CHAPTER 4
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VOLUNTARY-OPENING TRANSRADIAL PROSTHESIS FOR USE WITH WEIGHT TRAINING EQUIPMENT

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Client: Kristin Varon
Graduate Student: Chad Kennedy
Clinician: James M. Duston, Prosthetic Orthotic Associates, Scottsdale, AZ
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INTRODUCTION

An upper extremity weight training prosthesis was designed for a client who was born without her right wrist, hand, and the majority of her forearm. The prosthesis enables the client to grasp the weight lifting bar at the beginning of the exercise, and to release it at the end of the exercise, without any help from the left hand. The device is a voluntary-opening prosthesis that provides the client with a standard cable interface with which she is familiar.

SUMMARY OF IMPACT

A college student born without her right wrist, hand, and the majority of her forearm, required a prosthetic device to enable her to utilize weight training equipment. Her goal was to exercise the muscles of her

Figure 4.1. Photograph of the Transradial Prosthesis for Use with Weight Training Equipment.

right upper arm, shoulder, and back.

The prosthesis was designed to be used with pulling devices, including lateral pull-down and rowing machines. It could potentially be used for pushing exercises, including bench and incline press and various dumbbell exercises, by designing additional custom terminal devices.

TECHNICAL DESCRIPTION

This design incorporates a gated hook. A heavy-duty cable runs from the gate on the terminal device, or hand portion of the prosthesis, to a loose strap on an upper body harness. The gate of the terminal device opens when a maximum amount of tension is exerted on the cable. This occurs when the client performs various upper body motions, including biscapular abduction or humeral flexion. As the client relaxes her arm, the tension in the cable decreases and the gate closes. As she reaches out for the weight lifting bar, the terminal device opens, allowing her to clamp onto the bar. As she performs the weight lifting motion, the lever arm remains closed, keeping the bar from slipping out of the terminal device. When she extends her arm back to her original starting position, the tension in the cable increases and the lever arm opens, allowing her to release the prosthesis from the bar. This also allows her to quickly release the bar in the event of a problem.

The primary design specifications included: (1) the client can manually affix the prosthesis to the residual limb with only one hand; (2) the correct muscle groups are exercised during the weight lifting motion; (3) the device can withstand high normal and shear stresses under a wide range of loads; (4) the prosthesis mass must match, as closely as possible, the mass of the client's left forearm, wrist, and hand; (5) the length of the prosthesis should equal the length from the end of the client's residual limb to the metacarpophalangeal joints on a closed hand; (6) the device should maximize the range of motion of the client's elbow joint; and (7) it should be easy to maintain and repair.

The prosthesis is comprised of six different parts: the terminal device (hand), wrist unit, forearm unit, elbow socket, harness, and cable system. The design and function of the terminal device is similar to that of a mountain climbing carabiner, consisting of a "C" shaped outer bar and a spring-loaded manually opening "gate" which closes the opening of the C

Figure 4.2. Close-up of the Transradial Prosthesis for Use with Weight Training Equipment.

(Figures 4.3, 4.4, and 4,5). The outer C and gate of the terminal device are composed of aluminum alloy 7175-T66 while the lever arm and cable pins are made of stainless steel. The bottom of the terminal device has a ½" aluminum stud, which is used to attach the terminal device to the wrist unit. The C and stud were machined out of a single block of aluminum for strength. To enhance the wear resistance of the device, the aluminum components were anodized after fabrication and a rubber lining was added to the internal and external contact areas.

The wrist unit is a standard aluminum upper extremity prosthetic component from Hosmer-Dorrance. It connects the terminal device and the forearm unit and allows the user to position the terminal device prior to use. There is constant friction between the wrist unit and the terminal device during exercise.

The forearm unit and elbow socket were custom made to fit the client's residual limb. The forearm unit was made of a lamination, comprised of two layers of carbon braid sock, two layers of Kevlar, and seven layers of ny-glass lay-up. The elbow socket is comprised of two separate parts: the silicone socket and the hard socket. The silicone socket is made of a silicone-platinum gel that is covered with an external, nylon liner. It is a standard component from Ossur, a company in Iceland. An impression of the client's residual limb and elbow was made using a casting material, and the hard portion of the socket was created from this impression. The resulting socket shell is composed of serlin and is covered with Pedalin foam and the forearm unit lamination.

