Clinical Prosthetics & Orthotics

Sports Prosthetics

Volume 11, Number 3 **Summer, 1987**

Clinical Prosthetics & Orthotics

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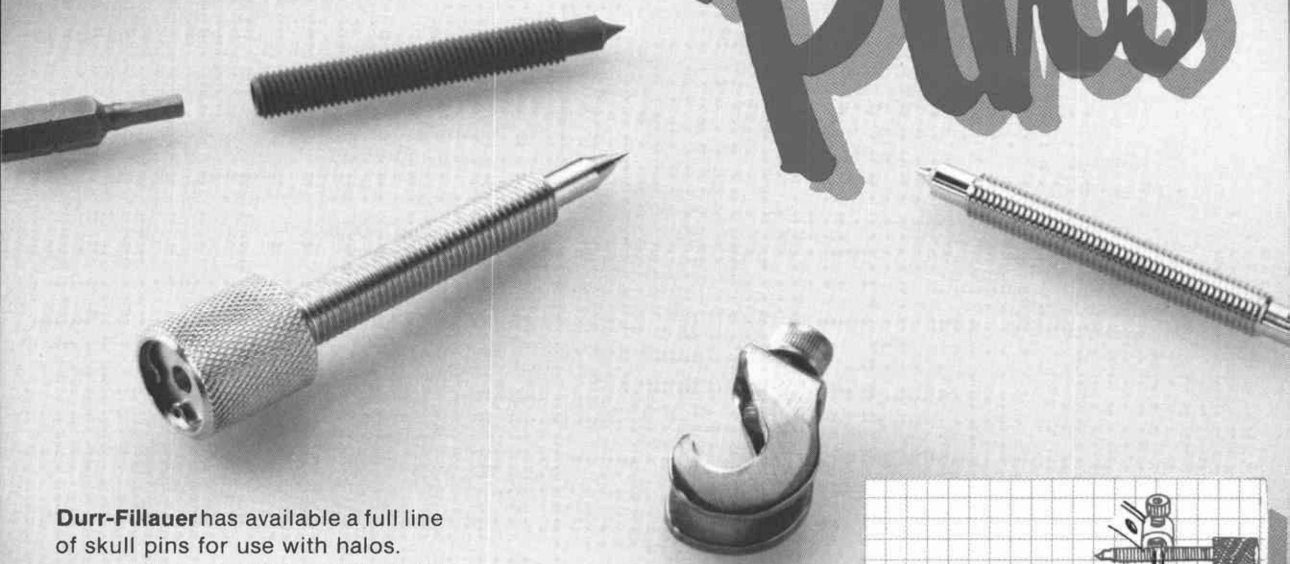

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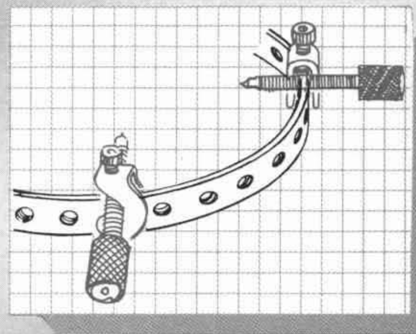

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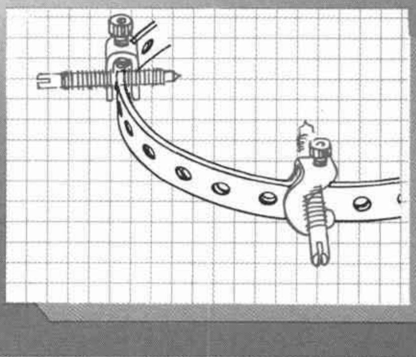

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CONTENTS

Volume 11, Number 3 **Summer, 1987**

Sports Prosthetics

FEATURES

ADVERTISERS' INDEX

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1:00 a.m.–2:00 p.m.	*Laboratory Practice:* Students do wrap casts
2:00 p.m.–5:00 p.m.	*Lecture and Demonstration:* "How to Modify the Diagonal Four Stage Master Model Using Total Surface Bearing Techniques"
DAY 2 TUESDAY	
8:00 a.m.–9:00 a.m.	*Lecture:* "Vacuum Forming the Flexible Transparent Suction Socket Membrane" (Prepare Mirror Image Master Models)
9:00 a.m.–10:00 a.m.	*Laboratory Practice:* "Vacuum Form Diagnostic Suction Sockets" (Prepare Mirror Image Models for Lamination)
10:00 a.m.–10:30 a.m.	"How to Fit and Perfect the Diagnostic Socket for Suction Below Knee Prostheses"
10:30 a.m.–12:00 p.m.	*Laboratory Practice:* Fit and Alginate Check Sockets
1:00 p.m.–3:00 p.m.	*Laboratory Practice:* Remodify Master Models to Prepare for Suction BK Prosthesis Procedures
3:00 p.m.–3:45 p.m.	*Lecture Demonstration:* "TSB Suction BK and Total Flexible Brim BK Fabrication Techniques and Alternatives (Mirror Image Finishing Techniques)
3:45 p.m.–5:00 p.m.	*Laboratory Practice:* Fabricate Suction Below-Knee Sockets
DAY 3 WEDNESDAY	
8:00 a.m.–9:00 a.m.	*Lecture and Demonstration:* "How to Fit and Align the TSB Suction BK Prosthesis"
9:00 a.m.–11:30 a.m.	*Laboratory Practice:* Fit and Align Suction BK Prostheses
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1000 Veteran Avenue
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Letters to the Editor

To the Editor:

I assume the provocative comments in the Winter, 1987 edition of *Clinical Prosthetics and Orthotics* were intended to stimulate controversy and discussion. Nevertheless, I find myself unable to resist "rising to the bait."

It is not at all clear to me that a "general objective of the Academy College Fund" is to be able to prescribe prostheses and/or orthoses or that the "College Fund goals and purposes are fundamentally different" than those of the program at the University of Connecticut. On the issue of prescription responsibility, however, I have a very definite opinion.

I should like to go on record as stating that I have absolutely no interest whatsoever in becoming the sole prescription authority for Orthotic and Prosthetic services. I find it reassuring to share the legal liability with my physician colleagues, and appreciate the counsel and collaboration that the current state of affairs engenders. Every knowledgeable physician I have worked with to date carefully considers my recommendations, and generally heeds my advice. On occasion, medical factors far outside my realm of interest will have a mitigating effect on the orthotic/prosthetic prescription. In that circumstance, I submit that the patient is well served by this collaborative approach.

I believe strongly that it is inappropriate to pursue sole prescription responsibility as a goal, since it will divert attention from the more important purposes for an advanced degree. We should focus our attention on expanding our professional knowledge, enhancing our technical and academic skills, and exerting a more direct control over the future of our profession via research, teaching, and clinical innovation.

It may well be that, at some point in the distant future, our overall mastery of the field will make prescribing our own services a logical responsibility. But that will be simply the byproduct of a much broader and deeper professional preparation. I would suggest that concentrating on the goal of a reputable, advanced degree from a top-notch University will accomplish much more than myopic focus on whose signature adorns the prescription pad.

Sincerely,
John W. Michael, M.Ed., C.P.O.
Duke University Medical Center
Durham, North Carolina

Dear Editor:

I enjoyed the timely review of "Wheelchair Options for Paraplegic Patients" by A. Bennett Wilson, Jr. in the Spring 1987 issue of *Clinical Prosthetics and Orthotics*. I was particularly pleased to see a section on sports chairs. However, as Dr. Wilson notes, ". . . a change in the design to emphasize one feature generally affects adversely one or more of the other features." Although the adjustable position of the rear axles permits one to vary the position of the occupant in relationship to the rear wheel and in space, this frequently is done at the expense of rear stability.[1,2]

References

[1] Loane, T.D. and R.L. Kirby, "Static Rear Stability of Conventional and Lightweight Variable-Axle-Position Wheelchairs," *Arch. Phys. Med. Rehabil.*, 66:174–176, 1985.

[2] Loane, T.D. and R.L. Kirby, "Low Anterior Counterweights to Improve Static Rear Stability of Occupied Wheelchairs," *Arch. Phys. Med. Rehabil.*, 67:263–266, 1986.

Sincerely,
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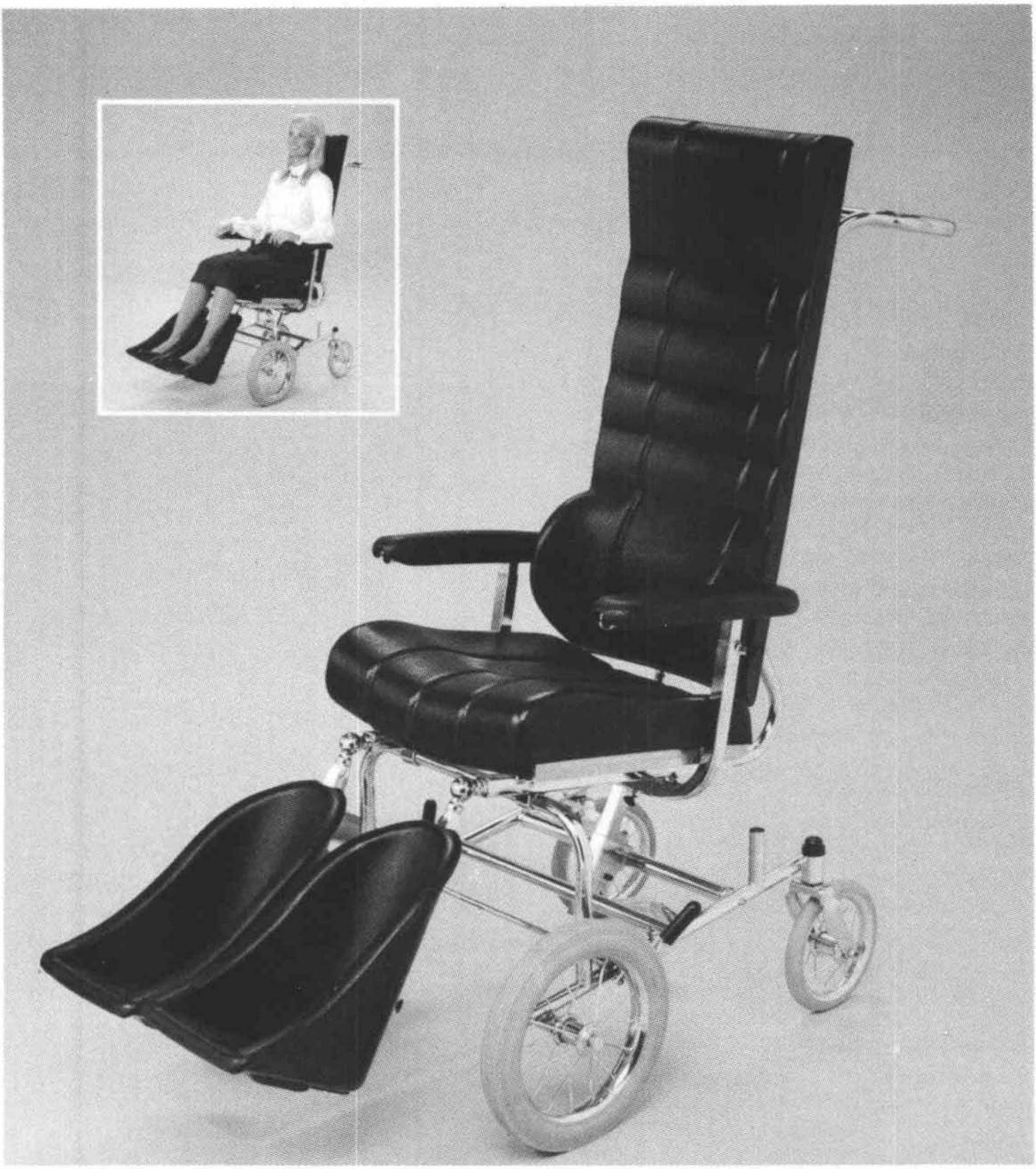

Clinical Prosthetics and Orthotics, Vol. 11, No. 3, pp. 109–113

The Amputee Athlete

by Richard Riley, C.P.

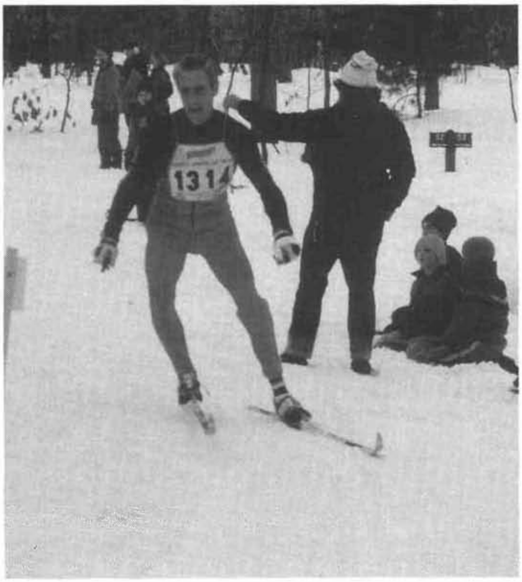

Figure 1. Below-knee amputee, George Lombard, member of the Fisher-Saloman Marathon Team and the U.S. Disabled Ski Team.

An increasing number of amputees in the United States are moving beyond mere ambulation into active sports and recreation activities. Estimates of the number of amputees actively involved range from 15,000 to 20,000, with over 5,000 participating in organized competitive sports.[1]

Ten years ago, the athletic amputee was a unique phenomenon in our practice. Today few practitioners cannot count two or three among their clientele. These amputees are at the cutting edge of our field because they push us as professionals to expand our perceptions of what is possible. They also provide the positive role models that we hold out to the rest of our clients as an example of what can be done.

The able-bodied sports world has taken some giant leaps of perception regarding the amputee athlete. No longer is it just "inspirational" to have a disabled person competing in sports. Today there are amputees that compete in world class events alongside the able-bodied. The skiing world has demonstrated this by naming below-knee amputee George Lombard to the Fischer-Saloman Marathon cross country ski team and awarding above-knee amputee Diana Golden with the U.S. Ski Writers Award for Outstanding Alpine Competitor.

Not only are there more elite amputee athletes today, there is a much larger body of recreationally oriented amputees. The days are gone when the prosthetist and rehabilitation team could be satisfied with being able to get the amputee to just walk. Expectations of our clients have changed. Not only the younger amputee, but also the active geriatric expects to be able to ride a bicycle, play golf, tennis, or jog around the block.[2] Our challenge is to meet these expectations.

Psychology of the Amputee Athlete

What causes one amputee to become an elite cross country skier (one of the most demanding physical sports in the world) and another with the same level of disability to be unable to even return to gainful employment? Part of the answer lies in the individual's ability to handle the stress and trauma of amputation. These are factors that we have little control over. The other part of the answer lies with environmental issues and can be addressed.

Most amputee athletes are highly motivated individuals with a strong desire to overcompensate for their disability. A percentage of these

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Table I.

people will rehabilitate themselves with practically no help at all and go on to accomplish great things in their personal lives as well as in sports. Others need the influence of role models to show them that their limitations are what they place upon themselves. One of the most positive experiences for any new amputee is when they meet another amputee with a positive attitude.[3] This positive motivation is best facilitated by a support structure of family, friends, and the rehabilitation team. If any one of these aspects is continually placing limits on the amputee, eventually the amputee will accept these limitations. There are physical limitations for the amputee, but these should be discovered not imposed. There are ways around most physical limitations by keeping an open mind and being willing to innovate.

Pain is an aspect of amputation that in many cases is initially the greatest barrier to overcome. All athletes know pain through training and the physical exertion of competition. People who are athletic prior to becoming an amputee will generally be able to deal with pain more easily due to their previous development of strategies to perform while enduring levels of pain. The successful amputee will develop ways of minimizing discomfort, either through increasing the conscious tolerance for pain or seeking a lifestyle that reduces trauma to the residual limb.

The amputee athlete not only has the pain of general physical exertion to deal with, but also the added trauma of torques and stresses far beyond normal to the skin and bone structure of the residual limb. Most of these athletes have developed very high pain tolerances and their body readily reacts to pain stimuli by releasing endorphines[4] (the body's natural pain medication) into the body. These factors enable the amputee athlete to achieve great physical accomplishments. It also sets up potential for serious damage to the residual limb tissue because of overactivity. Pain is the body's message to the brain that something is wrong and many amputees have developed ways to short-circuit this signal. This is a fact we must all be aware of in caring for and guiding the amputee athlete.

Prosthetic Care

For the prosthetic professional, the active amputee can be either a great source of pride and stimulation or a perpetual problem fraught with frustration. Nevertheless, this group of our clientele will continue to occupy a greater share of our patient load and we must develop strategies to successfully accommodate their needs.

As important to the success of the athletic amputee as the prosthesis is his knowledge of how it works. Of equal importance are the limitations of the prosthesis and problem solving strategies for residual limb breakdown. The time spent in educating the amputee about his prosthesis and ways to deal with skin problems is always well spent.

Regardless of how well fitting a prostheses is, there is a potential for skin breakdown of the residual limb due to overactivity.[5] Athletes will continually push themselves to their limits and beyond. If they are armed with methods to deal with skin breakdown, they will benefit greatly.

Advances in sports medicine for runners was bound to spill over into prosthetics. Of particular use is a skin protection material called "2nd Skin™" (Table I). It is a 1/16" thick piece of gel that is applied directly onto the skin. It prevents friction between the skin and any moving surface. It does not stick to normal skin, yet because of its viscosity, will stay where it is placed. It is perforated so as to let the wound breathe as well as being sterile to prevent infection. 2nd Skin™ absorbs secretions, feels cool, alleviates itching, and can relieve pain.[6]

2nd Skin™ comes with plastic on both sides of the gel material. Before the plastic is removed, cut a piece one third larger than the area to be covered. This allows coverage of the

Figure 2. Applying 2nd Skin™ to a residual limb abrasion.

affected area despite migration. The directions recommend removing the plastic from one side or from both sides. Personal experience has shown that removing the plastic from both sides prevents most migration.

Because 2nd Skin™ is so thin, it does not increase pressure on blisters or abrasions. It prevents most friction and can actually promote healing even during heavy usage. 2nd Skin™ comes in a variety of sheet sizes which can be cut to the size needed and has to be kept in the zip-lock container provided. Unfortunately, it can be used only once and has to be cleaned off the sock after use. It works very well on below-knee amputees, especially when used beneath a sheath. In above-knee amputees, only suction wearers will experience difficulty in usage due to excessive migration from pulling into the socket. Second Skin® is an inert material made from 96 percent water and four percent polyethylene oxide.

