilized and kept under good climate control. Nevertheless, misuse of this product without sterilization and climate control would definitely cause environmental problems because metal rust, dust and infected device could seriously cause health concerns.

Sustainability/Manufacturability
This device would be designed to be highly sustainable for long term by using good corrosion resistive materials and designing the device with foam padding that could be easily sterilized. Since, this device would be used for physical check ups and other medical conditions; sterilization is the big part for sustaining this device for long term purpose. If the designed project is to be used by manufacturing companies, it would be economically fit since this design would contain all the required elements desired by the disabled patients for medical purposes.

Ethical
Ethical constraints include the use of this designed model on different types of patients since this is
specifically designed in consideration to physically disabled community. For example, is it right to use this design only for those who are mentally, socially or physically disabled or should this be available to all the normal patients too. Also, is it wrong if the designed model attracts people with arthritis while discouraging people to use the device for knee surgery. Finally, the device should not cause any injuries to any patients.

**Health and Safety**

Health and the safety of the patient is the main concern in designing our project. Safety of the patient will be given the highest priority before designing this project. Since our design does not have any electrical component, there is absolutely no risk of getting electrocuted which could potentially harm the patient for life. The only safety concern is the malfunction of springs and the locking mechanism of the device which could potentially cause pain or fear to the patient. All the safety concerning the spring system, the screws, the bolts, the joints will be the biggest concern for the safety issue of a patient.

**Social /Political**

Socially, this device will not be intimidating or harmful in anyway during the medical procedures for the disabled patients. Politically, this device should meet international and as well as national standards. After the standardization test, this device has to be approved for use by the FDA which then tests the device for regulatory affairs, quality assurance and process development to maximize the performance of the mechanism. Also, pre market notification must be submitted in order to make sure similar design doesn’t exist on the planet.

**4. Safety Issues**

The safety of the patient and the practitioners while using this device is the top priority. For the assisted leg holding device for medical procedures many mechanical components and their associated movements need to be taken into consideration. Additionally, the safety of the comfort components and the biocompatibility of the device as a whole must be contemplated. If any one component’s safety is over looked, the entire apparatus could fail and have severe consequences for both the patient and the practitioner.

Overall, each component should be rated for more weight than will actually be applied so as to include a margin of error on the weight analysis of the patient. Materials should be chosen for the optimal balance of weight and strength. Additionally, because the device is used in a medical setting, it needs to be easily cleaned and will have to withstand long term use. The metals chosen should be corrosion resistant as weakened metals can limit the lifetime of use for the device and be a source of possible infection for the patient. Also, all moving parts should be made as frictionless as possible as to decrease wear over time. Lubrication may be used however; the device should avoid contamination of any part of the patient or practitioner with grease during the procedure. Additionally, overall, each component should have a safety locking mechanism to hold the patient is the position. In order to maintain further safety of the patient, especially for those who are paralyzed and do not have lower body sensation, cutoff points should be included for the ranges of motion available. These cutoff points would protect patients from over extending beyond the safe range for degrees of motion. This is extremely important for patients who have weakened muscles or are paralyzed since these patients may not be able to tell the practitioner that there is discomfort or pain. In no case does one want the use of this device to cause
further physical damage. Finally, a total locking mechanism should be included to secure the device’s position when not in the storage position.

Mechanical failure of the system as a whole can also provide a serious problem. A safety system should be installed with the spring system so that the speed at which the patient’s legs are raised is as controlled and smooth as possible, the same safety mechanism should also be applied to the lowering of the patient’s legs. Additionally, if one of the springs was to fail, the system should stay locked in its current position to allow time for the practitioner to respond and make the appropriate corrections. This will be possible due to the system of multiple springs for each leg support. The spring’s average lifetime should be taken into account so that replacement can be provided well before the end of a spring’s lifetime. Any moving mechanical components should be encased in a protective coating so that the patient’s or practitioner’s skin or clothing could not become caught within the product.