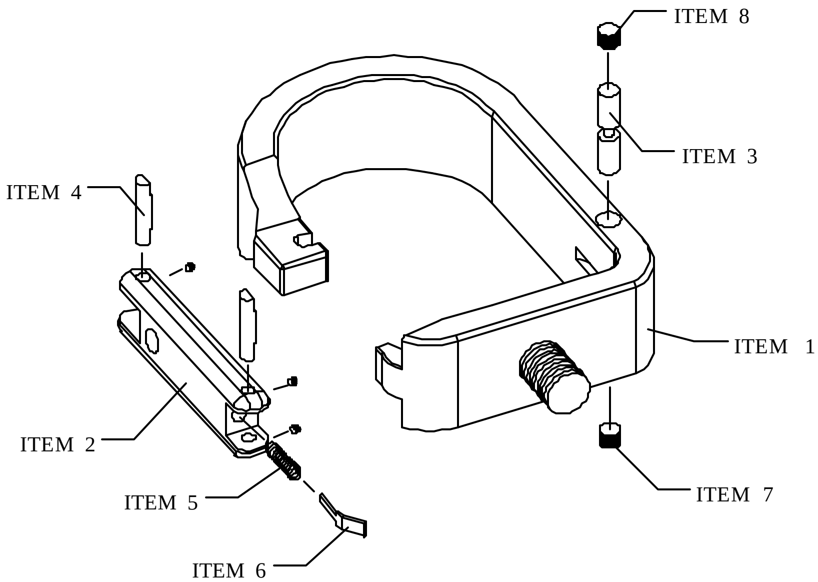
The harness is a standard upper extremity prosthetic component ordered from Hosmer-Dorrance. The harness is a configuration of Dacron straps, which wrap around the user's upper body and attach to the remainder of the prosthesis via a cable and cable housing. It serves two purposes: it helps to secure the remainder of the prosthesis onto the residual limb and upper arm, and it provides a mechanism for voluntary operation of the terminal device via upper body motion.

The cable system is used to provide voluntary control of the terminal device. A steel cable is attached from the terminal device to a loose strap on the harness, the control attachment strap. Between the terminal device and the harness, the cable passes through two aluminum housing units attached to the forearm unit. The cable housing units maintain the cable at a constant length throughout the range of motion of the elbow joint, help to secure the cable system to the prosthesis, and also align the cable toward its attachment location on the terminal device.

The device has been tested using the weight training equipment. It functions effectively for exercises that involve pulling (from an arm extended position to a flexed position). The client also uses the prosthesis to perform several other exercises not initially planned. These include push-ups, one-arm dumbbell rows, and shoulder shrugs. By wrapping a set of ankle or wrist weights around the terminal device, she may also perform both front and lateral shoulder raises. However, unless further adaptations are made, the device does not work as well in these other exercise modalities.

The client has used the device for lateral pull-downs and rowing, three times per week for six months. She suggests that the inner liner be made of a stiffer plastic for greater durability.

The final cost of the terminal device was approximately $1490. The socket and forearm orthosis was made with the assistance of Prosthetic Orthotic Associates of Scottsdale, AZ.



ITEM	DESCRIPTION	SHEET
1	BASE	2 & 3
2	LEVER ARM	4
3	CABLE PIN	5
4	LEVER ARM PIN	5
5	SPRING	6
6	SPRING	6
7	SET SCREW	NOTE 1
8	SET SCREW	NOTE 1

NOTES:
1. MAT'L:
   ITEM 1 & ITEM 2: ALUMINUM ALLOY, 7175-T66
   ITEM 3 & ITEM 4: STAINLESS STEEL
   ITEM 5: STD. STOCK SPRING
   ITEM 7: STD. SET SCREW, 2-56 X 2.54 LONG
   ITEM 8: STD. SET SCREW, 1/4-20 X 3.18 LONG
2. FINISH
   ITEM 1 & ITEM 2: HARD ANODIZE, BLACK, PER MIL-A-8625F
3. DEBURR ALL SHARP EDGES AFTER MACHINING.
4. ALL HOLES ARE TO BE MASKED OR PLUGGED PRIOR TO ANODIZE.