Another product which provides excellent friction reduction and is also reusable is "Spenco® Skin Care Pad" (Table I). This product comes in three thicknesses, ½", 3/16", and ⅛". The ⅛" thickness produces the least amount of pressure inside the socket. Spenco® Skin Care Pad acts like a second layer of fat to protect the skin from friction or abrasion. It adheres to the skin without sticking due to its viscosity. Made from a reticulated closed cell elastomer, it can be gas sterilized or washed in soap and warm water. It should also be stored in the zip-lock bag and has a shelf life of two years. It is best used as a preventative measure in circumstances where skin breakdown is a danger.[6]

One of the problems with most skin protection materials is that suction socket wearers cannot utilize them. When the amputee pulls into the suction socket, "2nd Skin®" or "Spenco® Skin Care Pads" become displaced and usually do not cover the areas intended. A product that can be of use to suction socket wearers, or any amputee for that matter, comes with a variety of names. It is a transparent dressing with one adhesive side that is paper thin and porous both to air and water. The trade names are "Op-Site," "Bioclusive," "Tegaderm," and "Acuderm" (Table I). This material can be applied directly to the skin and acts as another layer of protection, while still allowing normal dermal respiration and perspiration to occur. It can be left on the skin for four to five days before it needs to be removed. If left on much longer, the epidermis does not get an opportunity to slough off properly.[6]

These products work well to prevent friction, but do not provide any relief for pressure problems. The transparency of these materials allow for continual evaluation of the healing process. There is a problem that the adhesive is quite strong and oftentimes pulls hairs out upon removal. Different brands utilize different adhesives, but in general it is recommended that some soaking of the covered area in warm water will help remove the covering with minimal discomfort. Careful attention should be paid to the application instructions so as to avoid getting it adhered to itself when applying it. Most brands come with a paper backing and application method that allows it to be cut to the desired size.

Until the time when skin abrasions and adherent scars become a thing of the past, we will have the need for skin protection materials. These products can give relief to thousands of prosthetic wearers as well as prevent much discomfort for active amputees. They should become a standard part of the amputee's "survival kit."

Sports Organizations for Amputees

The perceptions that amputees have of their capabilities has risen dramatically in the last decade. Paralleling the growth of competitive

Figure 3. The United States Disabled Ski Team.

sports for amputees has been the organizations that provide the forum for these activities (Table II). Prior to these organizations bringing together amputees from around the nation and the world, there was little opportunity for exchange of ideas on the consumer level.

Organizations such as the "National Handicapped Sports and Recreation Association," sponsor and provide for competitive sports activities. Competition is based on ability and level of amputation with competitive levels ranging from local races to world class and a parallel olympic structure.

The impact of these organizations on the field of prosthetics has been enormous. All of us have fielded questions concerning amputee athletes and their various prostheses. This direction from the people whom we serve has been healthy for prosthetics for many reasons. First, we have had to expand our horizons and adapt technologies and techniques to accommodate these athletic amputees. Secondly, it has created a demand and thus a market for new components to accommodate extra-ambulatory activities. Third, there now exists a forum for amputees to exchange ideas, compare techniques, and services, as well as push each other to greater accomplishments. Another important contribution is the role model aspect of these athletic amputees. They provide inspiration to all of our clientele to continue to expand their perceptions of what is possible.

All of these factors have changed prosthetics. Because of publicity surrounding some of the more astounding accomplishments, not only has the field gained more public recognition, but there is a growing acceptance of us as professionals. These organizations will continue to provide and promote sports and recreation as a normal part of the amputees lifestyle. Not only is it our responsibility and challenge to continue to adapt prosthetics to these activities, but it will play a major role in the future of our profession.[7]

Amputee Sports Organizations

National Handicapped Sports and Recreation Association
1145 19th Street, N.W., Suite 717
Washington, D.C. 20036
301-652-7505

United States Amputee Athletic Association
Route 2, County Line Road
Fairview, Tennessee 37026
615-670-5453

National Amputee Golf Association
c/o Bob Wilson
5711 Yearling Court
Bonita, California 92002
619-479-4578

National Wheelchair Athletic Association
2107 Templeton Gap Road, Suite C
Colorado Springs, Colorado 80907

Table II.

Conclusion

As leisure time in our society increases, the need to accommodate sports and recreation in our society becomes essential. The perception of the amputee's lifestyle parallels this societal shift. Prosthetics must be able to accommodate this change in our patients' attitudes toward activity. This can best be accomplished through education and communication, as well as further development of componentry geared to the athletically inclined.[8]

The amputee athlete has given rise to a new specialty in our field. The sports prosthetist is now a viable specialist that as professionals we should recognize and refer our patients to. We will continue to provide state-of-the-art prostheses for our active amputees, and armed with information about proper care, they will be among the best athletes in the world.

Author

Richard Riley, C.P., specializes in sports prosthetics and has a private practice with SportsMedicine Portsmouth, in Portsmouth, New Hampshire.

Also a below-knee amputee, Riley is a member of the U.S. Disabled Nordic Ski Team and the Vice President of the National Handicapped Sports and Recreation Association.

References

[1] Riley, Richard, "The Amputee Athlete," *Sports Medicine,* Volume 4, October, 1984, pp. 31–32.

[2] Kegel, Bernice, "Recreational Activities of Lower Extremity Amputees: A Survey," *Archives of Physical Medicine and Rehabilitation,* Volume 61, June, 1980, pp. 258–264.

[3] Foort, James, "How Amputees Feel About Amputation," *Orthotics and Prosthetics,* Volume 28, March, 1974, pp. 21–27.

[4] Gaylor, Michael, M.D., personal communication, April, 1987. Presently Professor, Dartmouth College, Specialty in Sports Medicine.

[5] Levy, W. S., "Skin Problems of the Leg Amputee," *Prosthetic and Orthotic International,* Volume 4, 1980, pp. 37–44.

[6] Riley, Richard, "Skin Protection Materials," lecture given at American Academy of Orthotists and Prosthetics Annual Meeting, Tampa, Florida, February, 1987.

[7] Riley, Richard, "Sports Organizations for the Disabled and Their Impact on Prosthetics," lecture given at American Academy of Orthotists and Prosthetists Annual Meeting, Tampa, Florida, February, 1987.

[8] Riley, Richard, "A Survey of Active Below-Knee Amputees," study undertaken at Northwestern Orthotic and Prosthetic Research Center, Chicago, Illinois, December, 1980.

[9] Kegel, Bernice, *Sports for the Leg Amputee,* 1986.

Clinical Prosthetics and Orthotics, Vol. 11, No. 3, pp. 114–117

Winter Sports for the Amputee Athlete

by Doug Pringle

Organized participation in winter sports by people with disabilities has a relatively short history. It began in the early 1950s when amputee veterans of World War II began to experiment with skiing despite the loss of limbs. The West Germans are credited with the invention of the outrigger, a crutch with ski tips attached, which are used as balance assistors. This invention helped popularize the sport and several amputee ski clubs were formed in the United States.

During the late 50s and early 60s, amputee skiing was the mainstay of the sport. It was during the late sixties and early seventies that others with one "bad" leg, such as polio victims, began to ski using the technique developed for amputees. It was also during this time that amputees began experimenting with skiing with a prosthesis.

Simultaneously, visually impaired people began to participate and the sport began to include more than amputees. In the late 70s, the major innovation was development of the "Four-Track" technique, which allowed many types of severely disabled people to ski.

The 1980s have contributed the technique known as 'sit skiing.' This technique allows people who are wheelchair bound to participate in the sport.

The benefits of participation in skiing are numerous. Physically the participant develops stamina, strength, balance, and coordination. These are all valuable physical traits for a person trying to compensate for a physical problem.

Psychologically, participants begin to develop a positive self-image and a "can do" attitude. This positive thought cycle carries over into other aspects of life such as education and employment.

Skiing offers a unique opportunity as a sport that can be done with family and friends in a facility open to the public. In that sense it is a mainstreamed activity done with everyone else rather than in a special facility.

Finally, there is something wonderful and invigorating about the freedom of movement, speed, risk, and the natural environment of skiing. All these add to the experience.

Skiing is the only winter sport offered to people with disabilities through formal programs. These programs offer adaptive equipment, qualified instruction and a competition system. Participation in other winter sports is not extensive.

Downhill Skiing

Alpine Skiing

Alpine (or downhill) skiing is the most popular winter sport of people with disabilities in the United States. There are approximately 10,000 disabled skiers. The sport offers unique benefits to participants who are mobility impaired, not the least of which is that gravity supplies the means for movement.

The development of adaptive equipment and techniques has made it possible for even the severely disabled to participate. Adaptive skiing is divided into five major categories or techniques:

1. Three track skiing
2. Four track skiing
3. Blind skiing
4. Sit skiing
5. Other adaptive techniques

Three Track Skiing

Above-knee and below-knee amputees, persons with polio or birth defects, and those with a variety of other problems, ski three track in which the common element is having one good leg and two good arms. Above-knee amputees ski without their prosthesis because it is difficult to control. Below-knee amputees can ski with their prosthesis. The advantage is that they can stand on it when stopped. The disadvantage is increased risk of injury.

Adaptive equipment for three trackers are outriggers. Outriggers are forearm crutches with ski tips attached. They act as balance assistors and are used to "walk" on the flats. Three track skiing derives its name from the three tracks made in the snow by two outriggers and the single ski.

Some three trackers, especially racers, learn to ski with ski poles instead of outriggers. In fact, that is how people with one leg skied before the invention of outriggers. While more difficult, "one tracking" is also a possibility for many and skiing with poles is an advanced instructional method.

Four Track Skiing

Four track skiing is used by people with a wide variety of disabilities including: double leg amputees, spina bifida, cerebral palsy, muscular dystrophy, multiple sclerosis, stroke, head trauma, paraplegia, and polio. An individual with two legs and arms, natural or prosthetic, who is capable of standing independently (static balance), or with the aid of outriggers, could use this method. Many severely disabled people ski using this technique.

In addition to outriggers, a lateral stability device is often used. This device is commonly referred to as a "ski bra." It helps keep the skiis parallel and also allows the student's strong side to help control the weaker side.

Blind Skiing

Visually impaired students are taught the same as any other skier with the exception that the instructor must learn to communicate more clearly. A number of holds or assists have been developed as well. Once the student can ski, the task becomes one of guiding or talking them down the hill.

No adaptive equipment is required for the visually impaired. Often the student and instructor (or guide) wear bright bibs which signal to other skiers to be alert.

Sit Skiing

Sit skiing is the technique used by anyone who cannot ski standing. Sit skiers include people with muscular dystrophy, multiple sclerosis, cerebral palsy, spina bifida, paraplegia, and quadraplegia. This technique has been used since 1980 and it has opened skiing to people who are wheelchair bound.

The sit ski has a fiberglass shell and metal edges. It is steered by leaning the body and by dragging a "pole" on the side to which the skier wants to turn. An instructor skies behind the device holding a length of nylon mesh cord in order to stop the skier and to assist with turns when necessary. Sit skiers often become proficient enough to ski "untethered" or without the instructor and safety line.

The most recent development in sit skiing is the mono-ski. Here the fiberglass shell is mounted on a single ski and the skier uses outriggers. Use of a mono-ski requires good upper body strength. Therefore, it is a technique that is not suitable to quadraplegics and high-level paraplegics.

Other Adaptive Techniques

This catch-all category is used for a variety of people with disabilities who don't fit into any of the other four. Among them are upper extremity impairment: people who have lost the use of one or both arms. Those with one good arm use one ski pole and a pole can also be used with an arm prosthesis.

Below-knee amputees may choose to ski using their artificial leg or legs. A heel line is usually necesary to achieve a bent knee position. Waist straps and thigh lacers help provide lateral stability, a snug fit, and reduced pistoning and rotation. A special ski leg can be made if the student decides to seriously pursue skiing.

The combination of disabilities and adaptive equipment are numerous. In competitions, some 19 different classes are recognized. But, generally, most people ski using one of the four major techniques.

Instruction

There are a number of programs of ski instruction available. Most are voluntary, weekend programs. There are five full-time professional ski schools which specialize in adaptive skiing and about 25 voluntary ones. All but a few of these programs are chapters or affiliates of the National Handicapped Sports and Recreation Association (NHSRA).

The NHSRA has also developed a clinic team which trains instructors in adaptive ski teaching. The team also advises on program delivery. There is an instructor testing and certification program conducted by NHSRA which is approved and recognized by the Professional Ski Instructors of America.

Competition

A natural outgrowth of participation in sports is the development of competition. A very well developed system is in place. Learn to Race clinics and training camps are conducted by a few of the instructional programs locally and by the NHSRA nationally.

Those interested in competition can race in any number of programs open to the public such as NASTAR and United States Ski Association races. Further, there are ten sanctioned regional championships at which racers can qualify for the nationals.

Both the NHSRA and U.S. Association of Blind Athletes conduct annual national championships. Both organizations also select athletes for the U.S. Disabled Ski Team which competes in the World Winter Games for the Disabled and the Winter Olympics for the Disabled. In 1986, the U.S. Disabled Ski Team was number one in the world at the games in Sweden.

Resources

National Handicapped Sports and Recreation Association
4405 East West Highway, Suite 603
Bethesda, MD 20814

U.S. Association of Blind Athletes

Professional Ski Instructors of America
5541 Central Ave.
Boulder, CO 80301

Alpine Skiing, contact:
Vineland National Center
P.O. Box 308
Loretto, MN 55357

Nordic Skiing

Nordic (or cross country) skiing is also popular among people with disabilities. Since the sport does require more muscular effort for motion than Alpine skiing, it is not an option for some severely disabled individuals.

Among the participants are amputees skiing with their prosthesis and some who ski on one leg. Those on one leg must rely upon upper body strength and use their poles to push themselves along.

Nordic skiing is well suited for the visually impaired. They may ski with a guide or follow pre-set tracks in the snow.

Some more severely disabled people who would be four-trackers in Alpine skiing, such as those with cerebral palsy, muscular dystrophy, multiple sclerosis, stroke, head injury, etc., can also participate in Nordic skiing if they are able to ambulate well. Some will require assistance, pushing or pulling with a rope, and frequent rest breaks are always a safe practice.

There is a sit ski for Nordic skiing. The sit skier will need excellent upper body strength to push themselves over any appreciable distance. Again, assistance and rest stops will help.

Instruction

There are very few Nordic skiing instructional programs in the U.S. The sport is just beginning to develop. Those interested in learning the sport should check with a local cross country ski resort to see if they have an instructor willing and qualified. Most will have difficulty finding a program nearby.

Competition

The competition program described under Alpine skiing exists for Nordic skiing. Nordic events are held separately from Alpine events, but the U.S. Disabled Ski Team includes both Alpine and Nordic competitors.

Other Winter Sports

Snowmobiling has been a sport in which people with disabilities have participated for at least 15 years. It was one option open to more severely mobility impaired individuals before development of four track and sit skiing.

Ice boating and bike sailing are adaptable to a wide variety of mobility impairments. Ice fishing can also be enjoyed by many people.

Author

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The UCLA Total Surface Bearing Suction Below-Knee Prosthesis

by Timothy B. Staats, M.A., C.P.
Judd Lundt, B.S., A.E.

Introduction

While there was clear evidence to support examination of suction as a suspension technique for below-knee prostheses[1] in the early 1950s, overwhelming activity was in a direction that led ultimately to the development of the PTB design.[2] What is truly remarkable is the almost blind obedience that the practitioners and educators have given to PTB theories, a recognition that has rendered them all but untouchable gospel. Introduction and widespread use of transparent check sockets has probably done more to cause the prosthetist to question the accuracy of his PTB fitting methods than any other development in the last decade. Inaccuracy in socket fit that this powerful tool has revealed has led to the obvious conclusion: more precise casting and modification methods are required. This is the intent of the technique described here.

This paper presents a departure from PTB philosophy and technique. The methods described freely borrow from and recognize individuals who have developed alternative ideas, many of which have been integrated into the UCLA Total Surface Bearing Suction Below-Knee Prosthesis. The substance of this paper includes suction as the obvious mode of suspension. However, the essence of suction suspension, and of this article as well, is the critical anatomical accuracy of the socket fit. We refer to it as the total surface bearing or TSB technique. Without TSB, successful long-term suction suspension cannot be achieved. With TSB, the prosthetist can achieve suction if desired or may choose to fit with a sock and without suction if so indicated. Whatever the case, the final result will be improved fit and better patient comfort.

Suction Suspension

Suction below-knee prostheses are unique in that they do not require auxiliary suspension systems such as straps, cuffs, thigh lacers, or sleeves to maintain the socket on the residual limb. This is not to suggest that auxiliary suspension need not be employed as an extra measure of protection, particularly with a very active patient. However, in principle no other suspension should be required (Figure 1).

Three variations of suction socket are discussed in this article. The first is the "tension suction" variation.[3,4,5] This socket is made volumetrically smaller than the residual limb. Suction is maintained in the same manner as with the rigid above-knee suction prosthesis. This is probably through tension placed on the skin, thereby enhancing the friction between the tissue and the socket. Normally, a valve is placed at the distal end to release air while the socket is being applied. The second classification is "atmospheric suspension," mentioned by Murphy[6] in 1950 and later by others.[7] In atmospheric suspension, a non-elastic, but flexible interface is used, which virtually collapses around the residual limb when the prosthesis is unweighted. The third type of suction will be called "active compression suction." In this case, the socket interface is made of an elastic or elastomeric material which must be stretched or rolled over the residual limb, thereby gripping the skin through compression as well as through friction created between the skin and the socket.[8]

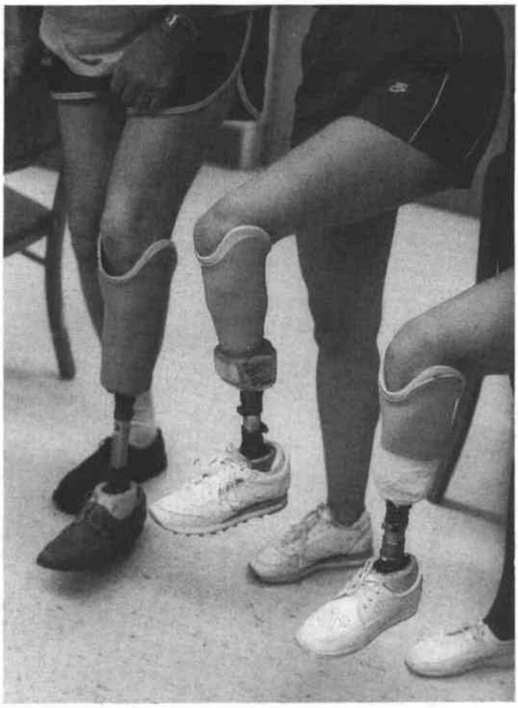

Figure 1. UCLA Total Surface Bearing Suction Prostheses.