Straps used to secure patients body parts must also be securely attached and adhere to medical safety standards. Decontamination of the device between patients will be necessary after each procedure. This is applicable to all components that are in direct contact with the patient. Since the design cause for using medical foam and medical cloth, these items need to be only wiped down or sprayed with a sterilization solution. During manufacturing the device will need to be produced using a certain protocol to ensure the quality and safety of the device. Random testing of devices could be used to ensure engineering standards are met before the device enters the medical field. Hence, the locking and unlocking mechanism is a way to secure the patient during procedures and also get good positioning of the patients leg, which is one of the primary purpose of this design. It not only helps to lower the total weight exerted by the patient’s body on the device itself, but also provides security to the disabled community. Security is issued as the key issue for our design. Although this design does not include any other injury problems such as electrocution because of lack of electrical components and wires, it will highly be considered during the preparation of this locking-unlocking mechanism. Some of the injuries that could potentially occur during the use of this mechanism are abrupt downfall of the patient’s leg on the ground, causing pain and possibly leg injuries to those disabled. In order to minimize this, every precaution will be taken care of, such as the size of the circular rod holder, the materials to be used for the cylindrical rod and possible stress test will be taken to understand the properties of the material that will eventually be used for locking-unlocking mechanism.

The final safety consideration with the addition of motors to the final design has to be patient and practitioner safety with the newly added electrical components. The large amount of metal combined with electricity should be a concern. Overall, the device will have to limit the human contact and electrical components. This has been accomplished in the teams design by having the motors placed on the opposite end of the device as the support areas. Also, all the wires have been encased so that there is no exposed wire for the medical professional to have contact with.

5. Impact of Engineering Solutions

As an engineer, one of the most important things to consider before beginning a design project is the impact that the proposed design will have on the world. Ideally, a new design should be an innovative, original contribution to society. At the same time, the design must be more useful, or have some advantage over similar products already on the market. If the new device is not affordable to produce or purchase, it will likely fail regardless of how advantageous it is compared to others. However, the device may have other impacts as well, and these are not considered immediately and may be overlooked. For
example, long term implications such as the consistency and durability of a device over time, as well as the ability to recycle the device after it has ceased to become useful, also must be considered for the device to truly be a success. Finally, if the conceived device has an impact globally, it must be acceptable according to the standards and values of different countries and cultures in order for it to succeed.

The assisted leg holding device should be considered from all of these perspectives. A successful design for this type of device could revolutionize how examinations are performed, and may encourage more people to receive necessary examinations. However, it is very important that this device be affordable and accessible so that it will succeed. Environmental issues must also be considered.

From a global perspective, one of the most important factors in the design of the assisted leg holding device is that the same procedures and protocols are not in place across the world. In Europe, many examinations are done without the use of any leg holding device. Of course, the protocols used for these examinations may make them extremely inconvenient or possibly even inaccessible for the disabled or handicapped, the populations being considered in this design. Therefore, it is essential for this proposed device to offer significant advantages, in order to make it attractive even in places where such devices would not be used traditionally. It is only in this way that the device will be purchased so that it can be available for those who truly need it.

The best way to make this device attractive is to make it economical. If a relatively inexpensive device is available for purchase, then it is much more likely that doctor would decide to buy one in order to accommodate for his handicapped patients. However, if nothing is available at a reasonable cost, then likely the same doctor would find a way to spend the money on something else that would be useful for patient care, at the expense of isolating handicapped patients from these particular examinations. In this case, handicapped patients become burdened with finding a way to get their examinations, which will likely be less convenient as well as more expensive. Thus, the overall goal of the design of this device is to make it so attractive and universal that doctors consider it an essential purchase and therefore make the technology and examinations available to all patients.

An engineer must always strive to create inexpensive devices. At the same time, however, quality can never be sacrificed in order to reduce a device’s cost. An engineer has a unique moral obligation: the technology developed by these professionals affects its users directly, and often, the engineer is directly responsible for having this be a good or a bad effect. Therefore, it is an engineer’s job to research each possible method of creating the device in order to serve its proposed purposes while at the same time reducing its cost as much as possible. If there is a less expensive way to create a device or the same quality, it is the engineer’s obligation to discover, create, or make use of this method. Otherwise, he is responsible for the people that he isolates because they cannot afford to use the device. In the case of the assisted leg holding device, if it is too expensive for doctors to justify its purchase, then millions of handicapped people may not receive the quality health care that they need and deserve.