Figure 4.3. Assembly Drawing of Terminal Device.

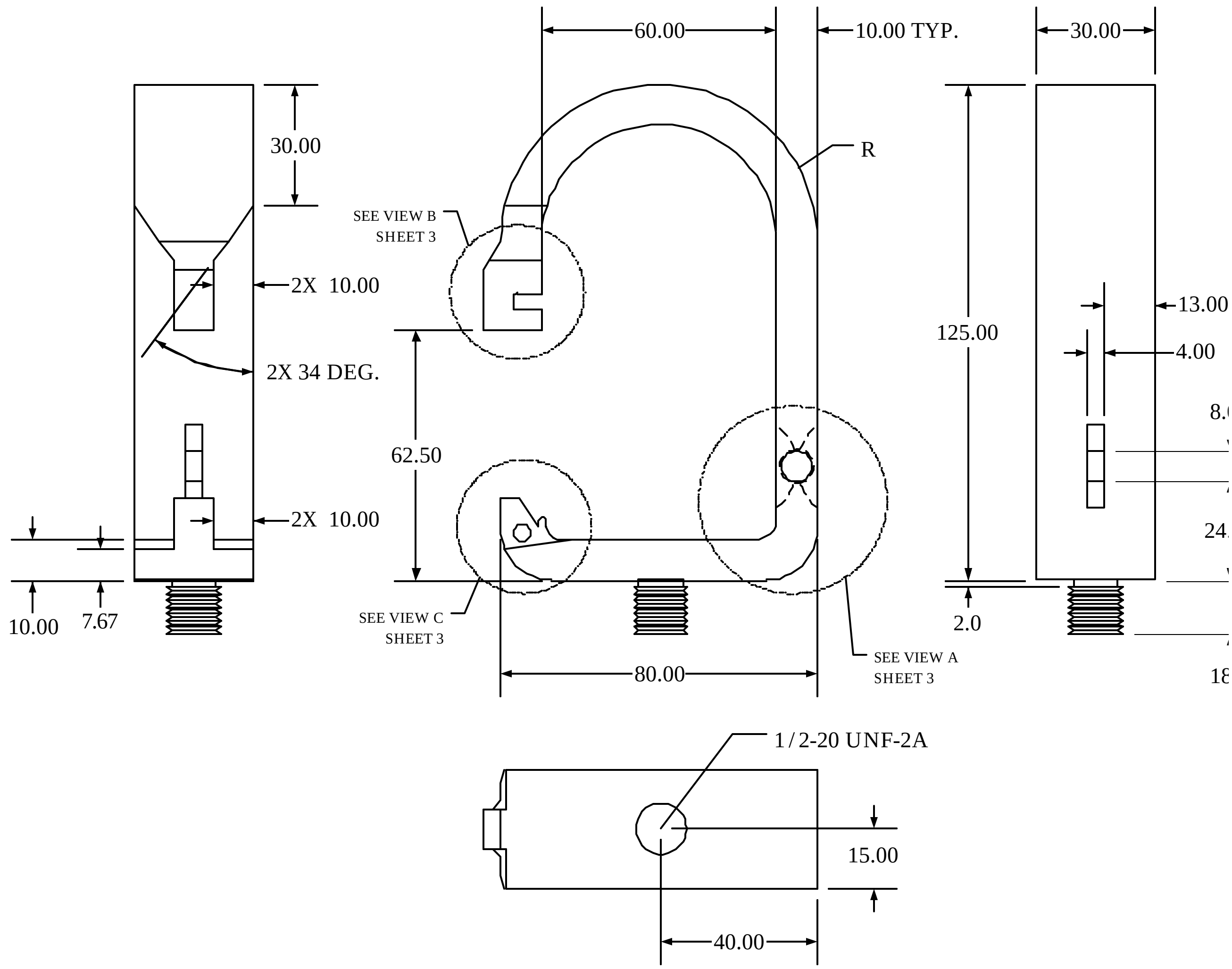


Figure 4.4. Dimensions of the Terminal “C” Device.