Fitting Variables

The primary concern of any prosthetist attempting to fit a suction below-knee prosthesis should be the general health of the residual limb tissues. The UCLA experience has been similar to studies by Holmgren[9] and Bedouin.[4]

Types of Patients

The suction below-knee prosthesis, properly fitted, appears to stimulate circulation and can be used on vascular amputees as well as amputations due to other causes. The suction below-knee may actually help to more quickly stabilize tissue fluid volume. Ages of patients have ranged from five to 88 years.

Skin Problems

A suction below-knee prosthesis virtually eliminates skin problems caused by movement and friction created between the residual limb and the socket interface. Problems of skin irritation related to hygiene and allergic reaction are covered in a later section.

Bony Prominences

Grevsten,[10] using x-ray evaluation of suction below-knee fittings, found that the movement of skeletal anatomy inside the socket is less than one-half that inside ordinary PTB sockets. The UCLA experience, which employs a more intimate casting and cast modification technique (TSB), suggests an even greater reduction in skeletal movement. More importantly, few problems with bony prominence pain or discomfort were reported by patients in the over 150 fittings conducted at UCLA and other locations during the teaching of this technique.

Length

We have found no correlation between residual limb length and the ability to wear a suction below-knee prosthesis. Fittings and suction suspension have been successfully achieved with residual limb lengths as short as 3½″. However, these are not all long-term results.

Volume

More important was the finding that many residual limbs initially fit with suction would lose this effect within one or two hours of wear. There is an immediate fluid volume adjustment. Patients fit with suction over longer periods of weeks and months will continue to experience residual limb volume changes until a point of volume stability is achieved. This normally will occur within six weeks. Any loss of body weight will certainly contribute to loss of suction as well.

Shape

Generally, with enough effort almost any shape residual limb can be fit with suction. However, to achieve suction with conical shape residual limbs, whether bony or fleshy, can be difficult. With such cases, it is often necessary to enlarge the gastrocnemius muscle bulge area of the socket while tightening slightly proximal to this to maintain suction. Many prosthetists might question the long-term effect of this technique on the health of the residual limb. Short term effects have not been adverse and results look encouraging.

Patient Cooperation

Patients who intend to wear suction below-knee prostheses must be intelligent, cooperative and aware of the critical nature and accuracy required in this type of fitting. Numerous adjustments may be required during the first several months to maintain the intimacy of the fit. The patient must fully understand the function of the valve and the socket liner. It is imperative that any patient wearing a suction below-knee prosthesis, no matter how effectively fit, wear an auxiliary suspension as a back-up in case loss of suction does inadvertently occur.

Comparison of Theories

In the below-knee prosthesis, suction is a mode of suspension that can only be maintained through a precisely fit socket. A major aim of this article is to present a technique whereby such a fit can be achieved. Development of the total surface bearing (TSB) below-knee socket combines a staged precision casting method with a significantly different model modification to yield this result. In order to understand these differences, it is necessary to contrast the TSB and the more traditional PTB sockets.

The basic philosophy of the patellar tendon bearing below-knee prosthesis can be stated as follows: Increase weight bearing on areas of the residual limb over pressure tolerant areas and relieve pressure over those areas which are pressure sensitive. With the total surface bearing below-knee prosthesis weight is distributed over the entire surface of the residual limb, including areas which have in the past been considered pressure sensitive. In TSB, the accuracy of fit and careful use of measurements has eliminated the need for relief buildups over bony areas of the residual limb during the plaster casting and model modification procedures. The resulting corrected model for a TSB socket is thus distinctly different from that developed in accordance with PTB modification techniques.

Evaluation and Measurement

Measurements include all standard below-knee prosthetics parameters. The following additional considerations are necessary.

Circumferences

Carefully located circumferential measurements are taken at one inch intervals. The intervals are laid out from a bony landmark which can be defined accurately during the plaster casting procedure. Normally, the apex of the head of the fibula or the distal anterior tip of the tibia are chosen, depending on which is more prominent. The tibial tubercle may also be used. However, it is necessary to measure at least one interval more proximal when this location is chosen. In very fleshy or redundant residual limbs, it is wise to select the fibular head as some elongation may occur during casting which will obscure the distal end.

Length

The length measurement must be accurately gauged from the distal end of the residual limb to both the medial tibial plateau and to the inferior edge of the patella while under forceful upward loading.

Evaluation

Patients with chronic skin problems or burn scar tissue may not be suitably fit in sockets where the skin is directly in contact with the socket liner, unless the interface surface is impervious to body fluids. Perspiration can cause maceration even in healthy skin and an appropriate interface must be selected in such cases.

Plaster Casting Technique

An essential element of a successful TSB socket is a precisely cast residual limb. The diagonal four stage casting technique which draws from work adapted from Fillauer,[11] Gleaves,[12] Tranhardt,[13] Morris,[14] Hayes,[15] Stokosa,[16] and Vinnecour[17] was developed to best achieve that end. Unusual elements of the technique include:

1. Sheer nylon stockings for an ultra-thin barrier between skin and plaster, resulting in a more accurate cast.

Figure 2. The entire medial tibial flare and all bony prominences are carefully molded.

2. A beveled anterior first stage splint which is very accurately tailored to encompass the head of the fibula, the shaft of the tibia, and the entire medial flare. This first stage (Figure 2) is carefully molded to all bony anatomical structures. If properly applied, it will establish the mediolateral dimension within ⅛″ of patient measurement in most situations and require little or no model modification of the anterior aspect of the medial flare of the tibia.
3. A second stage of elastic plaster bandage which is wrapped with about half the available stretch applied. This stage must not extend more proximal than about 1″ to 1½″ below the crease of the skin in the popliteal fold. The anterior stage is maintained in position during this second procedure with firm proximal compression. As the second stage sets, the proximal posterior aspect is lightly compressed to help define the antero-posterior dimension of the cast. The medial lateral dimension is never sacrificed in any attempt to decrease the antero-posterior dimension.
4. A third stage splint, which creates the posterior brim shape and completes the basic cast used when a non-supracondylar trim line, is desired. The salient point of the third stage is the hand molding of the plaster bandage in the hamstring tendon region. When properly applied, the posterior brim will appear premodified with a diagonal trim which accommodates the lower anatomical insertion of the medial hamstring muscle group. It is necessary to do four things simultaneously to create an acceptable third stage, and generally will take considerable practice before repeatable accuracy and skill is achieved. It is necessary first to locate and create the shape of the tendons; secondly, compress the antero-posterior dimension of the cast both proximally and compressionally; third, mold the medial and lateral posterior areas of the third stage to prevent looseness in the hamstring areas proximal to the medial tibial plateau region; and fourth, spread the fingers of both left and right hands to stretch the plaster bandage to prevent a ridge from forming in the posterior aspect between the second and third stages (Figure 3).
5. A fourth stage splint is used when supracondylar suspension is planned. It is applied in a manner similar to that used in Fillauer's three stage casting technique.

Figure 3. The posterior trim and hamstring muscle reliefs are created during the wrap casting procedure.

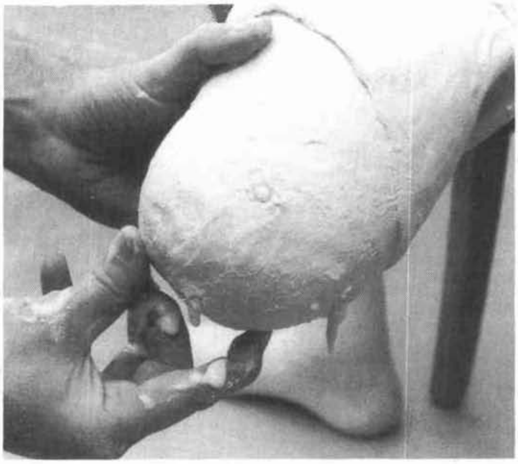

Figure 4. The wrap cast is alginated and pressure fitted.

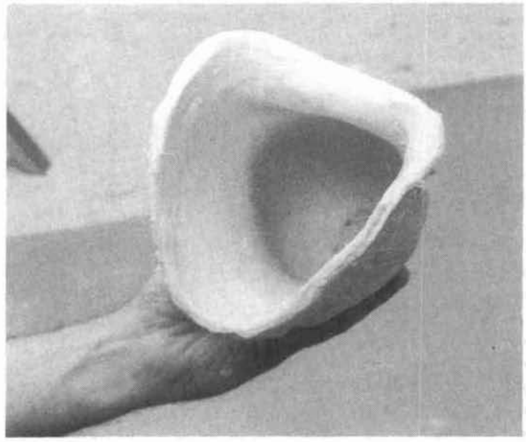

Figure 5. The completed diagonal four stage wrap cast.

Alginate Pressure Fitting

The first step in the fitting process occurs immediately after the hardened cast is removed. Through application of dental alginate to the inside of the wrap and a refitting on the patient, a more intimate contour is achieved. Though somewhat of a messy procedure, this will minimize the need to remove plaster from the model during modification. When casting very obese patients or those with excessive redundant tissue, this step may not be successful and may result in distortions in the final model.

The nylon stockings are carefully removed from the cast and a hole is cut in each of the distal, lateral, medial, and posterior aspects to permit air to escape when the alginate is applied. The holes should be approximately 1/4″ in diameter and should be cut using a knife. (A hand drill or drill press will likely grab the fabric in the wrap and destroy it.) About eight to ten ounces of dental alginate are mixed to a thick, but creamy consistency and quickly applied to the entire inner surface. The cast is replaced on the residual limb and forced proximal with moderate pressure. Alginate should exude from all cut holes (Figure 4).

The instant the alginate stops flowing from the holes, they are covered with the hands or fingers to prevent further leakage. Any excess alginate can be smeared about the proximal brim to perfect the fit in this area (Figure 5). This procedure must be conducted quickly and precisely or air pockets will occur. If air pockets do occur, we have found that additional algination attempts have been unsuccessful.

Total Surface Bearing Model Modification

The antero-posterior and medial lateral are modified exactly to residual limb measurements. The anterior modification of the antero-posterior is markedly different from the PTB "Bar." The TSB modification follows the shape of the anatomy in this region as shown in the xeroradiograph of the below-knee amputation (Figure 6).

Notice that the shape of the tibia angles posteriorly immediately above the tibial tubercle. Plaster removal follows this shape. The inferior edge of the patellar area is modified as though the patella were being lifted proximally about 1/4″. In other words, the true tibial plateau is below the inferior edge of the patella in most cases (Figure 7). The posterior aspect of the model normally requires only smoothing or only slight reduction to establish the correct AP.

Plaster is removed from the posterior aspect of the medial flare of the tibia. This half moon shape sweeps into the medial hamstring area. Up to 3/8″ of plaster may be removed in a very redundant residual limb. It is not unusual to see a medial hamstring 1/2″ to 3/4″ lower than the

Figure 6. Xeroradiographic lateral view of below-knee amputation. Notice the shape proximal to tibial tubercle.

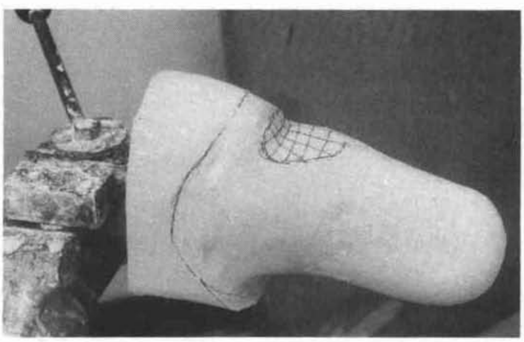

Figure 7. Modification inferior to patella simulates shape of anatomy rather than "PTB" patellar bar.

lateral side. Generally, the lateral side hamstring can be kept almost at tibial plateau level and is maintained at this level across the popliteal fossa.

Absolutely no buildups are applied to the crest of the tibia, the head of the fibula, the anterior distal aspect of the tibia, or any other bony prominences. Reliefs are created by removal of plaster from around these areas to accentuate their shapes and to compress the tissues. Usually no more than $1/8''$ of plaster is carved away using a curved blade flexible knife (Figure 8).

The model is next measured for circumferences using the previously established bony landmark as a guideline for accurately locating the measurement levels (Figure 9).

It is generally found that the model at this point will be approximately at the residual limb measurement or somewhat larger, even if fairly liberal modifications have been performed. If the model were to be smoothed and a socket fabricated at these measurements ($0''$ to $+1/8''$) it will result in about a two-ply heavy cast sock fit or about one "Socket Liner Stump Sock."[18] However, this may not in itself achieve suction.

In order to create a suction fit, the model must be carefully reduced in its circumferential measurements starting from a point approximately one inch above the tibial plateau and proceeding distally the entire length of the cast. As a beginning, a minimum of $1/2''$ of tension reduction less than the patient's measurements is applied at each measured level. Ultimately, in a new patient (any patient who has never

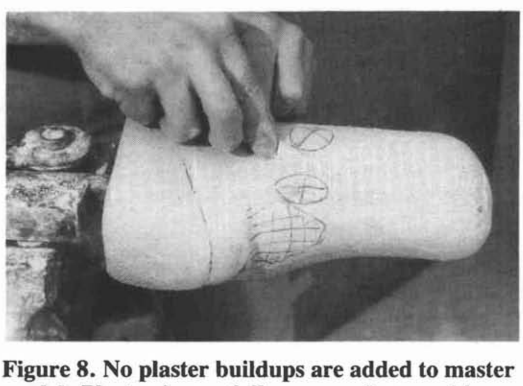

Figure 8. No plaster buildups are added to master model. Plaster is carefully removed around bony prominences and over bony prominences.

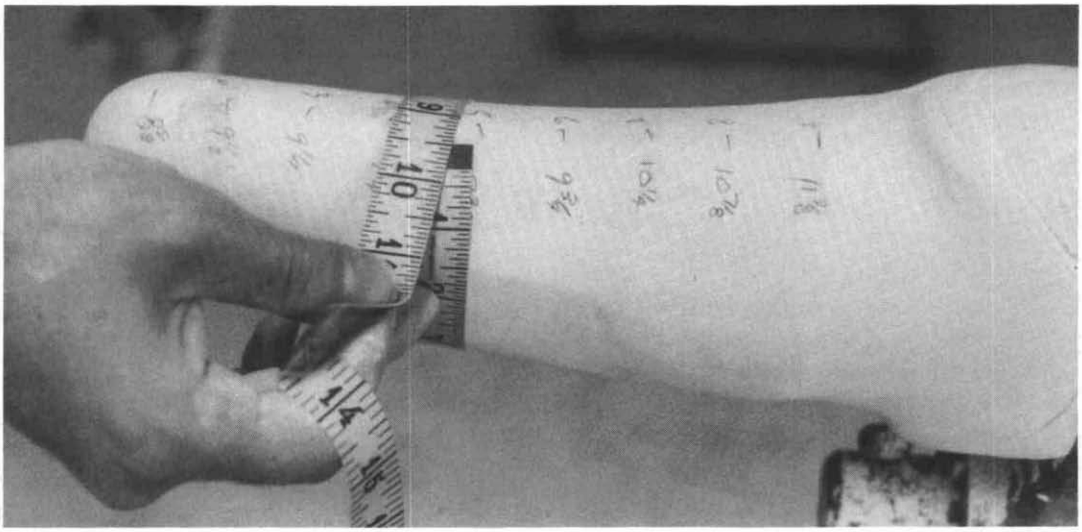

Figure 9. Circumference measurements of master model are reduced below patient measurements to achieve suction.

worn a suction socket) the tensions may well reach ¾″ to 1″ less than the original anatomical measurements. However, it is not a simple matter of initially bringing the tensions on the model to these values. This is inadvisable and potentially harmful for the patient. A gradual reduction process over time must be followed in order to achieve the results just stated.

In pilot studies and in pilot courses conducted at UCLA in 1984, an attempt to empirically arrive at appropriate TSB suction tension values was made. Each prosthetist was asked to carefully record how much reduction in residual limb measurements was required to finally achieve suction suspension. The compiled results of these efforts suggest an initial tension value of ¾″ is necessary at each level to achieve suction. This value may vary depending on residual limb musculature, length, and tissue type.

Check Sockets

It is advisable, if not imperative, to use transparent check socket fittings to confirm the accuracy and precision of the wrap cast and subsequent model modifications. The UCLA technique involves two types of check sockets: flexible check sockets and more conventional rigid check sockets.

The Flexible Check Socket

A check socket is vacuum formed using ⅛″ Surlyn® plastic. On a five to seven inch residual limb this will result in a very thin socket probably no thicker than 1/32″. A valve is located distally to release air from the socket as it is donned (Figure 10).

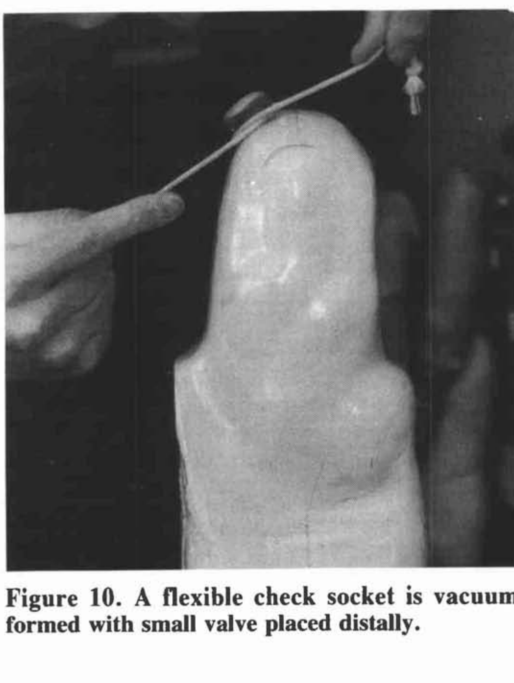

Figure 10. A flexible check socket is vacuum formed with small valve placed distally.

Figure 11. The flexible check socket is "wet" fit to the patient.

Figure 12. Suction, total contact, volumetric and anatomic accuracy of check socket are determined in the flexible check socket.