The moral obligations described above are not new: engineers have been struggling with these issues since the beginning of the profession. However, in the past few decades a new aspect of engineering obligation has been introduced. Modern engineers not only have to worry about creating accessible, inexpensive, quality devices, but must make their inventions recyclable and environmentally friendly. With all of the recent concerns regarding El Nino, global warming, the destruction of the ozone layer,
and how man-made objects have catalyzed these problems, the world has become much more environment-conscious.

In this era of “green” engineering, engineers who do not consider the effect of their products on the environment are destined to fail. Therefore, the components of the assisted leg holding device must not only be low in cost, but these components also must not contribute to any of the problems that the human race has already caused to the environment, or create any additional difficulties. Ideally, the perfect invention should be completely degradable into natural and harmless materials that could be reused after it has served its purposes.

In the case of the assisted leg holding device, most of the components will not be degradable, because this may compromise their abilities to function safely as parts of the device. Therefore, it is essential that the materials chosen can be recycled, so that they are not left in landfills to take up space and harm the surrounding environment. It is possible that biodegradable foam could be used for the padding that will be incorporated into the device, as long as it will not degrade while the device is still being used for procedures. None of the materials chosen should be harmful to the patient or practitioner.

If all of the considerations listed above can be manipulated successfully, then this device could have a positive impact on society in several ways. At this time, it may be difficult for handicapped people to have medical procedures or examinations that require leg supports. There have not been many efforts to make assisted leg supports that accommodate this population. Therefore, handicapped people might be less likely to make or attend appointments for these procedures, because of the additional effort needed to make these appointments successful. Also, the problems and discomfort already associated with these procedures may be enhanced in the handicapped population. It is possible that if there is improved technology in this area, this population of people will have better experiences with leg holding devices and their corresponding procedures, and therefore make and attend appointments.

Other than the handicapped population, the availability of a cheap, comfortable, and user-friendly leg holding device may also improve the experiences of healthy members of society who could also use this device. If the device itself is more affordable, appointments may be less expensive and therefore more accessible for those with limited or no health insurance. At the same time, if the device can improve the experiences of healthy people as well as the handicapped, these people will also be more likely to make and attend their appointments.

It is essential for people to have the examinations and medical procedures that require the use of leg holding devices. Routine gynecology examinations check for cancer and it is likely that the cancer can be cured if caught early through these tests. Therefore, making people comfortable in leg holding devices could be a matter of life-or-death. At the same time, using traditional leg holding devices can cause pain or even injury.

The proposed assisted leg holding device will attempt to combat these problems. By making use of all of the engineering considerations explained above, including economic, global, environmental, and social concerns, it is possible to create a device that will succeed in the marketplace and therefore become available so that the public can benefit from the technology.
6. Lifelong Learning

According to the concept of lifelong learning, there is something new to be learned from any experience. A design project, especially when it is a first attempt at any type of design, holds even more potential for acquiring knowledge.

The most important thing to learn from any design project is the imminence of failure. Most of design is based on failure, and realizing that an idea cannot possibly work in the way that it is first conceived. After this is accepted, one must realize how to work with the idea and adapt it so that it can succeed, or else how to give up an idea that might have taken a lot of research and time to develop. For example, in this project, the original idea for the anti-gravity component was a spring, as is described in the “Methods” section above. However, after thinking through the design, it was realized that in order to use the spring method a practitioner would still be forced to position the leg holding device so that patients can be loaded into it. While it is less difficult for the practitioner to hold the device down than to lift it up once it is loaded, this is still not an ideal situation. However, once this flaw was realized, the crank system was devised so that the device could still work as planned, reducing strain on the practitioner.