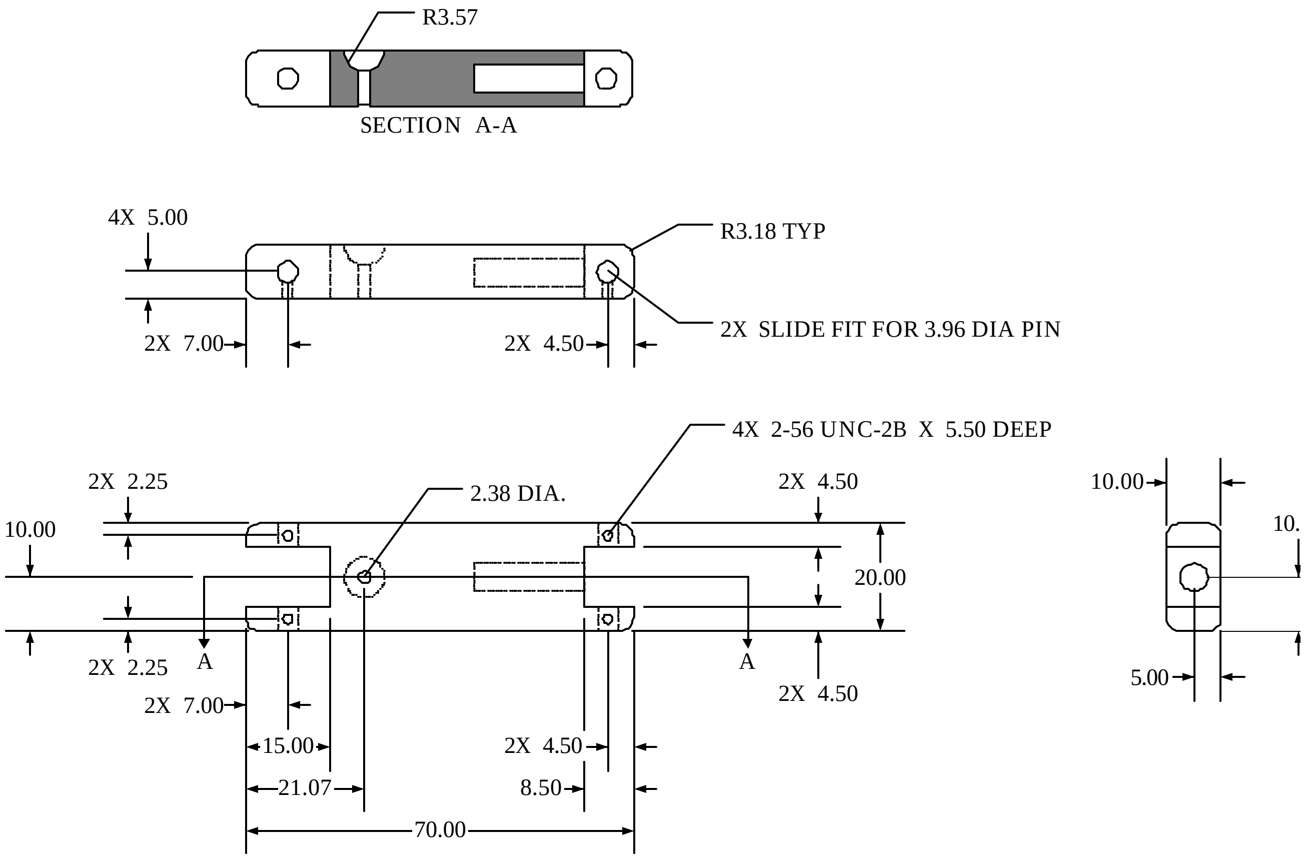


Figure 4.5. Dimensions of the Manually Operated “Gate” of the Terminal Device.

SHOWER CHAIR FOR A CLIENT WITH DE SANTIS CACHIONE

Designer: Kevin Cordes
Client: Angel Bueno
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INTRODUCTION

This project's objective was to create a shower chair which would ease bathing and transfers to and from the shower for a client with an extremely rare condition, *de santis cachione*. This condition has been diagnosed approximately 20 times since its discovery in 1932. It has many of the common traits of cerebral palsy, except that *de santis cachione* causes a progressive deterioration in condition.