Lotion or Vaseline® is used to lubricate the surface of the residual limb to aid in donning[19] (Figure 11). Flexible socket fit can be confirmed by direct palpation of the anatomy from the outer surface. Any air spaces or otherwise loose areas are located and subsequently corrected on the model. It is not unusual for this flexible socket to hold suction even if inadequate tensions were applied to the model (Figure 12).

Accordingly, if the socket is made rigid by an application of a roll of fiberglass casting tape to the outer surface, suction will invariably be lost almost immediately. This demonstrates one of the many problems facing anyone wishing to fit or wear a suction below-knee prosthesis. The flexible socket in this case is exhibiting atmospheric suction. The socket collapses around the residual limb as any attempt is made to remove it. Rendering the socket rigid transforms this flexible membrane into a rigid socket and as the socket wall cannot move, suspension is lost.

The Rigid Check Socket

A rigid check socket may be used after the model corrections, determined by the fit of the flexible check socket, have been performed. With the rigid fitting, it is common to find the need to increase tension values to an average of ⅝" to ¾". It must be assumed that fluids rapidly leave the residual limb as a more rigid, accurate fitting socket is applied. It might also be speculated that the muscles flatten out somewhat as excess fluid leaves the residual limb. Examination of residual limbs in properly fit rigid transparent suction check sockets after several hours of wear reveal good color and lack of a distal discoloration which one might expect in a "tight" socket.

Socket Materials

A variety of materials and fabrication techniques have been examined for their application to the suction socket. Varying levels of success have been achieved; however, there are usually trade-offs involved. Suction may be achieved with a removable liner/insert alone that keys into the prosthesis much like a liner in a PTB socket. A prosthesis may also be constructed with a hard suction socket with no liner or with a soft liner that is permanently attached. In any case, some type of valve is usually necessary, installed either in the liner, in the socket, or at the end of a tube extending from the distal end of the socket to the outside finish lamination of the prosthesis. Valveless liners are also possible; they will be discussed later.

In considering a method of constructing a suction socket, it is important to realize that there will be no sock to absorb moisture; the patient will likely require some type of powder, cream or lotion application to don the socket, and the skin will be in direct and intimate contact with the inner material. All of these factors dictate a non-porous, easily cleaned material that will minimize the growth of bacteria, yet provide the necessary cushioning and comfort for daily or specialized activities. Whichever approach is taken, the prospects of success are limited only to the ingenuity of the prosthetist and the materials employed.

Hard Socket Variations

This is perhaps the most difficult variation with which to achieve success since the demands of precision required for fit and comfort are the highest. Firm residual limbs of good muscle mass are the most likely candidates for this design.

The hard socket is undoubtedly the easiest to fabricate, and for the patient is the easiest to keep clean. Even if accepted by the patient, these sockets will feel hard and, while suitable for walking, they are probably not appropriate for heavy activities such as running. However, hard sockets, with the addition of a single nylon sheath, have been very successful in the long-term with low activity level patients. Flexible acrylic and polyester laminates backed on the outer surface with soft foams such as PE-LITE™ or Aliplast™ have enjoyed about the same level of success as a hard socket. Patients report that these sockets feel hard despite the padding. Additionally, allergic skin reactions seem to be more common when flexible resins are used. Minute cracking in the interface may create a breeding ground for bacteria or lead to skin irritation through surface friction.

A number of thermoplastic liners have been successfully fit (Figure 13). Some have been quite comfortable, notably the "total flexible brim" variation suggested by IPOS[20] and Sabolich.[7] Both are frame-supported polyethylene designs. Since thermoplastics may exhibit "cold flow" and may actually shrink, they are not ideal materials. An interesting characteristic of thin thermoplastic sockets is the enhanced capability of atmospheric suction. However, this advantage is basically negated by a lack of long-term durability. The suggested ease of refabrication and/or inexpensive nature of replacement does not hold up to criticism by patient used to no-nonsense prosthetic care. Another negative characteristic of thin thermoplastic liners such as Surlyn® and polyethylene is the inability to make adjustments after fabrication.

A major point of consideration in fitting any socket material that directly contacts the skin is the coefficient of friction at the interface. There are definite differences which are recognized empirically and clinically, but not objectively related to prosthetic fit in the below-knee as well as in above-knee suction sockets. For example, Surlyn® and Durr-Plex both seem to have a surface which adheres very well to slightly damp skin. When these surfaces are lightly sanded, they lose some of this gripping capability. This can be both a positive and a negative factor, depending on the skin tolerance of the patient involved.

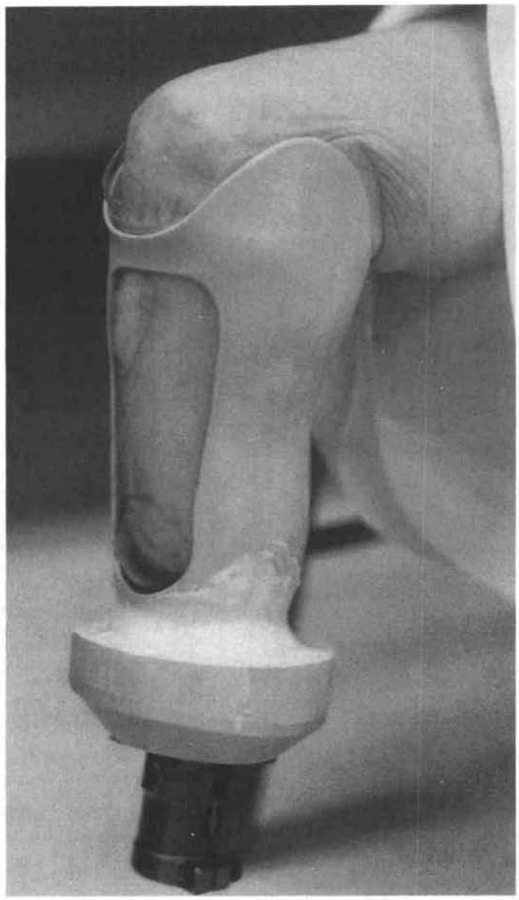

Figure 13. Surlyn® inner flexible socket with outer frame fitted in 1985 as a suction below-knee prosthesis.

Generally, hard socket variations of suction below-knee prostheses, while feasible, are not very practical for most patients. Moreover, the instance of inadvertent loss of socket suction must be expected. This is not really considered a problem since we recommend that auxiliary suspension be worn even on the best suction below-knee fitting.

Figure 14. Pelite™ liner with Plastozote distal end, distal valve and Surlyn® outer shell fitted as suction below-knee prosthesis in early suction below-knee courses at UCLA in 1985.

Figure 15. The TSB Suction below-knee can be fitted on almost any length below-knee residual limb. Auxillary suspension is not shown in this diagram but is recommended for all suction below-knee wearers.

Soft Socket Variations

Early suction liners were made of leather backed with Neoprene®. Even when given a sealant coating, the leather will begin to deteriorate and develop offensive odors in a fairly short period. However, good comfort has been achieved as has adjustability. Replaceability is not really possible in this variation.

PE-LITE™ and Surlyn®-backed PE-LITE™ have both been successfully used for soft suction liners (Figures 14 and 15). It wears fairly well and can be cleaned with baking soda, vinegar, or rubbing alcohol to eliminate both odor and dirt. These liners will likely pack-out in time, and thus, normal prosthetic delivery should include a duplicate. Replacement duplication after wearout of thermoplastic foam liners is not really practical to the level of precision necessary to maintain suction.

Another major advantage of these materials is that they may be easily added to or otherwise adjusted. By use of selectively placed materials of varying durameters, comfort can be achieved in very bony patients and those with poor skin conditions. It is important to further note that some foams are not closed cell and will, therefore, permit moisture, dirt, and bacterial buildup which may not be easily removed. However, coatings have been developed which may solve the interface cleansing problem. Additional considerations in the use of a liner coating are potential allergic reactions, alteration of friction and shock absorption characteristics of the liner material, and adequacy of adherence.

Foam liners, it must be remembered, provide comfort by absorbing load forces of axial, shear, and torque. The shock of impact is absorbed in the compression of the foam or in the compression of the gases within the individual cellular structure of the foam. Any buildup of heat within a liner could lead to problems for the patient in an intimate suction fit.

In summary, soft foam liners are very practical from the point of view of comfort and the ability to adjust to maintain fit. Their major drawbacks are that they change shape with wear and they do get dirty and smell if not meticulously cleaned daily.

Three known types of silicone liners are presently in use or in experimentation at this time. Koniuk[21] reported fabricating cast silicone liners (Figure 16) which can be later duplicated from the same mold. There have been some problems with tearing of these liners in early phases of development, but this is viewed as a materials problem only. Early liners were fairly thick and heavy which can be detrimental. Some problems of skin reaction to direct contact with silicone have been reported. Since silicones are relatively inert, skin irritation most likely may be attributed to friction between the skin and the liner. It may actually be holding the skin too well. Some patients may also be allergic to the catalysts used in the preparation of the silicone elastomer.

Experiments with very thin laminated sheath-like silicone liners have been attempted with some positive initial results. However, adjustments are not possible because of the inability to cement to the material, a characteristic of the entire silicone group. Bedouin has reported using fills between the socket liner and the outer lamination as a means of reestablishing lost suction.

Kristinsson[8] has demonstrated a preformed silicone liner which either rolls on or is pulled on the residual limb. The effect is to create distension of the distal tissues. Some problems have been seen in initial demonstrations, among which are tearing of the liners during application, some discomfort by patients with a hairy limb, and heat build-up. It may be too early in the development of these direct-contact silicone liners to determine with fairness their

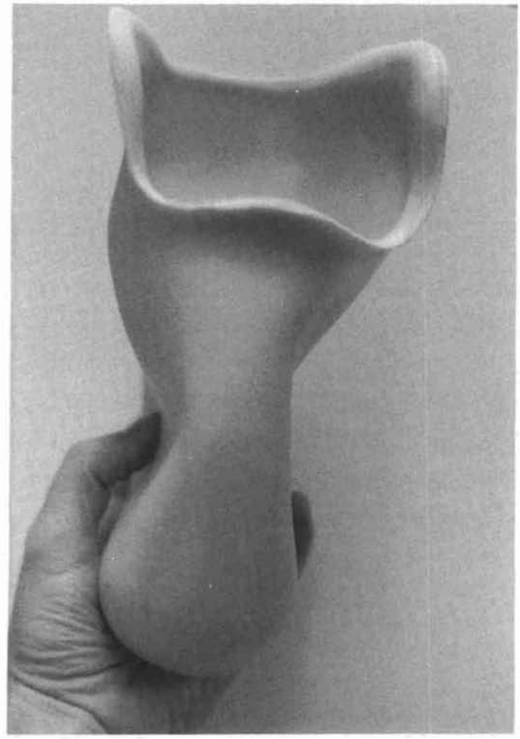

Figure 16. Silicone below-knee socket liner with expulsion valve installed.

ultimate practicality. It is certainly true that lack of adjustability will likely continue as a source of considerable concern.

A relatively new system, the PM Liner, developed by Peyton Massey[22] has been used as a suction below-knee liner. While proprietary in nature, it appears to be a vinyl-like foam which may be heated and formed with ease directly over the below-knee model. It has the comfort and padding of silicone but is much easier to work with and does not migrate as is the tendency with some silicone materials. Massey has been adapting this liner for use with adhesives so as to make it possible to glue patches of similar material to the PM Liner.

A new concept in liners under development, called the Socket Liner Stump Sock,[18] offers an additional variation for potential use with a suction below-knee prostheses. It is a neoprene sock that is fabric-backed on both sides. When properly fitted, it maintains suspension by compression. The problem with this variation at present is that the smooth surface of the cloth outer face of the liner against the smooth inner socket surface does not provide sufficient friction to hold suspension. A coating is under development to resolve this problem. This liner offers an excellent compromise for the patient wishing to have an intimate TSB fit without complete suction. There is reportedly very little or no motion between the liner and the residual limb.

Suction Below-Knee Valves

Several specialized valves have been developed for the suction below-knee prosthesis although any valve can probably be used. An important feature in a valve for suction below-knee application is air expulsion capability. With such a valve, the patient simply forces his residual limb into the socket to expel the air through the distal end. Problems experienced with all valves have been accessibility and leakage brought on by inability to securely bond the valve seat to the liner.

Auxiliary Suspension

As has been previously emphasized, auxiliary suspension is mandatory on all suction below-knee prostheses. Sleeve type suspension offers the best compromise of comfort, security, and maintenance of suction. Cuff suspension in all forms has been tried, but cannot assist in sealing the socket to the residual limb. Three types of sleeves should be considered.

The Latex Sleeve

This provides the best seal and the most positive suspension, but has the problem of skin irritation, durability, odor, discoloration, and loss of shape.

The Neoprene Sleeves

These offer an acceptable seal that, while not as positive as the Latex, are acceptable so long as the sleeve has been properly manufactured. Neoprene sleeves are similar to Latex sleeves with respect to skin rashes and durability. Daily cleansing with alcohol can greatly reduce the incidence to skin problems. Providing the patient with multiple sleeves and proper hygienic education will reduce the incidence of skin rashes.

Cloth Lined Neoprene Sleeves

While these sleeves do not work well for total suspension, they can afford a margin of back-up for good suction wearers.

Some Suggestions for Skin Problems

For any serious rashes or other skin conditions, the patient should always be directed to his physician. A number of techniques have been tried by patients to clear up simple rashes. One technique is to wear a "Baggie®" or a thin polyethylene sheet directly against the skin of the residual limb until the rash clears. Some patients wear this inner protection at all times as a method of preventing rashes which might be caused by friction. When used with sock fittings, this will keep moisture out of the sock, thereby helping to prevent skin maceration. Some athletic patients apply transparent surgical tape over areas that are known to be prone to skin breakdown during heavy sports activities. Some brands that have been successfully used include 2nd Skin™, Op-Site, and Bioclusive Pads®.

Conclusion

The suction below-knee prosthesis, while an excellent option for some patients, may for others be the triumph of valor over reason. Should the decision be made to proceed with suction, both the prosthetist and patient must be completely aware of the long and difficult route involved. There will be obvious changes in the residual limb following initial fit which will require socket adjustment and refabrication over an extended period. There will probably be the need for some experimentation with materials and fabrication methods to arrive at an optimum fit for the patient. However, once these factors have been resolved, the results of a well-fit suction socket will be a marked improvement in patient comfort, satisfaction, and in a prosthesis that the patient "feels" is more a part of his person.

If, on the other hand, suction is not a goal, the Total Surface Bearing casting and modification techniques that support a suction fit are entirely valid for every below-knee fitting regardless of the socket interface or method of suspension. In the view of the authors, these improvements over more traditional methods of below-knee prosthetics have been long overdue. Clearly, the superiority of Total Surface Bearing has been established and undoubtedly is the most important dividend of the research and education on suction below-knee fittings.

Authors

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References

[1] Murphy, E., "Lower Extremity Components," *Orthopaedic Appliance Atlas,* Vol. 2, J.W. Edwards, 1960.

[2] Radcliffe, C.W. and J. Foort, *The Patellar-Tendon-Bearing Below Knee Prosthesis.* University of California, Berkeley, Biomechanics Laboratory, 1961.

[3] Grevsten, S., *The Patellar Tendon Bearing Suction Prosthesis.* 1977 Functional Studies, Doctoral Thesis, University of Uppsala, Sweden.

[4] Bedouin, Leo, personal communication, Dan Muth Company San Francisco, California, 1981–March, 1987.

[5] Friestadt, Ake, "The Swedish Suction BK Prosthesis," presentation at UCLA Advanced below-knee Prosthetics Seminar, October, 1984. Contact Een Holmgren Co., Uppsala, Sweden.

[6] Murphy, E.F., "The Fitting of Below Knee Prostheses," Klopsteg PE, Wilson PD (eds), *Human Limbs and their Substitutes,* New York, McGraw Hill, 1954, pp. 693–735.

[7] Sabolich, J. and T. Guth, "Below Knee Prosthesis with Total Flexible Socket: Preliminary Report," *Clinical Prosthetics and Orthotics,* Vol. 10. No. 2, Spring, 1986, pp. 93–99.

[8] Kristinsson, O., "The ICEROSS System," lecture at UCLA Advanced Below-knee Prosthetics Techniques Seminar, Fall, 1986. Contact: Ossur hf. Reykjavik, Iceland.

[9] Holmgren, G., "The Patellar Tendon-Bearing (PTB) Suction Prosthesis," *Disability,* Strathclyde Bioengineering Seminars, August, 1978, MacMillian Press, Chapter 47.

[10] Grevsten, S. and U. Eriksson, "Stump-Socket Contact and Skeletal Displacement in Suction Patellar Tendon Bearing Prosthesis," *J. Bone and Joint Surgery,* 56, 1974, pp. 1692–1696.

[11] Fillauer, C., "A P.T.B. Socket with a Detachable Medial Brim," *Orthotics and Prosthetics,* Vol. 25, No. 4, December, 1971, pp. 26–34.

[12] Gleaves, J.A.E., *Moulds and Casts for Orthopedic and Prosthetic Appliances,* Charles C. Thomas Publishers, Springfield, Illinois, 1972.

[13] Tranhardt, T., "Trimlines for Prosthetics," lecture to California Association of Prosthetists and Orthotists, Lake Tahoe, California, Spring, 1978.

[14] McQuirk, A. and A. Morris, *Controlled Pressure Casting for PTB Sockets* (Teaching Manual), Hangers, Roehamptom Lane, London, England, 1982.

[15] Hayes, R., "A Below-Knee Weight Bearing, Pressure Formed Socket Technique," *Orthotics and Prosthetics,* Vol 29, No. 4, December, 1975, pp. 37–40.

[16] Stokosa, J., "Prosthetics for Lower Limb Amputees," in Haimovici, H., *Vascular Surgery,* Norwalk, Connecticut, Appleton Century-Crofts, 1984.

[17] Vinnecour, K., "Clinical Below Knee Prosthetics," lecture at UCLA Prosthetics Education Program Advanced below-knee Symposium, Fall, 1983.

[18] Cascade Orthopedics, Chester, California.

[19] Staats, Timothy, "Advanced Prosthetics Techniques for Below-Knee Amputations," *Orthopedics,* 8, 1985, pp. 249–258.

[20] IPOS Manual, "Below Knee Supracondylar Flexible Socket," IPOS-USA, Niagara Falls, New York, 1982.

[21] Koniuk, W., "A Pure Silicone Below-knee Socket Liner," lecture at American Academy of Orthotists and Prosthetists at San Francisco, California, Winter, 1986.

[22] Mr. Peyton Massey, New Life Laboratory, Santa Monica, California.