As there is always something new to be learned from a situation, it is the acquisition and storage of past knowledge that makes this new learning useful. Biomedical engineers are required to take many classes in a wide range of subjects. For this project, it is essential to assimilate this knowledge with the new experience of working on a design. For example, in a static or biomechanics class, students are taught to draw free body diagrams based on problems generated by authors in a book. Now, it is necessary to apply this knowledge of free body diagrams to a real system: the assisted leg holding device.

At the same time, this senior design project introduces some completely new concepts and ideas in several categories. In order to create an original design, it is first necessary to understand what has already been invented, and therefore a patent search is required. Since this is the group’s first experience with design, this has been the first opportunity to perform a patent search, to learn how to read and understand a patent, and find which patents are pertinent to this project.

Another new experience associated with this design project has to do with computer software. Some of the requirements for this project are that each group learns and use programs such as Microsoft Visio, which is a drawing program for the construction of free body diagrams, and Dreamweaver, which is for website production. In order to be competitive as an engineer in industry, it is essential to be able to adapt to different types of computer programs and interfaces.

This semester, all of the lifelong learning is theoretical, as this project requires recall of skills learned in the past. Next semester, much of the lifelong learning will be hands-on. In the next few months, all members of the group are required to take a machine shop training class. For most students, this is a completely new, but very useful skill. Then, this knowledge will be combined with the theory in order to produce a successful final result.

It is important to understand and reflect upon the idea of lifelong learning while undertaking any project. The ability to learn, remember, and integrate information is a skill that must be learned in order to succeed as an engineer. For this project, lifelong learning occurred in many ways, and surely there will be many more to come before it is finished.
7. Budget

7.1 Budget

Table 1 shows the proposed budget for the assisted leg-holding device. While the project originally had a $2000 limit as part of the RERC student design competition, Dr. Enderle removed the group from the competition and increased the team’s budget as to allow for further advancement to the device. While the total shows $4447.63, the actual total maybe higher as the worksheets from the machine shop have not come in with the cost of the machining that was included in the project.

When first beginning this project, the question was raised as to whether a medical examination table should be purchased as part of the budget. After consulting with Dr. Enderle who indicated that the table could be useful to future projects, the decision was made to go ahead and order the table. While the table would not be considered part of the team’s expenditures, it has been included so that the score of money put into this project can be fully appreciated.
8. Team Member Contributions to Project

During the first semester, Team One met multiple times, outside classroom time, each week to work on the design as a group. Additionally, so that much of the group time could be spent on design thought, layout, and critique of the proposed design, each group member was assigned an aspect of the report to write which was then compiled during the week for a review prior to an individual report’s due date. The work was coordinated by breaking down the sections, highlighting who would do what and then compiling. Each week, a different group member took care of editing and formatting the final product as well as handing it into the BME office. It is the consensus of the group that this project was designed and planned by all the members in the group. In the second semester, the group took turns creating and presenting the weekly reports. Additionally, each member was assigned different tasks to accomplish regarding the project. Additional time outside of the required lab period was often required. The focus of each individual group member, and their work contributed, is summarized below.