The client once had nearly full function in all modalities, but his condition has steadily progressed so that, at his current age of 26, he has lost his ability to ambulate, speak, and see. He still responds to light and darkness, and to auditory stimuli. The disease is now affecting his hearing, and has caused a skin disorder known as *xenoderma pigmentosa*, which causes skin damage after exposure to direct sunlight. Due to the severity of the client's condition, he is supervised continuously.

SUMMARY OF IMPACT

Before the design of this project, the client's mother carried him from his wheelchair in the living room to a plastic patio chair used in the shower. During the shower, his muscles would relax, causing him to slide out of the chair, or lean to one side.

The shower chair was designed to hold the client upright comfortably in the shower, at an optimal height for his mother to bathe him. It allows for easy and safe transfer and meets bathroom size constraints.

Figure 4.6. Angel in his Shower Chair with his Mother and Graduate Student Coordinator

TECHNICAL DESCRIPTION

The technical specifications of the shower chair were derived primarily from ergonomic factors. The client's weight and body dimensions determined the seat area of the chair, while the transfer and bathroom space limitations were used to determine much of the chair base design (Figure 4.7). For safety reasons, the design was tested with individuals weighing about two and one-half times the client's weight of 60 lbs. A four-wheel base configuration was chosen for ease of rolling and to prevent tipping. The 3-inch diameter caster wheels easily negotiate the rugs, sill, and threshold of the home and bathroom, and are rated at 150 psi, or nearly 10 times the expected loading. The frame is made from one-inch outer diameter T6061 aluminum tubing with a 1/8-inch wall thickness. All frame joints were welded, except for the pin connections for the adjustment rod. To adjust the reclining angle, the person giving the user a shower uses the adjustable pin positions on the adjustment rod to rotate the chair from an upright sitting position to one reclined at 45°. An adjustable spring/damper device connected between the base and the rotating seat controls the rate of rotation. The device resists motion in both directions, and can be set to give variable resistance using a screw setting. An adjustable 2-inch nylon-webbing belt with a Delrin clasp is used to secure the user and is positioned across the chest, away from his feeding tube and button. The seating material is made from a polyester mesh typically used for outdoor furniture. It is mildew-resistant and porous enough to allow water to pass through it, while retaining enough strength to support the client's weight. The material was attached to the frame by stretching it around the tubing and securing it with aluminum POP rivets and washers.

Since the shower chair was to be used in a corrosive environment, all component pieces, fasteners, etc. were made of corrosion resistant materials. To improve the appearance of the chair, the aluminum frame was coated with bright blue Hammerite® paint.

Though every effort was made to make the chair stable and structurally sound, it is assumed that the user is under supervision at all times.

The overall material costs were estimated at $141.58.

Figure 4.7. Client and his Shower Chair in the Shower Enclosure.

A FLY CASTING ORTHOSIS FOR A PATIENT WITH QUADRIPLEGIA

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Client: Don Price, Fishing Has No Boundaries, AZ Chapter
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INTRODUCTION

A prototype fly-fishing orthosis was designed for use by a patient with mild quadriplegia. The device was designed to allow him to perform a proper casting stroke, control slack line, and reel - - all motions that are necessary for fly fishing. The person for whom the device was designed has no independent finger movement or grip strength, but he is able to move his arms well. Special devices were needed to attach the rod to the user's hand, to catch the slack line coming from the first "stripper" line guide, to grip the line during the cast, and to release the line at the end of the casting stroke. Combinations of mountable support devices, alternative reels, and wrist brace attachments were considered before a final design concept was selected. The final prototype consists of two polypropylene orthoses fitted to the user's hands and arms. The left hand orthosis is strapped onto the forearm and hand and has a hole to allow turning of the reel handle and a "finger" to allow hooking, grasping, and releasing of slack line. The right arm orthotic is strapped to the forearm and hand and tightly grips a standard cork fly rod handle.

Figure 4.8. Client Testing the Fly-Casting Orthosis.