Suggested Readings

Roberts, Ruth, "Suction Socket Suspension for Below-Knee Amputees," *Archives Physical Medicine and Rehabilitation,* Vol. 67, March, 1986, pp. 196–199.

Grevsten, S., "Ideas on Suspension of Below-knee Prosthesis," *Prosthetics Orthotics International,* 2, 1978, pp. 3–7.

Grevsten, S., "Patellar Tendon Bearing Suction Prosthesis Clinical Experiences," (Uppsala) *J. Medical Science,* 82, 1977, pp. 209–220.

Grevsten, S. and L. Marsh, "Suction-type Prosthesis for Below-Knee Amputees: Preliminary Report," *Artificial Limbs,* 15, Spring, 1971, pp. 78–80.

Pearson, J.R., S. Grevsten, B. Almby, and L. Marsh, "Pressure Variation in Below-Knee, Patellar Tendon Bearing Suction Socket Prosthesis," *J. Biomechanics,* 7, 1974, pp. 487–496.

Murphy, E., "Sockets, Linings, and Interfaces," *Clinical Prosthetics and Orthotics,* Vol. 8, No. 3, Summer, 1984, pp. 4–10.

Schuch, M. and A.B. Wilson, "The Use of Surlyn® and Polypropylene in Flexible Brim Socket Designs for Below-Knee Prostheses," *Clinical Prosthetics and Orthotics,* Vol. 10, No. 3, Summer, 1986, pp. 105–110.

Kay, H. and J. Newman, "Report of Workshop on BK and AK Prostheses," *Orthotics and Prosthetics,* Vol. 27, No. 4, December, 1973.

Abrahamson, M., et al., "Improved Techniques in Alginated Check Sockets," *Orthotics and Prosthetics,* Vol. 40, No. 4, Winter, 1987, pp. 63–67.

Pritham, C., "Suspension of the Below-Knee Prosthesis: An Overview," *Orthotics and Prosthetics,* Vol. 33, No. 2, June, 1979, pp 1–20.

Holley, Teresa, "The Suction BK Prosthesis," UCLA Prosthetics Education Program term paper, 1984.

Clinical Prosthetics and Orthotics, Vol. 11, No. 3, pp. 131–153

Upper-Extremity Prosthetics: Considerations and Designs for Sports and Recreation

By Bob Radocy

The population of upper-extremity amputees, including congenitally limb-deficient persons, in the United States and abroad is placing increased demand upon the profession for improved prosthetic designs and devices which will allow its members to participate competitively in sports and recreation activities.[1,2,3] Recreation trends indicate that these demands will most likely increase.

Until recently, prosthetics did not directly address the needs of the sports-oriented amputee. Prosthetic designs focused on domestic and vocational needs and did not necessarily target the criteria necessary to perform in the vigorous environments of sports or recreation. Over the years, select prosthetists working with individual amputees have developed "one of a kind" sports devices for their patients. These devices sometimes proved adequate, but most were never made available commercially.

Two commercially available sports terminal devices have been available for many years: the Baseball Glove Attachment and the Bowling Attachment.[4] Recently, other specialized prosthetic devices have become available to meet the sports-minded amputee's needs. These are the SUPER SPORTs,[5] Amputee Golf Grip,[6] and the Ski Hand.[4] Additionally, new variations in the designs of body-powered terminal devices are allowing amputees to participate in many sports activities without the need for specialized aids or radical modifications.[7,8]

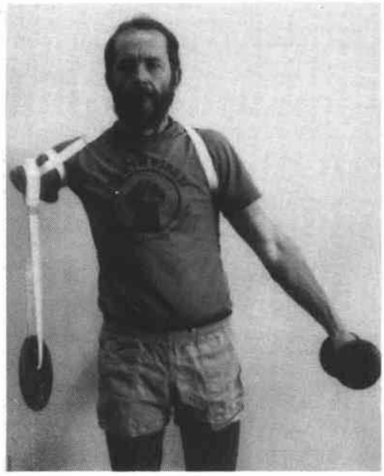
The measure of performance by the amputee in any activity, as always, depends upon proper limb design. Socket design, materials, alignment, and components all play a vital role in any amputee's ability to perform competitively. Another important factor is the amputee's physical condition. The prosthesis, no matter how well designed and constructed, cannot supplement atrophied muscle, limited range of motion, or inadequate strength.

Sports prosthetics begins with the evaluation of the need and of the capacity of the amputee being served. A physical therapist and potentially a clinic physician will be important components in the rehabilitation of an amputee wishing to become active in sports and recreation.

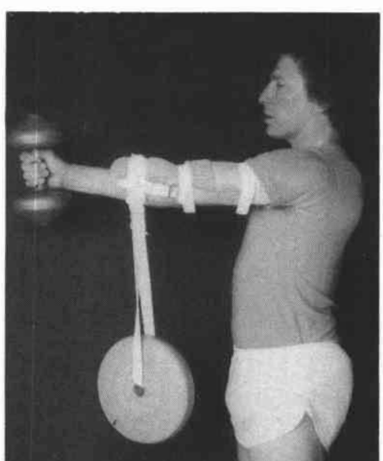
Exercise and conditioning with or without a prosthesis will be required as a preliminary step for an amputee who wishes to excel without injury in sports. Exercise can take multiple forms. Proven exercise techniques exist. Isometric, isotonic, and passive and active resistance all have specific goals and methods. Education is required so that the amputee is knowledgeable about how to proceed with an exercise program and to determine the objectives, i.e. is muscle hypertrophy (bulk) required for strength or is muscle endurance more appropriate? Additionally, how are flexibility and range of motion impacted?

Preprosthetic exercise may be required or desired. Weight harnesses[9] (Figures 1, 2, and 3) rather than strap or cuff weights are a better way to approach exercise without a prosthesis. A properly designed harness will prevent weight slippage during exercise and will enable many variations of upper-extremity conditioning (Figures 4, 5, and 6).

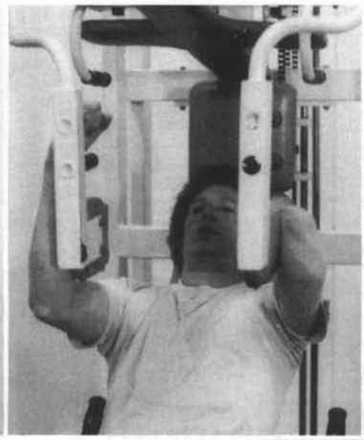
Bilateral exercise using a dumbbell on the non-affected side is important to maintain muscle balance and reduce spinal stress. A full



Figures 1, 2, and 3. Weight harnesses, rather than strap or cuff weights, are a better way to approach exercise without a prosthesis.



Figures 4, 5, and 6. A properly designed harness will prevent slippage during exercise and will enable many variations of upper extremity conditioning.


Figures 7, 8, 9, (above) and 10 (right). Certain weight machines also allow for non-prosthetic exercise, but exercise will be limited to certain muscle groups.

length mirror aids the amputee in viewing him or herself in order to correct postural deficiencies or extraneous movements to optimize resistance exercise efforts.

Certain weight machines also allow for non-prosthetic exercise, but exercise will be limited to specific muscle groups (Figures 7, 8, 9, and 10). Complete upper-body conditioning will be most effectively accomplished while wearing a prosthesis. Furthermore, exercise while wearing a prosthesis will help condition the residual limb to the skin stresses and shears a prosthesis will create when under load. Modern exercise equipment systems, such as Nautilus, Hydra-Fitness, and Universal, are available virtually everywhere in YMCAs, community recreation centers, health and sports clubs. A planned program for the amputee can be structured by professional instructors to the amputee's goals. Free weights are another alternative or can complement a weight conditioning program with the convenience of low cost and home use. Equipped with a proper terminal device (Figure 11), an arm amputee can safely handle dumbbells or barbells in weight training.

Proper conditioning balanced by flexibility achieved through passive stretching, aerobics or any number of alternatives will result in the range of motion and strength an amputee will need for high performance in sports and recreation. A regular conditioning program will

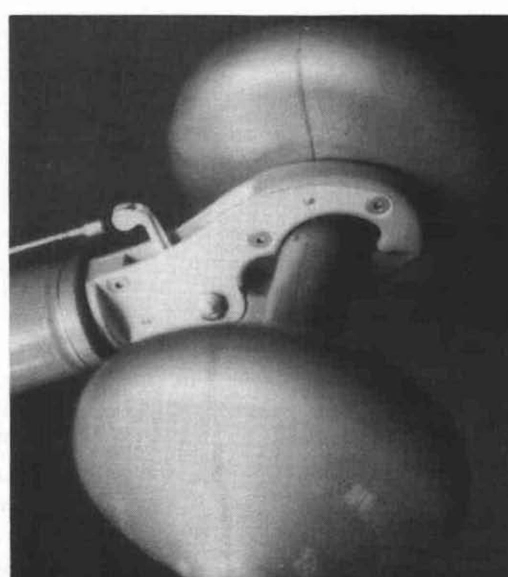


Figure 11. Amputee lifting dumbbell with a terminal device.

especially enhance the use of body-powered prostheses which require activation through body-controlled movements.

Sound limb design, mentioned previously, is a major component in an amputee's performance potential. Lightweight yet strong prostheses are ideal, but strength should not be sacrificed just to achieve reduced weight. Socket design is dictated to a certain extent by stump configuration, but it is the author's belief that, if at all possible, a supra-condylar socket should be used.[10,11] Supra-condylar sockets with all their variations (Muenster, Bock, etc.) have evolved rapidly with advances in electromechanical limbs. A supra-condylar socket need not be unduly restrictive, and such a limb allows for less complicated harnessing.

Carbon fiber and acrylic resins are two materials which lend well to the lightweight but high strength prosthetic objectives. Socket padding,[10] whether fully or partially lined, aids in protecting the condyles, olecranon, and distal residual limb end from trauma. If adequately reinforced, ISNY[12] style sockets may prove to be applicable for sports as well, but the published data on below-elbow applications is scarce.

In addition to padding, the author recommends a heavy residual limb sock or two regular weight socks for most sports activities. Highly absorbent terry lined socks (designed for athletic footwear) are excellent. A polypropylene sock can be used effectively as a liner if heavy perspiration is a problem.

An adjustable excursion harness,[13] such as the modified Northwestern (Figure 9) which allows for excellent range of motion and terminal device control, can be applied, although other designs will work. Rapidly adjustable excursion is a plus for actuation of voluntary closing terminal device systems and in sports where gross motion of the arms is required, i.e. archery, golf, baseball, etc. Cable efficiency may also be targeted for consideration. Several experienced amputees known to the author wax the stainless steel cables before assembly into the cable housing. The wax is clean and reduces cable to cable housing friction, thus improving efficiency.

Alignment of the prosthesis on the residual limb also requires consideration, depending upon the amputee's sports needs. Preextended, as opposed to preflexed, socket designs have useful applications in sports. They allow for full elbow extension while limiting flexion only slightly and usually not unacceptably. Wrist alignment is also of consequence and affects the manner in which the prosthesis torques on the residual limb when load is applied. It is important to emphasize the need for prosthetists to be concerned with dynamic forces on the prosthesis. A mere static fitting with a check socket will not suffice because it doesn't accurately duplicate what will occur in the definitive prosthesis. A secondary fitting session with a foamed, but unlaminated, prosthesis donned and the chosen wrist unit and terminal device in place can determine the optimum alignment of the components. Changes can be made accordingly and retested so that the definitive prosthesis will fit correctly. Testing the prosthesis in this manner will also determine if undesirable trim lines exist in the socket or whether extended padding is required. A supra-condylar fit socket on short residual limbs can cantilever on the epicondyles and cut in proximal to the olecranon when the prosthesis is loaded distally making it impossible to carry any significant load (Figure 12). Extending the trim line can direct pressures to the back of the humerus instead of into the joint.

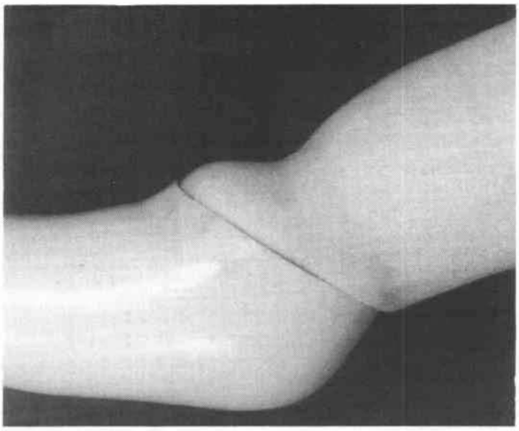


Figure 12. A supra-condylar fit socket with an undesirable trim line.

Two other techniques which can aid in creating a more suitable sports prosthesis are external padding and suspension sleeves. Nylon covered neoprene rubber, such as a diver's wet suit material, is readily available and makes an excellent "stretch to fit" cover for a prosthesis (Figure 13). Thicknesses from

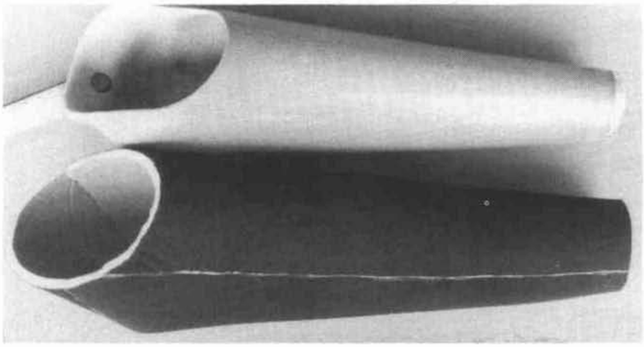


Figure 13. Nylon covered neoprene rubber, such as a diver's wet suit material, is readily available and makes an excellent "stretch to fit" cover for a prosthesis.

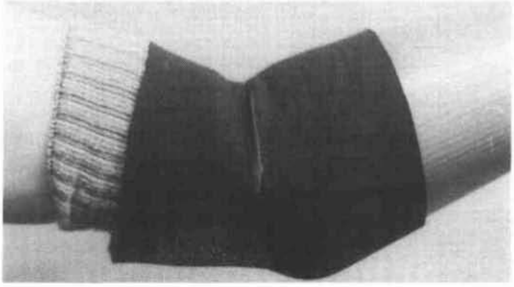


Figure 14. Both latex and neoprene sleeves designed for below-knee amputees are available and can be modified for upper extremity use.

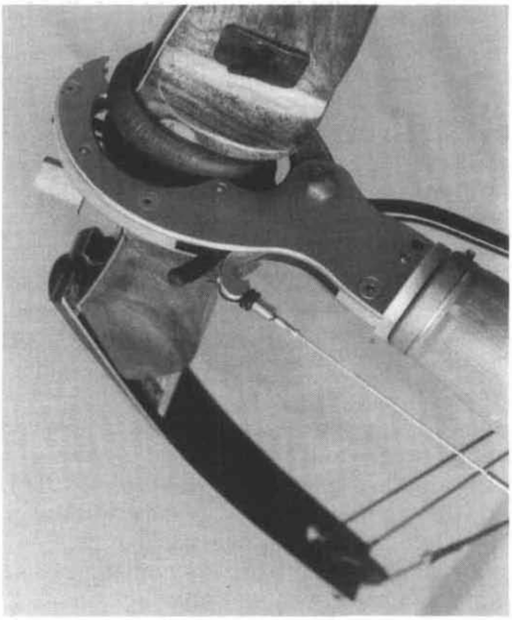


Figure 15. A bow riser (handle) can be modified to create a functional bow grip.

3 mm to ¼″ are available. The material provides a good cushion for contact sports, helps reduce limb trauma during a fall, and the thicker materials have enough bouyancy to float a prosthesis. This technique has satisfied the requirements for a padded prosthesis in several school systems around the country.

Suspension sleeves can improve a supra-condylar fit, especially when using a passive recreational device where the cable is absent or does not play a role in prosthetic suspension. Both latex and neoprene sleeves designed for below-knee amputees are available and can be modified for upper-extremity use simply by cutting them down in length (Figure 14). The advantages of using a commercially available below-knee sleeve is that angulation for a joint is already built in. The author prefers neoprene due to its durability. Both cause increased perspiration within the socket. Designed properly, a neoprene prosthetic cover can function as a suspension sleeve as well.

The remainder of this article will focus on modifications for specific sports and recreation to which the author has been exposed either directly or indirectly. In some cases, the solutions are simple; in others, performance dictates a more complex technical solution. Photographs and drawings have been used as often as possible rather than the written descriptions to illustrate a modification, device, or technique. Activities are dealt with alphabetically for convenience sake.

Archery

Modern archery equipment is easily adaptable to certain types of terminal devices. Figure 15 illustrates how a bow riser (handle) can be wrapped with consecutive layers of rubber,

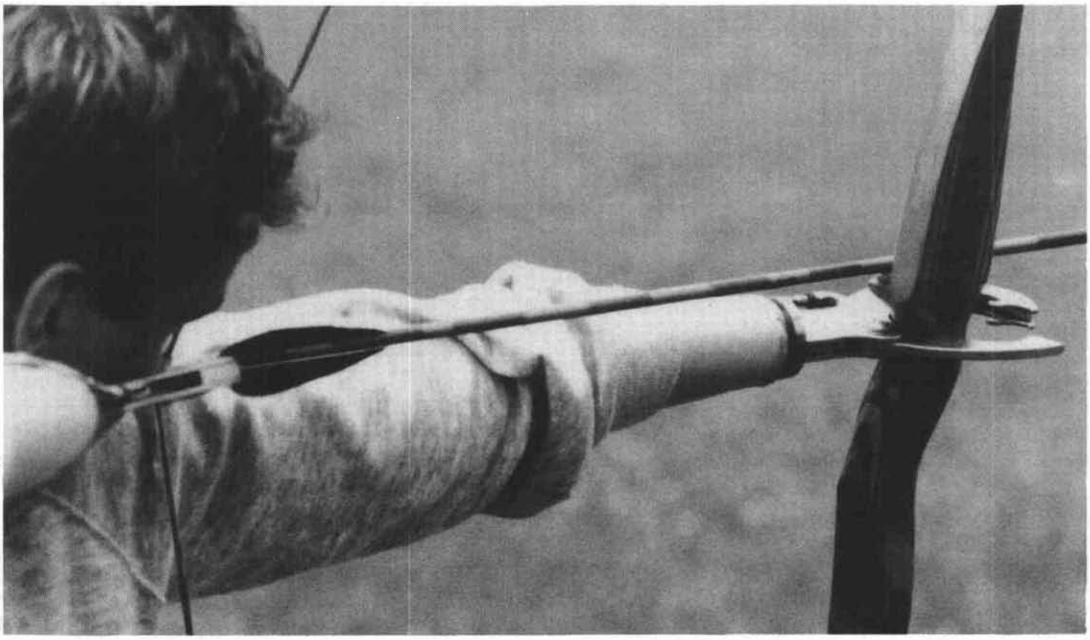


Figure 16. An amputee can simply hold on to the bow as shown.

foam, and bicycle inner tube to create a durable, functional bow grip.[8] A chuck or pin can be used to jam the thumb of the terminal device closed around the riser or the amputee can just "hold on" as illustrated by Figure 16.[14] Performance capabilities are exemplified by the amputee archer in this photo. He is a skilled hunter who has harvested three deer in a four year period.