Jennifer’s main assignment for the first semester was development of the assisted leg-holding device was to explore different options for the lifting mechanism of the “subcomponents”. She did most of the technical analysis for each subcomponent, especially including calculations determining the range of motion of the device, spring rate, and amount of tension found within the cord, deflection of the bar, capabilities of the joint for supporting the required applied load, and friction considerations for the linear bearings. As the biomechanics major of the group, she was responsible for drawing free body diagrams and finding equations to use in the calculations described above. Jennifer also wrote the “budget” section, the “engineering constraints,” and the segment on “lifelong learning,” as well as assisted with the abstract, compilation, and editing of the report. At the beginning of the second semester, Jennifer spent ample time working with her teammates to re-design the assisted leg holding device in order to incorporate the anti-gravity theory explained above. She studied the paper “A Simple Technique to Passively Gravity-Balance Articulated Mechanisms” (1) in order to understand this concept, and then applied the observations and calculations from this reference to the multi-link system decided upon by the group. Jennifer was responsible for determining that by adjusting the “a” and “b” dimensions, it is possible to keep the same spring throughout the entire range of patients that will use the device, and wrote an Excel computer program to optimize these dimensions based on a patient’s weight. When it was decided that motors could be used to adjust the “a” and “b” dimensions, Jennifer helped to come up with the idea of using a threaded rod coupled to a motor to drive a platform vertically along the supports. She found and ordered the integrated motors/drivers that were used in this project, and built the couplers as well as the platforms in the machine shop. Jennifer also used the 8020 website to find and order the extruded aluminum profiles used for this project, as well as accessories for these profiles including the linear actuators for the foot and thigh supports and the pivots for table attachment. Jennifer assisted in building and installing the motor mounts and table attachments. She performed calculations to determine the proper springs that should be used in the device, and then located, ordered, and installed these springs. Finally, Jennifer assisted her team in assembling the device as a whole, adjusting the cord to the proper length and tightening it into place, and testing the device. For the final reports, Jennifer was responsible for writing about the spring theory, springs, cord, motor couplings, “a” and “b” adjustments, braking system, and MRI addition, and the “Introduction” and “Maintenance” sections of the Operator’s Manual.
Katherine’s contributions have mainly consisted of focusing on what type of metals to use and how to attach the support devices. As the biomaterial major, Katherine looked for metals that could conform to the safety and medical requirements of the project with the strength required by the free body diagrams and equations provided by Jennifer. With the attachment of support devices, Katherine researched what system of poles to use so that the height of the support devices could be changed to increase the range of patients whom could benefit from this new device. Additionally, the angle rotation of the position of each device had to be designed in such a way that the support device could rotate however could only be attached to one of the adjustment poles. Finally, with respect to the attachment pieces, the repositioning of the pieces along the main pole had to be safe and easily accomplished by a practitioner with one hand without interfering with anti-gravity device. Katherine and Jennifer collaborated in this aspect as Katherine had to ensure that the repositioning design did not interfere with Jennifer’s design of the anti-gravity device. Katherine did all of the research on current products available on the market, as well as the estimation of the initial budget based on the proposed three alternative designs. On a majority of the reports, the introductions were written by Katherine. Katherine was also in charge of the safety concerns with the proposed designs. Like all group members, Katherine shared the responsibility of writing the abstract, compiling and editing the report. In the second semester, Katherine was instrumental in helping re-design the assisted leg holding device to its new improved link system. Katherine came up with the idea of how to adjust “a” and “b” by using an eyehook system that was welded together with a locking bolt from 80/20. This allowed for smooth, controlled movement while changing the lengths since the 80/20 material is all machined to fit together nicely. Katherine also machined all the motor mounts for the 8 motors and determined how the pieces should attach. Additionally, Katherine also worked on the attachment to the table, designing the layout of how the pieces would attach and machining the required metal pieces to do so. Five trips to Home Depot were conducted by Katherine over the course of the semester. When the idea of a Bluetooth scale was added to the project, Katherine researched and ordered the particular scale and the associated Bluetooth receiver that was required for communication. Katherine spent time meeting with Dave Kupputa who has also been working with the scale for a previous project. Katherine also created a circuit for the Bluetooth receiver but has been unsuccessful in establishing a connection due to limitations of the microprocessor the team has been using. Katherine and Jennifer also attached the device to the table, finished the machining and drilling all of the components and build and connected the springs. For the final reports, Katherine was responsible for the writing of the table, links, support devices, Bluetooth components, and compiling the report. For the Operator’s Manual, Katherine worked on the trouble shooting section.