SUMMARY OF IMPACT

The client is presently one of the cofounders of the Arizona Chapter of "Fishing Has No Boundaries", an organization dedicated to introducing persons with disabilities to fishing and enabling them to participate in the sport. While electric reels and reeling devices, spring loaded casting devices, specialized tires for "off-road wheelchairing" have been developed to enable people with quadriplegia to fish with conventional fishing tackle, no known devices enable such persons to fish with a fly rod and fly line. Instead of performing only a long forward casting stroke with a heavy weight and light line, as in conventional fishing, fly fishing requires one to perform both a backward stroke (the backcast) and a forward stroke. Because good fly casting only requires a short backward and short forward stroke that are timed appropriately, it was felt that people with quadriplegia could participate in fly fishing. People with mild quadriplegia typically have enough upper body mobility and voluntary arm movement to support the movements involved in fly fishing. The most difficult thing to teach a non-disabled individual is not to flex the wrists backward during the backcast. With an orthosis that prevents backward wrist flexion, people with quadriplegia would not have to unlearn this highly unproductive movement. With further development and appropriate modifications, this prototype might be made as a commercial device that could be made available to other people with quadriplegia.

TECHNICAL DESCRIPTION

The final design of the fly-fishing device consists of a right and left orthotic (Figure 4.9) and a slightly modified reel handle. The left hand orthotic straps onto the hand and wrist and has two attachment functions: 1) to grasp and pull in slack line, 2) to grasp the handle and turn the reel when fighting fish or reeling in slack line. The grasping and pulling functions are accomplished with a forked extension, shown in Figure 4.9. The reeling is accomplished by way of a milled slot and 7/16" hole built into the palm area which mates with the reel handle. The slot enables the user to find the reel handle easily so that once the reel handle is located within the hole the spool can be turned. The plastic reel handle was extended slightly for more accessible use. The opposing orthosis straps onto the palm of the right (casting) hand. This device cradles the rod in a thermal cork lined inset, shown in Figure 4.9. The polypropylene material flexes and the cork lining compresses to accommodate the many rod handles available on the market. 1-inch nylon webbing straps with Velcro closures and steel rings were attached to secure the orthosis to the rod and to further secure the connection between the orthosis and the hand. The interiors of both orthotics are lined with Alliplast, a soft foam-like material, for comfort. Prototypes of the design were made at the Prosthetic Orthotic Associates facilities in Scottsdale, Arizona. Casts were made of the right and left arms, with plaster bandages cut away, stapled back together, and used to form plaster molds of the arms. The dried and shaped molds were used to shape the preheated Alliplast liners and polypropylene sheets. The polypropylene was then sealed and vacuumed to pull the plastic tight around the mold. Once cooled, the shapes were further refined and smoothed to the desired shape. Thermal cork was heated and glued to the right orthotic and then shaped to grip the handle of a standard fly rod. During operation, the user pulls the slack out of the line by hooking the line or sliding the fork prongs around the line, slightly twisting, and pulling down. When enough slack is pulled out, the user holds the line by pressing the fork with the line down into his lap. Slack is released when necessary. As with non-disabled individuals, learning these movements requires practice before actual use on the stream. Although designed to fit most individuals, each individual's mobility and skills determines how effective the device is for fly-fishing. It was found that the client did not actually need the left hand orthosis, as he was able to loosely hold the line with his left hand, an essential component to successful fly casting. Although the concept was effective, the right hand orthosis was found to be a bit bulky and a new design is being considered. Also, it was determined that because of the client's weakness, a specially designed fly rod that is shorter and lighter in weight would make it easier for him to accelerate and decelerate. Total costs for the prototype device were estimated at $120.