Basketball, Soccer, Volleyball, and Football

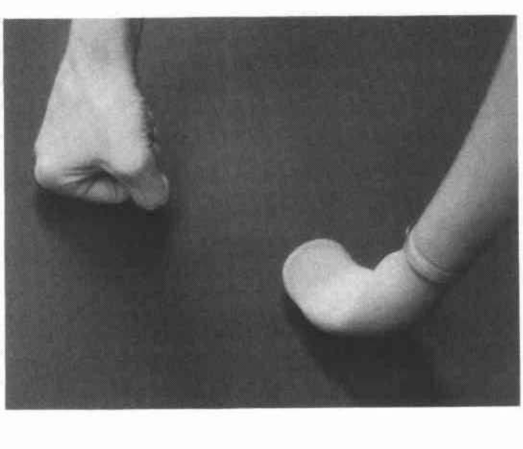
Until recently, aids for amputees in ballsports were limited to padded hooks, cosmetic hands, and custom one-of-a-kind terminal devices. Although these devices were useful, they rarely provided the type of high performance characteristics the sports-minded amputee required to compete successfully.

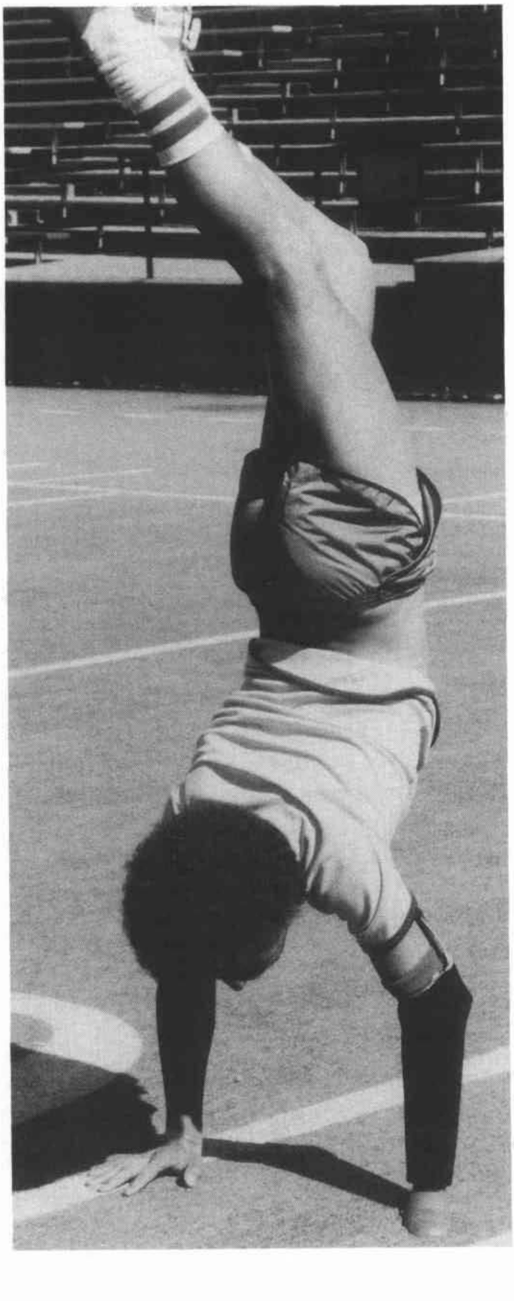
One possible answer or solution is now available. The SUPER SPORTs devices, sized for all ages, are designed specifically for ballsports and other rigorous recreations in which hand/wrist flexion/extension is needed. Additionally, they absorb shock as well as store and release externally applied energy (Figures 17, 18, and 19). SUPER SPORTs are passive, not cable activated, but are helpful in catching and ball control when used in opposition to an anatomical hand or another device. SUPER SPORTs combined with padded arm covers create a safe, effective prosthesis for sports, such as football, basketball, and soccer in which interpersonal contact is inevitable.

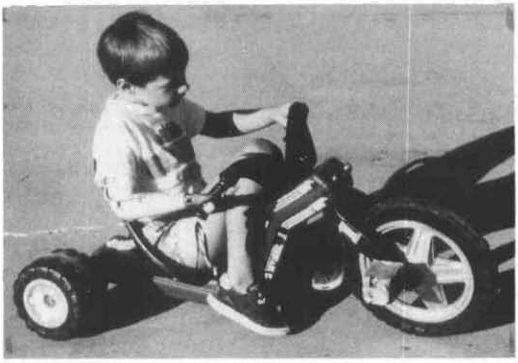
Bicycling, Tricycling, and Motorcycling

Bicycling or tricycling has proven to be an aggravation for amputees equipped with conventional style hooks. Lack of adequate gripping strength and finger shapes have hampered performance. Presently, however, children and adults equipped with newer style voluntary closing terminal devices (Figures 20 and 21) can control two or three wheeled cycles as well as their two-handed peers. No modifications are required except when hand brakes are present. Front and rear brakes can be actuated from a single hand lever. Brake pressure must be regulated so that braking forces are always applied to the rear wheel first for safe handling. Your local bicycle shop can usually solve hand brake complications.

Figures 17, 18 and 19. The SUPER SPORTs devices sized for all ages, designed specifically for ball sports and other rigorous recreations in which hand/wrist flexion/extension is needed.







Figures 20 and 21. Children and adults equipped with newer style voluntary closing devices can control two or three wheeled cycles as well as their two handed peers.

Special adapters have been designed for or by individuals interested in competitive bicycle racing (Figure 22).[15] The prototype illustrated is simple and is designed for safety to "quick disconnect" or "break away" at certain levels of force.

Motorcycling is a natural extension of bicycling. Again, hand brakes and, in this case, a clutch hand lever complicate the situation. Unilateral amputees missing their left hands can shift and clutch with one hand with practice. Brakes again can be combined. A single foot lever is practical for driving dual master cylinders for hydraulic brakes. The rear wheel braking must occur first however. A local motorcycle mechanic or custom motorcycle shop can provide ideas or adaptations and modifications to standard equipment.

Canoeing and Kayaking

The author's experience with conventional terminal devices proved frustrating during these types of recreation. Split hook finger shapes did not adequately adapt to a paddle or oar. Lack of prehension inhibited the bilateral arm function required for these activities. Locking type terminal devices should *never* be used in water sports activities. Figures 23 and 24 illustrate how new technology and minor modifications to paddles can overcome problems in canoeing.

Kayaking (Figure 25) with a double-bladed paddle requires only coordination and practice. Rubber rings on the paddle which are used to keep water off the central shaft work equally well in preventing terminal device slippage.

Gross arm movements, such as paddling or rowing, inherently activate voluntary closing devices and keep them closed. Rowing using an oar and oar lock can be enhanced by adding a stop or flange to the oar handle to prevent the terminal device from inadvertently pulling off during a power stroke.

Dance/Floor Exercise and Gymnastics/Tumbling

Activities, such as dance, tumbling and floor exercise gymnastics, have been treated similarly to ball sports in the past due to a lack of specialized terminal devices that were readily available. Padded hooks, cosmetic hands and

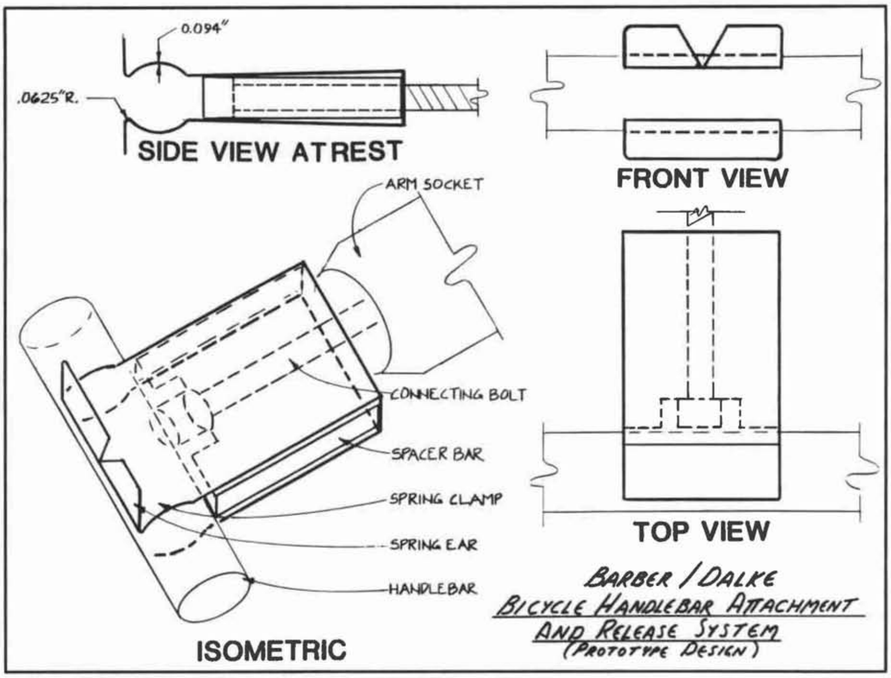
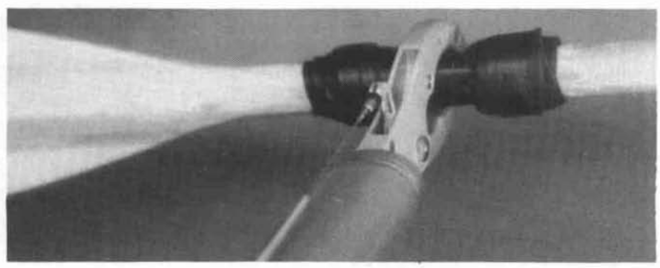


Figure 22. Special adapter for use in bicycle racing.



Figures 23 and 24. New technology and minor modifications to paddles can overcome problems in canoeing.

some custom pedestal style terminal devices have been applied to attempt to satisfy the amputees' needs for balanced bilateral function. Figure 26 illustrates how the SUPER SPORT terminal devices can be applied to satisfy these specialized recreation niches.

Fishing

Fishing is a sport and pastime everyone has access to and should be able to enjoy. Amputees using split hooks who wish to have improved control of reels might want to consider the Ampo Fisher I[16] which adapts to their prosthesis and reel (Figure 27).

Another alternative for the high level amputee is the Royal Bee Electric Retrieve Fishing Reel system (Figure 28).[17]

Amputees equipped with voluntary closing terminal devices do not require many modifications to fish. A handle modified with some rubber inner tube or tape is usually all that is required to operate a spinning or bait casting reel, due to the improved prehension of these types of terminal devices (Figures 29 and 30).

Casting with a prosthesis is awkward due to lack of wrist flexibility. Amputees usually control the pole with their natural hand then switch hands to reel or reel with the terminal device. Most reels are available in left and right handed models to suit various physical conditions.

Figure 25. Kayaking with a double-bladed paddle requires only coordination and practice.

Figure 26. SUPER SPORT terminal devices can be applied to satisfy specialized recreation niches.

Figure 27. Amputees using split hooks may want to consider the Ampo Fisher I which adapts to their prosthesis and reel.

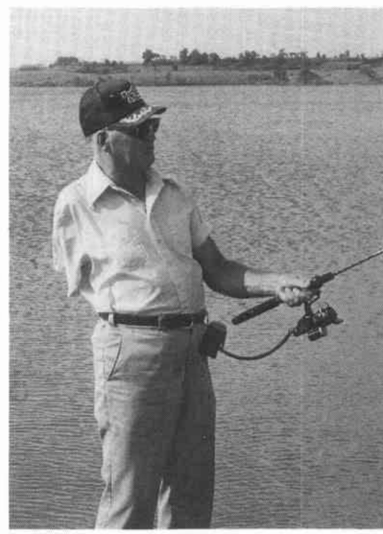
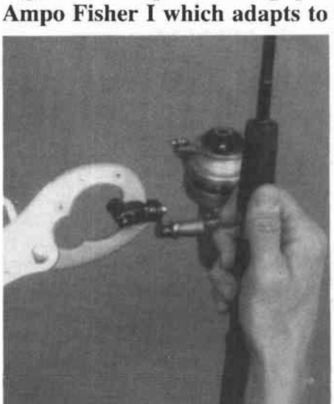
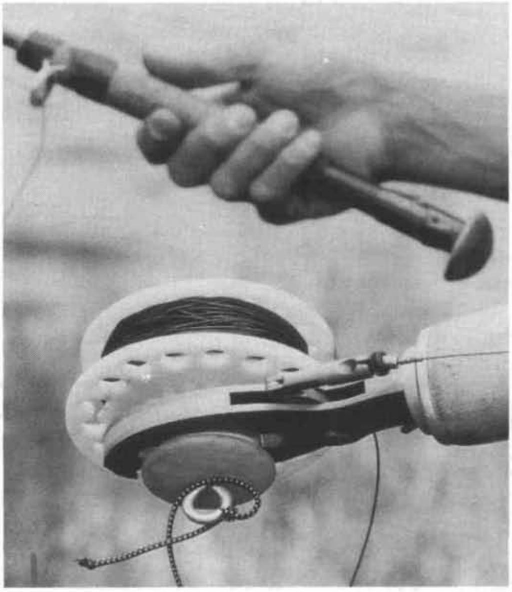
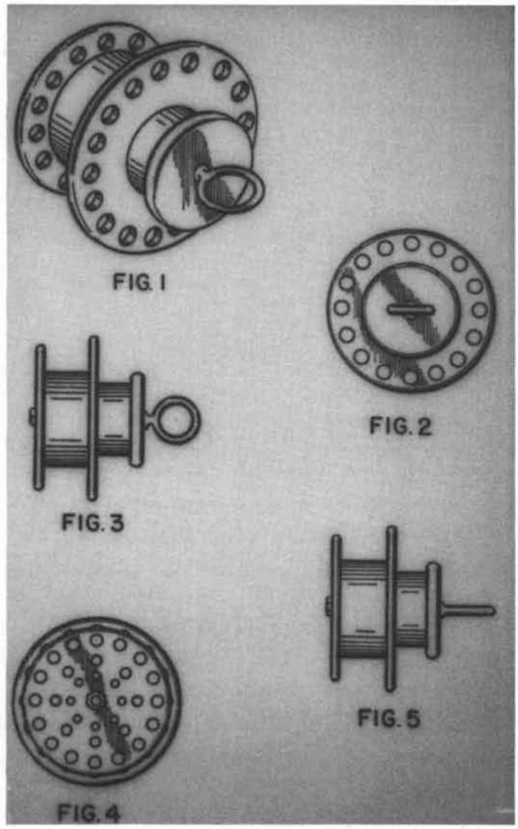


Figure 28 (above). The Royal Bee Electric Retrieve Fishing Reel systems.



Figures 29 and 30 (left). A handle modified with some rubber inner tube or tape is usually all that is required to operate a spinning or bait casting reel.





Figures 31 and 32. The Fly Fishing Reel for Amputees.

Fly fishing poses more of a challenge due to the two-handed dexterity required in handling the fly line. One alternative is the Fly Fishing Reel for Amputees[5] (Figures 31 and 32). This system has been used successfully, although the author feels there is still a need for improved alternatives.

Automatic fly reels have been experimented with unsuccessfully due to the difficulties involved in "pulling out line" to wind up the return spring in these reels. Additionally, it was discovered that the spring force was only sufficient to pull in slack line, not with line under drag or a fish engaged.

Golf

Due to its popularity, golf has rules (USGA 14-3/15) regarding artificial limbs established by U.S. Golfing Association for tournament play.

Variations in golf aids have evolved over the years primarily as individual designs to suit specific amputee's needs. Recently, however, a device called the Amputee Golf Grip (AGG)[6] has been introduced. The AGG is a standardized manufactured product which meets the USGA requirements (Figures 33 and 34). The device is somewhat similar to the Robin-Aids Golfing device[18] (Figures 35 and 36). Both devices utilize a flexible member to attach to the prosthesis and do not require club modification. They allow for *complete* wrist/club flexion and extension. The Amputee Golf Grip also allows for unrestricted rotation.

Other attempts to produce a functional aid should also be noted. One custom device is designed to have clubs attach directly to the prosthesis (Figure 37).[19] Similarly, another model, the Atkins Golf Aid,[20] also attaches into the end of the club, but uses a ball-socket swivel. The swivel allows for a limited degree of wrist/club, flexion/extension, and complete rotation.

The author has tried several devices and prefers those that do not require club modification and which provide for total flexion/extension/rotation at the wrist/club interface. This allows for a complete back swing and smooth follow through capability.

Figures 33 and 34. The Amputee Golf Grip is a standardized manufactured product which meets the USGA requirements.

Figures 35 and 36. The Robin-Aids golfing device.

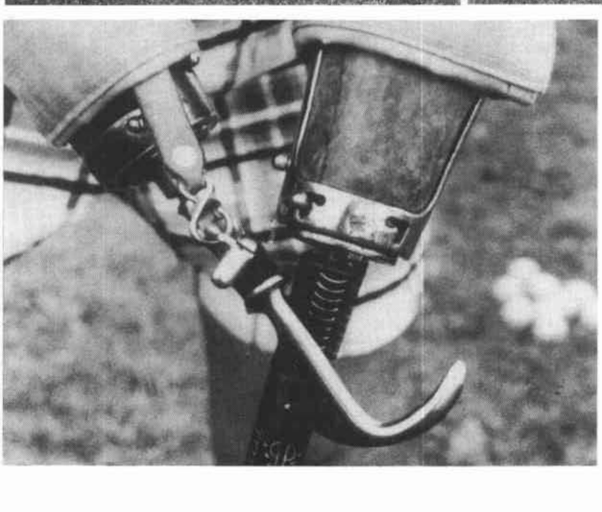


Figure 37. A custom device designed to have clubs attach directly to the prosthesis.