Based upon the track, Gehendra was mainly responsible for the electrical component of the design that included building a correct circuit for PIC16F877 to use 8 motors, controlling 8 motors with a PIC microcontroller and writing program to rotate and stop the motor as desired by the team. In addition to this, he also contributed the beginning of the semester finding the right table for our design project and searching for motors and linear slides. He was also responsible for updating his weekly reports every week like everyone in the group. In addition, he was also able to program the PIC16F877 using MPLab software. His code was written in C language and was successfully able to rotate the motor at desired rotation. Hence, being a bioinstrumentation major, Gehendra had more contribution towards the circuit design, MPLab software, understanding the motor, understanding the PIC16F877 and the c code.
9. Conclusion

In conclusion, medical devices with better functions and flexibility for the seniors and the disabled are in high demand by the clinical society. Current medical devices like as the assisted leg holders for medical procedures are highly desired for those seniors and disabled with arthritis, muscular/bone degenerative diseases and also people with various ranges of heights and weights. The design of the assisted leg holding device for medical procedures is proposed based on this information.

In comparison to other alternative designs, the optimal design is relatively low cost and has less risk of injury during use. There is less risk of injury using a mechanical design such as springs compared to an electrical design incorporating motors. Also, in this design low cost springs will be incorporated rather than expensive stepper motors and circuit boards or the hydraulic circuit.

Hence, this optimal design will be low-cost, compact, reliable, user-friendly and more comfortable than the existing models, allowing better service of the patients. As was explained in the objectives, it will assist the medical practitioner in positioning a patient’s legs, and use a locking mechanism to prevent any injuries or discomfort during medical procedures. This device will be adjustable over the average range of heights and weights for both men and women. The device will allow medical personnel to adjust and lift the patient into the device with minimal effort via an anti-gravity mechanism. Also, minor adjustments will be accomplished using locking rotational devices that mimic the natural movement of the hips while repositioning the patient for optimal alignment during a given procedure. The current devices on the market lack the adjustability required for many of the RERC patients. However, by using the principles of dynamics, it is possible to design the leg assisting device that opposes gravity, allowing for better positioning of a patient’s legs for medical procedures. The device should be able to accommodate for a wide range of heights and weights using springs mechanism. Hence, the purpose of this project is to design leg assisted holder medical device, for those disabled with muscular or bone disease and for wide range of people while keeping safety as one of the main priorities, and the design proposed in this report will succeed in reaching this goals.
10. References


[13] [No author] 80/20 The Industrial Erector Set Catalog Online www.8020.net.


11. Acknowledgements

Team One would like to thank Dr. John Enderle, Mr. Dave Price, and the RERC Competition program for their contributions of time and funding for this project. The team would also like to thank Dave Kaputa, Rich and Serge from the machine shop for their hands on assistance.

12. Appendix

12.1 Device Specifications

Device Mechanical Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum weight</td>
<td>300 pounds</td>
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<tr>
<td>Minimum weight</td>
<td>75 pounds</td>
</tr>
<tr>
<td>Maximum leg length</td>
<td>44 inches</td>
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<tr>
<td>Minimum leg length</td>
<td>20 inches</td>
</tr>
<tr>
<td>Maximum leg adduction</td>
<td>90 degrees/leg</td>
</tr>
<tr>
<td>Maximum angle with horizontal</td>
<td>45 degrees</td>
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<tr>
<td>Minimum angle with horizontal</td>
<td>0 degrees (parallel)</td>
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Spring Specifications

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<tbody>
<tr>
<td>Purchased from</td>
<td>Lee Spring Company</td>
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<tr>
<td>Model Number</td>
<td>LE177L02M</td>
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<tr>
<td>Spring Constant</td>
<td>46.9 pounds/inch</td>
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<tr>
<td>Resting Length</td>
<td>5 inches</td>
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<tr>
<td>Maximum Length</td>
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<tr>
<td>Change in Length</td>
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<tr>
<td>Outside Diameter</td>
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<tr>
<td>Wire Diameter</td>
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<tr>
<td>Maximum Load</td>
<td>161.2 pounds</td>
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<tr>
<td>Initial Tension</td>
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Motor Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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</thead>
<tbody>
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<td>Input voltage</td>
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<tr>
<td>Microsteps/step</td>
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<tr>
<td>Maximum frequency</td>
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<tr>
<td>Steps/resolution</td>
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