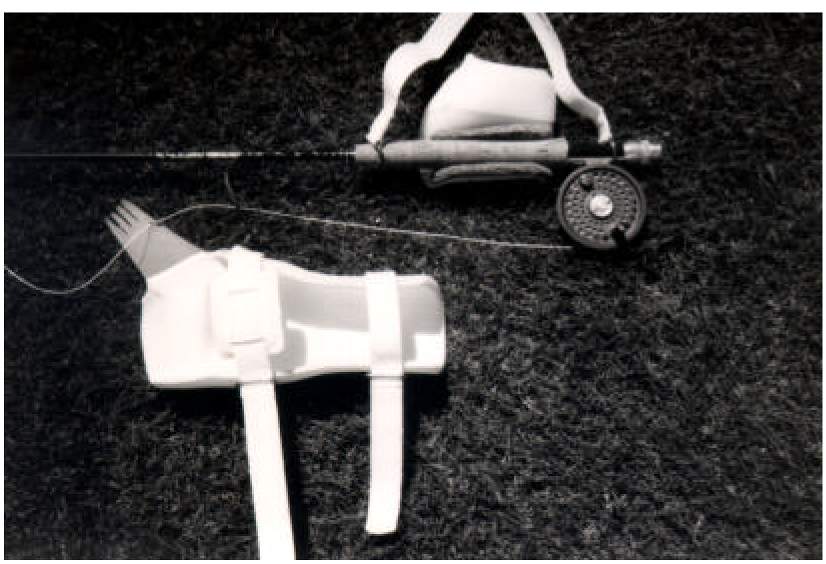

Figure 4.9. The Left Hand Orthosis (Bottom) Reel Handle, Attached to a Standard Fly Rod Using a Friction Fitting, Two D Rings, and Velcro Straps.

AN EXERCISE/RANGE-OF-MOTION BIKE FOR A PATIENT WITH PARAPLEGIA

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INTRODUCTION

An exercise / range-of-motion (Ex / ROM) bike was designed for a person with paraplegia. The client requested a hand-driven device that would move his legs repeatedly through a wide range of motion. He had found that ranging his joints was useful because it reduces contractures and spasticity. The major design components included a hand-controlled drive sprocket, a gear driven leg follower sprocket, a sliding seat, ankle and foot supports, and the overall frame.

SUMMARY OF IMPACT

The aim of this design was to allow an efficient way for an adult with paraplegia to stretch and range his legs by cranking with his arms. The need for such a device is not limited to the individual for whom it was designed, but extends to other people with paraplegia, as well as to others requiring passive motion. Currently, similar devices are being used to rehabilitate many individuals with various lower limb disabilities in the U.S. Most of these devices use electromechanical motors and gear arrangements to provide actuation.

This design promotes range-of-motion exercising of the lower limbs, which improves circulation, reduces muscle spasms and contractures, relieves joint stiffness, and promotes mental and physical health in patients with spinal cord injury. This device also offers some upper body conditioning, since the upper body provides the work to range the lower body.

TECHNICAL DESCRIPTION

The overall design is a synthesis of all major component designs (See Figure 4.10). The hand-controlling sprocket is positioned at approximately the user's arm height. Foot pedals were used as handles in this design, but will be replaced with handgrips before delivery to the user. Studies have shown that many people with lower limb disabilities prefer an average cadence of 15 rpms. The hand sprocket has a gear diameter ratio of 8:5 with respect to the leg sprocket. This allows the user to pedal more slowly, at a rate of about 9.4 rpms, to achieve the preferred cadence. It was easy to drive the legs through a cycle, even though the arms have a mechanical disadvantage via this gear ratio.

The leg pedals have plastic footpads and Velcro straps that hold the feet and provide proper foot positioning. The ankle supports are made from a stiff but flexible plastic (similar to the plastic used in ski boots) and are strapped around the user's shins. The ankle supports were found to be unnecessary for the client and were removed. The seat is made of medium-stiff foam, attached to plywood backing and covered with vinyl upholstery. The seat is bolted to steel bars that are welded to a slider collar. The collar slides along a 2" diameter tube with 4 possible pin settings spaced 2" apart. A ½" steel pin placed through the holes in the collar and mainframe tube allows 6" of travel at the 4 different pin settings.

The support frame is constructed of 1" square and 1" outer diameter mild steel tubes (all 1/8" wall), welded together and painted. Other final modifications to be made to this device include: adding a chain tension sprocket, adding a chain guard, installing a square tube and slider collar, and adding further frame support behind the device to maintain stability during use.

Material costs for the Ex/ROM Bike were less than $250.00, as standard bicycle parts were used for most of the components.

Figure 4.10. Prototype for Exercise/Range-Of-Motion Bike.


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