Figure 42. The SR-77.

Figure 43 (right). The Para-Quad shooting system.

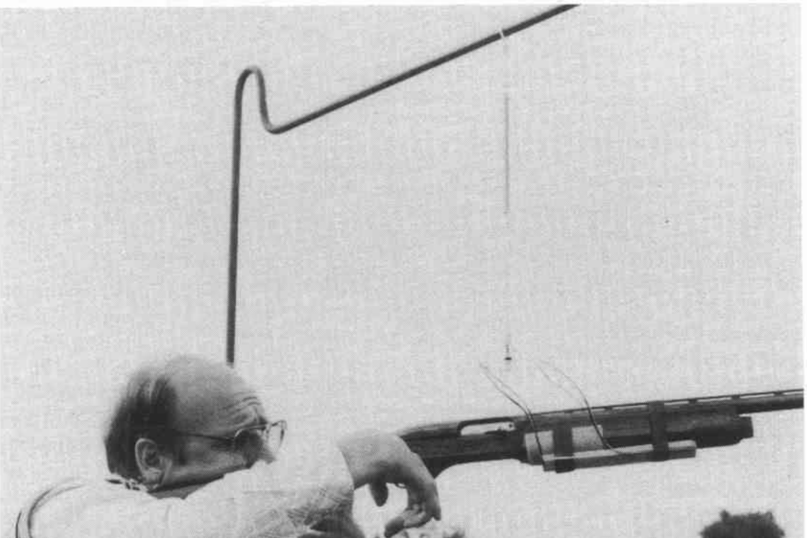


Figure 44. An over and under shotgun modified to shoot one-handed.

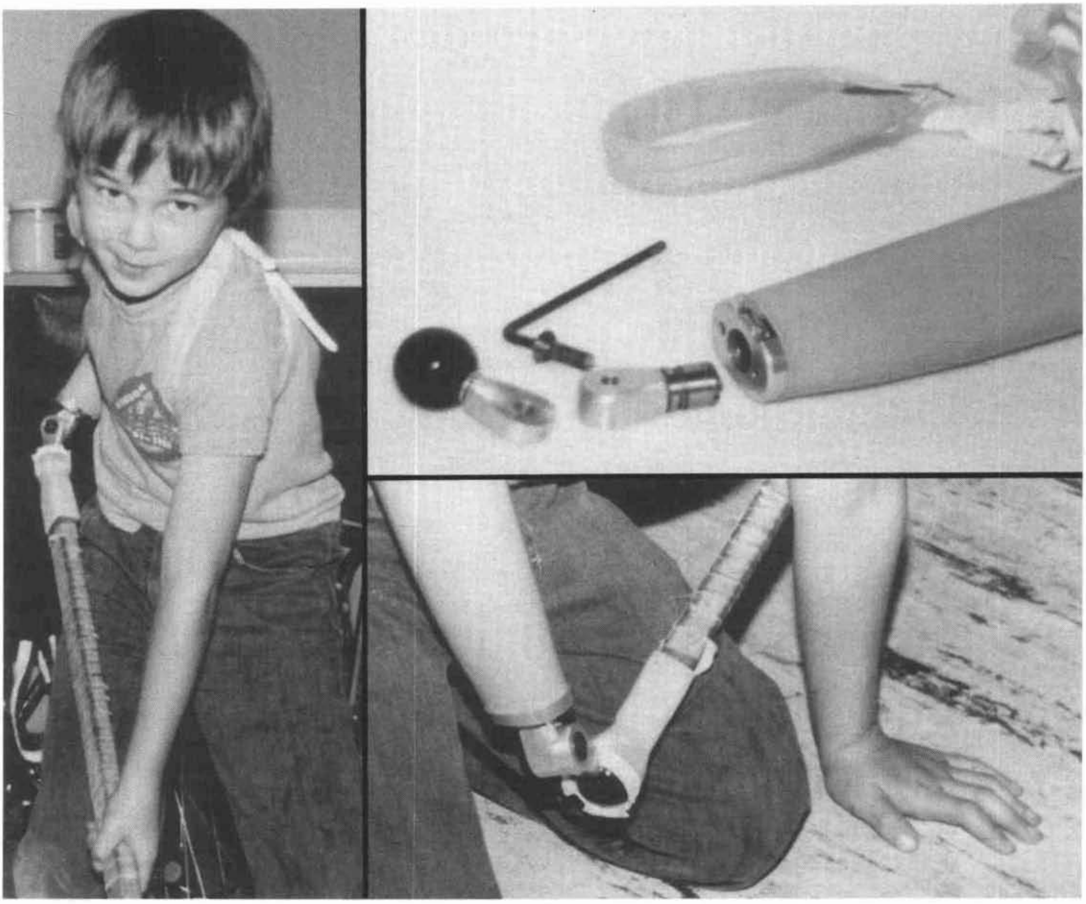


Figure 45. A terminal device for hockey developed in Canada.

Music

Information and devices to aid amputees playing instruments is scarce. Recently, however, information on a new guitar prosthesis was published in Canada[19] (Figure 48). Dan Roy, the guitarist, in conjunction with specialist Armand Viau have developed a prosthesis which allows Roy to use his shoulder to strum the guitar. The arm is lighter than a conventional prosthesis and can hold a guitar pick.

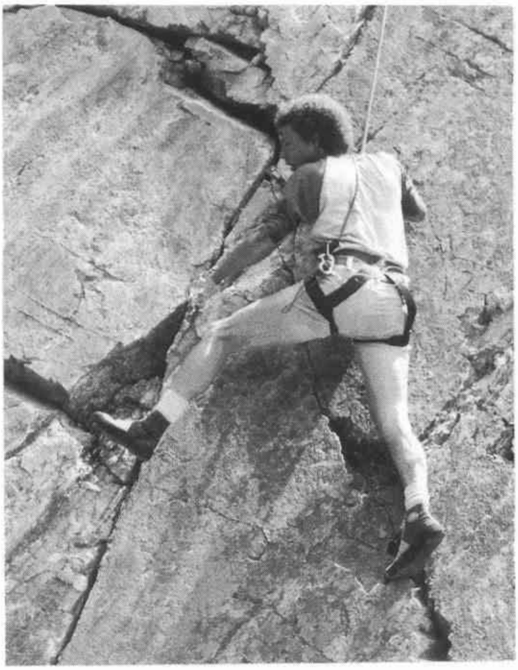
Figures 49 and 50 illustrate how some newer terminal devices, such as the ADEPT,[5] have proved to be viable solutions for children wishing to "play" musician.

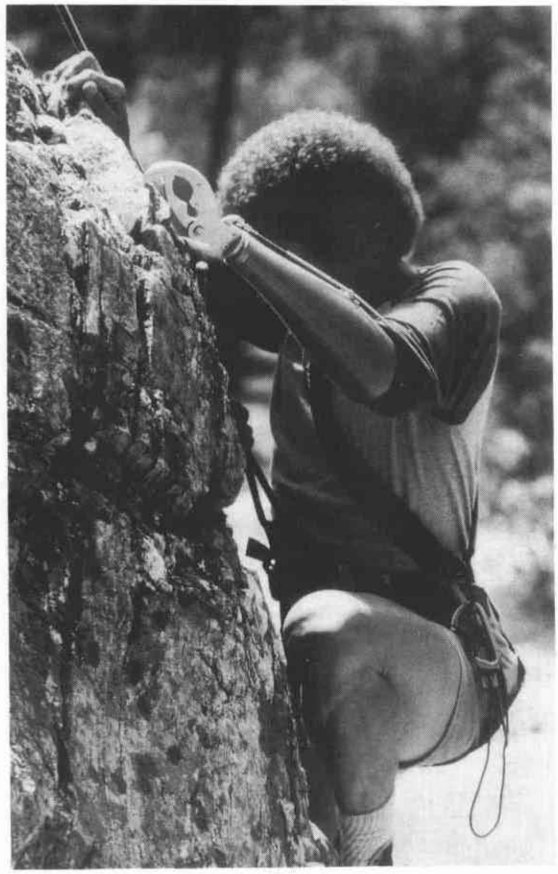
Photography

Custom photography and camera adapters have been fabricated for years. Now a device called the Amp-u-Pod[5] (Figure 51) is a standardized, manufactured product which has proved to be an extremely effective aid for the amputee photographer. Designed to replace the amputee's regular terminal device, the Amp-u-Pod mounts directly to the prosthesis and adapts to any 35mm, movie, or video camera equipped to receive a tripod.

Sailing

Amputees are less restricted in this recreation, but handling rope lines and other types of sailing gear can place demands on the sailor to have two-handed capabilities. Figure 52[22] illustrates a triple amputee who found a GRIP[5] terminal device to be one of his best assets for sailing.





Figures 46 and 47. The author during a technical climbing training session.

Figure 48. A new prosthesis which enables guitarists to strum their instrument using their shoulders.

Figures 49 and 50. Newer terminal devices, such as the ADEPT, have proved to be viable solutions for children wishing to "play" musician.

Figure 51. The Amp-u-Pod has proven to be extremely effective for amputee photographers.

Figure 52. A GRIP terminal device used for sailing.

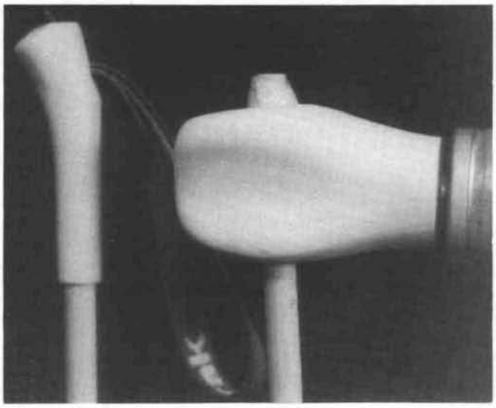


Figure 53. The Ski Hand.

Snow Skiing

Amputees have experimented with a number of ways to attach a ski pole to a prosthesis with little functional success. The Ski Hand[4] (Figure 53) is the first standardized manufactured terminal device designed specifically for skiing. Available in varying sizes, the amputee force fits the Ski Hand over a ski pole after removing the standard hand grip. The Ski Hand proved worthwhile for cross-country skiing where upper-body strength is required for propulsion. During downhill skiing, the author found the device of less advantage due to the shallow angle to which the pole enters the hand. The pole basket had a tendency to drag in the snow and was therefore more difficult to control. Novice skiers, however, will find the Ski Hand useful because it enhances maintaining balance and getting up after a tumble.

Swimming

Swimming for many upper-limb amputees requires no aid whatsoever. However, for those individuals who wish to perform better or compete in the water, several devices have evolved as custom, one-of-a-kind solutions. The Viau-Whiteside Swimming Attachment[19] (Figure 54) and the P.O.S.O.S./Tablada Swimming Hand Prosthesis[23] (Figures 55 and 56) are two with which the author is most familiar, although others may exist.

The Tablada hand is flat rather than curved to prevent submarining of the prosthesis during pre-stroke arm extension (Australian Crawl) in order to generate greater stroke volume. Additionally, note that the Tablada system uses a prosthesis which is close to actual anatomical arm length, whereas the Viau system has a shortened forearm section. Both utilize a pre-flexed, rigid elbow design. The Viau arm was designed primarily for back stroke swimming and may therefore account for the curved terminal device shape which would not hamper this style of swimming.

The author is also aware of the use of SUPER SPORT devices for swimming, especially for children unaccustomed to the water.

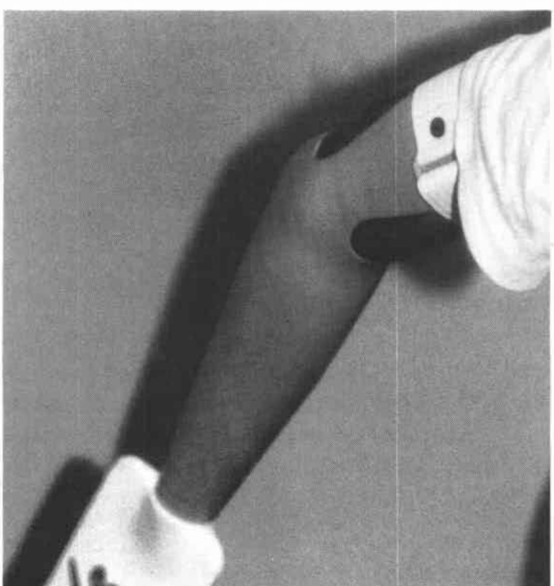
Pistoning of the prosthesis can be one of the most common occurrences during swimming. A suspension sleeve can aid in eliminating this action. An additional consideration related to swimming and skin or scuba diving is that the prosthesis is not as buoyant as the body and can seem heavier than normal in water and sometimes will impair performance.

Water-Skiing

Water-skiing can be an extremely dangerous recreation if not approached with caution. The author suggests the following rules of good judgment if water-skiing is on an amputee's wish list of recreational pursuits. First, don't ever lock onto a ski rope handle with any terminal device or use a terminal device which requires a cable and harness system. Second, use a ski rope equipped with a single handle. Third, wear a self-suspending, condylar socket that can be twisted free of under stress. A suspension sleeve will aid support but not impair release of the socket due to the flexibility of the material. Fourth, have a neoprene arm cover for the prosthesis which will float the arm in the water if it comes off. Fifth, *always* wear an approved floatation vest.

The Water Ski Hook[5] (Figure 57) is a simple solution to water skiing that has proved safe when set up and used properly. The Ski Hook should be mounted on the prosthesis in a canted position and tightened into place so that it cannot rotate freely. The shallow hook design provides support, yet will twist off a ski rope handle. Should a fall occur where twisting off is impaired, the supra-condylar socket can be "torqued off" the arm and save the amputee's shoulder from potential trauma.

Figure 54. The Viau-Whiteside swimming attachment.



Figures 55 and 56. The P.O.S.O.S./Tablada Swimming Hand Prosthesis.

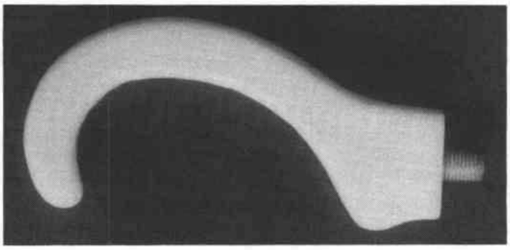


Figure 57. The Water Ski Hand is a simple solution to waterskiing problems.

Another solution to prevent injury is to have the tow rope attached to the boat with a quick release, or equipped with a second handle (for small children only) and always manned by an observer/handler. Should the amputee skier go down, the observer can release the rope instantly, preventing injury.

The Ski Seat[24] (Figure 58) and E-Ski[25] illustrated in Figure 59 are viable answers for the high level bilateral amputee and the paraplegic or quadraplegic who wishes to enjoy the thrill of skiing. The sled is custom constructed and has two skis. The E-Ski, a newer device, has only one ski and a cage seat.

Wind Surfing

Wind surfing is a relatively new recreation which combines aspects of sailing, surfing, and hang gliding. Load coordination and balance compounded by the need to grasp, maneuver, and rapidly let go of a cylindrical boom as well as uphaul a rope with mast and sail in tow are some of the obstacles the amputee windsurfer faces. A prototype voluntary closing wind surfing terminal device is illustrated in Figures 60 and 61. Other considerations should include special adjustable harnesses and cable systems for ocean or cold water sailing. Salt accumulation can foul cable function and negate terminal device operation. Wet suits, due to their tight elastic fit, will also interfere with cable function if the cable is worn inside the suit. The harness and cable system must be designed to fit on the outside of the wet suit for unrestricted terminal device operation. Leather on the prosthesis or harness should be avoided, as well as hardware which corrodes. Performance wind surfing is a physically and mentally demanding sport, and the amputee needs to be cautious and prepared to participate safely.

Summary

The varied demands of sports and recreation create a multitude of factors which impact the design, construction, and use of a sports prosthesis.

Physical fitness and conditioning, prosthetic design and materials, harness styles, and terminal devices all have roles in determining whether an amputee can engage in a sports activity successfully and safely.

New improved prosthetic devices and designs will continue to evolve to meet these varying demands. Communication between professionals is important in order to share information on the improvements which are made. Designs for high performance limbs and devices for sports and recreation may well pave the way for improved prosthetic technology as a whole.

An open mind, a fresh outlook, an understanding attitude, as well as the patience and willingness to experiment and develop, will inevitably lead to a brighter future for the disabled in sports and recreation.

Figure 58. The Ski Seat.

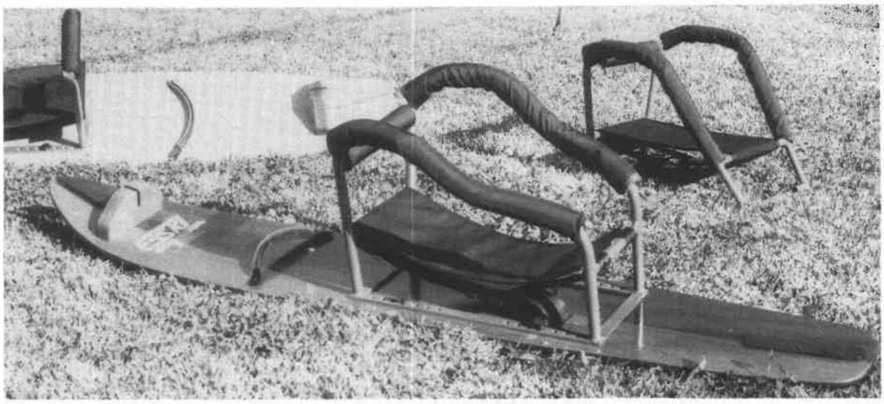
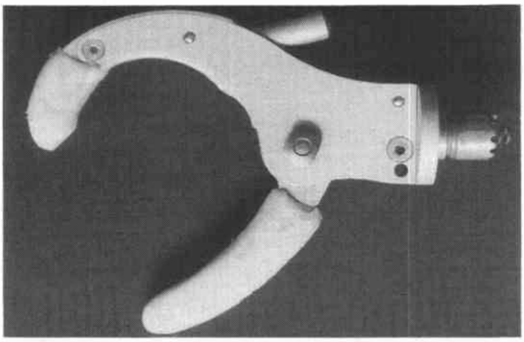


Figure 59. The E-Ski.



Figures 60 (above) and 61 (right). A prototype voluntary closing wind surfing terminal device.

References

[1] Chadderton, O.C., C.A.E., "Survey: Consumer Interests," *The Fragment,* Winter, 1986, Vol. 151, pp. 29–31.

[2] Robinson, W.D., B. Pflanz, B. Watkins, and A. Viau "Recreational Limbs AMPUTATION III," *The War Amputations of Canada,* April, 1986, pp. 19–33.

[3] Mensch, G. and P.E. Ellis, "Running Patterns of Transfemoral Amputees: A Clinical Analysis," *Prosthetics and Orthotics International,* 1986, Vol. 10, pp. 129–134.

[4] Products and trade names of Hosmer-Dorrance Corporation, Campbell, California.

[5] Products and tradenames of T.R.S., Inc. of Boulder, Colorado.

[6] Product and tradename of Recreational Prosthetics, Inc., North Dakota.

[7] Radocy, R., "Sports Designs for Upper Extremity Amputees," a symposium presentation at the National Sports Prosthetics and Orthotics Symposium, U.C.L.A. Prosthetics/Orthotics Education Program, October, 1985.

[8] "Bow Modifications Serve Amputees," *Archery World,* February, 1987, p. 22.

[9] Weight harnesses designed and tested by Bob Radocy, T.R.S., Boulder, Colorado {not commercially available}.

[10] Radocy, B. and Randall D. Brown, "Technical Note:

An Alternative Design for a High Performance Below-Elbow Prosthesis," *Orthotics and Prosthetics,* 1986, Vol. 40, No. 3, pp. 43–47.

[11] Billock, John N., "Northwestern University Supracondylar Suspension Technique for Below-Elbow Amputations," *Orthotics and Prosthetics,* December, 1972, Vol. 26, No. 4, pp. 16–23.

[12] Berger, N., et al, "The Application of ISNY Principles to the Below-Elbow Prosthesis," *Orthotics and Prosthetics,* Winter, 1985/86, Vol. 39, No. 4, pp. 10–20.

[13] Radocy, Bob, "The Rapid Adjust Prosthetic Harness," *Orthotics and Prosthetics,* 1983, Vol. 37, No. 1, pp. 55–56.

[14] Courtesy of Bill White, bilateral amputee using two GRIP terminal devices, Waterford, Pennsylvania.

[15] Courtesy of Kent Barber & Bill Dalke, Prototype bicycle aid not commercially available. Inquiries to T.R.S. of Boulder, Colorado.

[16] Courtesy of Bassamatic, Inc. of Canton, Ohio.

[17] Courtesy of Royal Bee Corporation, Pawhuskas, Oklahoma.

[18] Courtesy of Robin-Aids Prosthetics of Vallejo, California.

[19] Courtesy of The War Amputations of Canada, Ottawa, Ontario.

[20] Tradename and product of Innovation Research Corporation, Milwaukie, Oregon.

[21] Courtesy of SR-77 Enterprises, Inc. of Chadron, Nebraska.

[22] Courtesy of R.F. Meyer's photograph of R. Wityczak, a triple amputee.

[23] Courtesy of Carmen Tablada, C.P., Professional Orthopedic Systems of Sacramento, California.

[24] Ski Seat, Mission Bay Aquatic Center of San Diego, California.

[25] E-Ski, Courtesy of E.S.C.I. of Gretna, Louisiana.

[26] Courtesy of the Rehabilitation Centre for Children, Winnipeg, Manitoba, Canada.

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Energy Storing Feet: A Clinical Comparison

by John Michael, M.Ed., C.P.O.

The human foot is an exceedingly complex structure. The pair contain 52 separate bones, dozens of intrinsic muscles, and scores of extrinsic ones. The feet are composed of multiple layers of ligaments, fascia, and muscle, and contain numerous interrelated articulations.

In combination with the ankle complex, the foot provides the dual functions of support and propulsion. Paradoxically, this is accomplished by combining the diametrically opposite characteristics of flexibility and rigidity as the foot adapts to the gait cycle.[15]

Despite hundreds of historical attempts to imitate this remarkable structure, very few designs have ever achieved widespread acceptance. Within the last three years, however, four new foot components have become commercially available—all in the previously unheard of class called "energy storing" designs. These intriguing new developments will be discussed in chronological order, summarizing our experience at Duke.

Seattle Foot™

In 1978, Bernice Kegal of the Prosthetics Research Study in Seattle published a paper entitled "Functional Capabilities of Lower Extremity Amputees,"[13] and noted that a major prosthetic limitation in sports activities was the inability to run. The vigorous amputee athlete was competing despite the components rather than because of them.

The Prosthetics Research Study, in cooperation with engineers from Boeing aircraft, began developing a prosthetic foot specifically designed to store energy and release it at push off: the Seattle Foot™. First introduced in 1981 at a course in modern prosthetic rehabilitation presented by the American Academy of Orthopedic Surgeons, the Seattle Foot™ was later field tested by hundreds of Veterans Administration clients. Today, it should be widely acknowledged as the stimulus for the current explosion of new concepts in this area.

The design specifics have varied over the past few years as the concept was refined. Originally, the keel was a fiberglas multi-leaf design, somewhat similar to an automobile suspension spring. The key concept was that as the patient increased his cadence, stiffer portions of the spring came into play. Various exotic materials were considered, including titanium, but were clinically impractical.[12]

The commercial version first became available in October, 1985 and consisted of a Delrin bolt block and integral keel, with Kevlar® toe pad (Figure 1). The entire structure is contained in a lifelike injection-molded polyurethane shape. To date, over 8,000 Seattle™ feet have been used in the United States.[2]

Although patient acceptance has generally been good, several technical difficulties have been noted with this design. During the VA field-testing, catastrophic failure of the plastic keel occurred in some cases. This has been greatly reduced in the commercial version, provided the proper keel configuration is selected using the manufacturer's guidelines.

Because of ongoing problems with failure of the flexible rubber toes at the keel tip, the polyurethane composition has recently been reformulated for more tear resistance.[4] About one third of our feet at Duke have failed in the forefoot, although all were replaced under manufacturer's warranty. We have experienced no catastrophic failures whatsoever in our series.

The "Life-Molds," although very natural in appearance, have presented some difficulties. The first is that the forefoot is fairly wide and

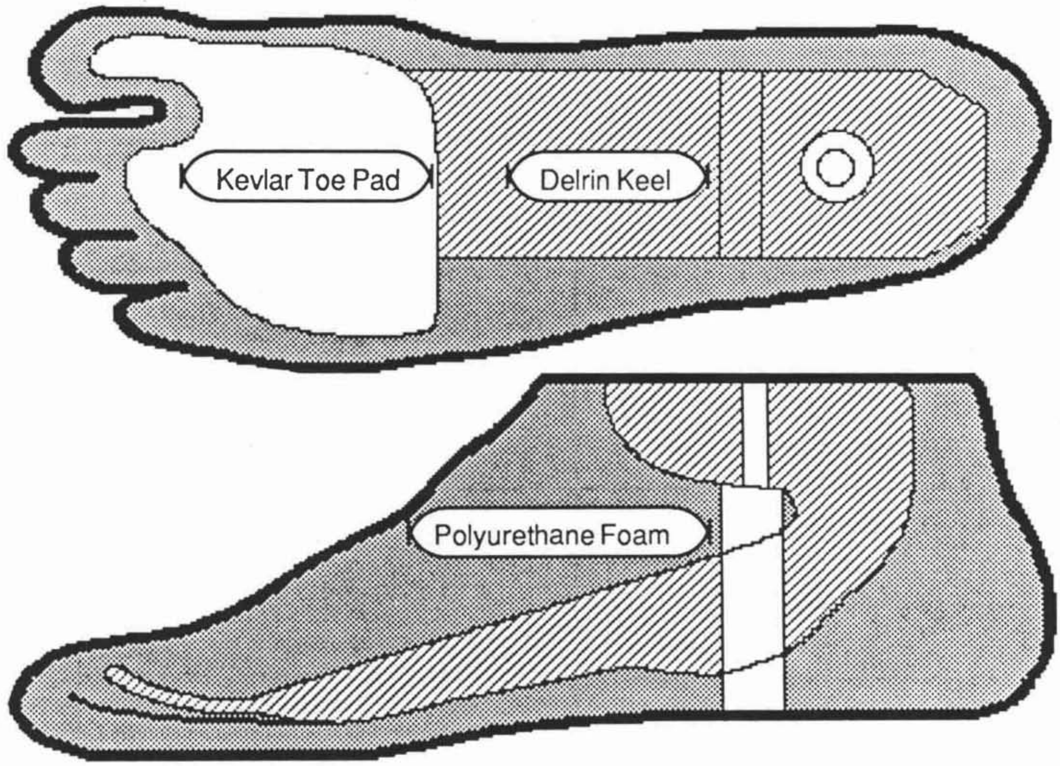


Figure 1. Seattle Foot™; note cantilevered plastic spring keel to store energy (Courtesy MIND).

often difficult to fit into dress shoes, particularly narrow widths. In addition, there is no uniformity in dimensions from size to size, or even between left and right in the same size. For example, if a patient returns requesting a foot one size smaller since purchasing tighter shoes, and a 26cm foot is substituted for a 27cm foot, the prosthesis has been inadvertently shortened by 5mm (¼″). Also, the stark contours of the original "Life-Molds" can be difficult to blend into the prosthetic ankle at the retromalleolar area, and are too muscular for some patients.

The recently available "Ladies Molds" have effectively addressed the problems noted above. Redesign of the male version is underway, and is expected to achieve similar results.

The Delrin keel has also been a source of problems. Because it is very slippery, inadvertent rotation and loss of toe out has occurred. Since drilling and pinning the bolt block would significantly increase the risk of breakage, the manufacturer recommends bonding the foot to the ankle block or endoskeletal adapter with hot-melt glue. This has eliminated problems with loss of toe out in our series at Duke, although we still experienced occasional problems with the keel "slipping" completely out of the polyurethane shell for active walkers.

Problems have also been reported with occasional bolt breakage, and speculation regarding cold creep of the plastic has been voiced. The manufacturer supplies special bolts, locktite, and torque specifications to address this issue. We have experienced no bolt problems at Duke.

Finally, this is the heaviest solid ankle design commercially available. Although most patients have no apparent difficulties, some find the weight objectionable. One volleyball player, in particular, rejected the foot for jumping activities, even though she found it excellent for jogging and similar sports.

Despite the technical difficulties noted, our experience at Duke has generally been favor-

Figure 2. Flex-Foot™, showing full-length composite strut for energy return (Photo courtesy Flex-Foot, Inc.).

able. Patients often comment on the "lively" step permitted by the cantilevered spring design. We particularly favor this component in the smaller sizes (26cm and below), as the incidence of breakage seems reduced. One unilateral hip disarticulation amputee commented that the more active push off "lets me pass someone in a crowd for the first time since I became an amputee."[21]

Flex-Foot™

At the same time the Seattle Foot™ was being developed, an independent collaboration between a plastics engineer and a young research prosthetist-amputee resulted in creation of the Flex-Foot™. This lightweight graphite composite structure offers a radically different approach. All are hand made from a computer-generated design specific to each individual patient. Data such as weight, activity level, and residual limb characteristics determine the specific orientation and thickness of reinforcement fibers.

Ultra high pressure, high temperature molding insures the greatest possible strength to weight ratio, but requires several weeks for fabrication. Although this is a very costly approach, it does permit fitting the widest range of individuals. The chief restriction is that a minimum of five inches is required from the end of the residual limb to the floor, and seven inches or greater is preferred. Thus, the Flex-Foot™ is not suitable for small children, Symes and similar amputations, and very long below-knee residual limbs.[8]

Unlike any other component currently available, Flex-Foot™ utilizes the entire distance distal to the socket for function. Since it stores energy throughout its entire length rather than just within a four inch keel, this results in a very responsive and resilient component. It also significantly improves the mass distribution of the prosthesis (Figure 2).

Most multi-functional feet bolt onto the prosthesis at the ankle block, and are heavier than a conventional SACH foot. With the weight concentrated at the distal end, the limb swings as if it were a sledgehammer. Overcoming the inertia of this mass in order to propel it through space consumes energy, and the patient perceives it as "heavy."

The Flex-Foot™, however, is more akin to an inverted sledgehammer. The bulk of the weight is in the socket and attachment cone, with the rest uniformly distributed in the pylon. This is analogous to holding the head of the sledge and swinging the handle through space. Even if the Flex-Foot™ prosthesis weighs nearly as much as the conventional limb, the patient finds it much easier to propel, and perceives it as "light." Actual weight savings of 10–15 percent are common, but patients typically perceive that the Flex-Foot™ weighs "half as much."

Another advantage unique to the Flex-Foot™ is the ability to independently adjust the anterior and posterior lever arms. Overall stiffness is fabricated in at the factory, but tilting the pylon increases the anterior flexibility. Varying the length of the heel pylon independently controls its resistance. Conventional AP linear slide adjustments affect the resistances in the conventional manner: sliding the foot forward decreases posterior leverage while increasing the anterior resistance.

Due to the complexity and magnitude of the inter-related alignment changes possible with the Flex-Foot™, we advocate use of a prototype prosthesis, at least initially. By dynamically aligning the new socket on a conventional foot using a conventional alignment fixture, mediolateral alignment and the quality of socket fitting can be easily evaluated and refined.

Once these are satisfactory, the vertical transfer fixture can be used to permit substitution of the Flex-Foot™ pylon. A secondary dynamic alignment is then performed, permitting concentration on sagittal plane characteristics without being distracted by a multitude of adjustments in other planes.

Although use of slow-motion video analysis has been of some value in refining the sagittal alignment, we strongly encourage an extended field trial prior to finishing the limb. Application of a PVC bag over the alignment fixture followed by several layers of fiberglass casting tape reinforcement will permit the patient to use the limb clinically for a week or two.

Upon return to the laboratory, the fiberglass tape can be removed and the alignment further enhanced. As the patient becomes accustomed to the function of the Flex-Foot™, he will often prefer stronger anterior resistance. A knowledgeable physical therapist can be an asset at this stage, as the person must learn to shift his weight onto the Flex-Foot™ throughout stance phase and "ride it into toe off" in order to achieve maximum benefit from its push off characteristics.

Casting tape should be reapplied and the field trial continued. Only when the patient returns, needing no additional alignment changes, can it be assumed the alignment is optimized, permitting transfer and finishing to proceed.

A comprehensive fabrication manual is provided by the manufacturer,[8] and the instructions should be followed explicitly, particularly regarding reinforcement of the attachment cone. Tremendous stresses are concentrated where the resilient pylon meets the rigid socket, and structural failures of the lamination can occur if improperly fabricated.

Cosmetic finishing is difficult and time-consuming, but results in a finished structure that is highly water resistant since the foam provided is used in life preserver construction. If immersion is anticipated, a final sealing coat of Lynadure or other flexible "skin" is recommended.

Although our series is small, we have experienced no failures with the Flex-Foot™ system, even on very large and very active individuals. One high school athlete, who destroyed SACH and SAFE feet two or three times per year, has been playing varsity football with the Flex-Foot™ for two seasons without incident.

The manufacturer reports an overall failure rate of less than four percent with over 2,500 units in the field. Most failures occurred where the heel pylon bolts attached to the anterior pylon. One common denominator has been a sudden increase in the patient's activity level after being fitted with the Flex-Foot™. A highly active individual (or one who has recently gained weight) using a pylon originally designed for standard duty applications is at risk, so the prosthetist must anticipate the ultimate stresses that will be applied.[9]

The recent announcement of a "Modular Flex-Foot™" (MFF) represents an effort to expand the usefulness of the Flex-Foot™. Available in standard configurations, these pre-made pylons can be supplied within two weeks. The heel lever arm bolts through the forefoot rather than the highly stressed ankle area, to enhance durability. A refined attachment system permits easier socket replacements, which should encourage application to more recent amputees. And, limited alignment refinements are possible even after permanent attachment to the socket, via Otto Bock "Modular" components or the "pylon connector" (Figure 3).

We believe the cost and complexity of the Flex-Foot™ can be justified due to the degree of function offered. A competitive volleyball player reported her vertical leap nearly doubled when using the Flex-Foot™, and its low inertial drag made activities less tiring.[20] A severely debilitated geriatric amputee, who ambulated with a cane due to impaired balance, claimed he could walk "twice as far before my wind gives out" after fitting with the Flex-Foot™.[1] And a 47 year old nurse completed the New York Marathon's 26 mile race on the Flex-

Foot™ one hour thirty-two minutes more quickly than with a conventional design.[16]

Hard data to buttress these anecdotal reports are very limited at this time. A motion analysis conducted at the University of Illinois suggests that the Flex-Foot™ allows a more normal range of motion than the SACH foot, even at normal cadences.[25] Several centers are reportedly conducting oxygen consumption studies in an effort to verify claims of lowered energy consumption, but none are yet published.

Although most Flex-Foot™ prostheses have been used for unilateral and bilateral below-knee amputees, a significant percentage have been applied to above-knee amputees as well, and some hip disarticulation fittings have been completed.[9] Our experience at Duke has been chiefly at the below-knee level. Although higher level amputees would benefit greatly from reduced energy consumption, the addition of a passive knee mechanism may dissipate some of the potential return and bears further study.

Carbon Copy II

The Ohio Willow Wood Company introduced the original all-plastic SACH foot a decade ago called the "Marvel" foot. After its demise due to the availability of lighter and more durable feet from other suppliers, they embarked on a research and development project for what they termed the "next generation" of solid ankle feet.

A few years ago, Mauch Laboratories approached Ohio Willow Wood to design a foot shell for Mauch's hydraulic ankle. This lead to the development of life-molds, a special microcellular polyurethane elastomer blend, and engineering of a carbon composite keel. The result was Carbon Copy I, a relatively rigid shell whose function comes primarily from the ankle mechanism.

Development continued, and in May, 1986, Carbon Copy II was introduced as the latest entry into the energy storage arena. In many ways, it represents the synthesis of some of the best attributes of previous designs. This is a conventional solid ankle design, available with three durometers of heel cushion for simulated planter flexion.

The keel, however, is a unique dual structure: a rigid posterior bolt block plus flexible anterior deflection plates. The bolt block is a special ultralight reinforced Kevlar/nylon design which recently won the plastic composite industry's "National Award of Excellence" for innovative engineering. A fiberglass/epoxy attachment plate resists deformation by both exoskeletal and endoskeletal ankle blocks, while very low density Styrofoam fills the cavities and prevents infiltration of the heavier polyurethane elastomer which forms the outer shell.

The anterior deflection plates provide two-stage resistance at heel off. In normal walking, the thin primary deflection plates (which run to the PIP joints of the toes) provide a gentle energy return. At higher cadence or during more

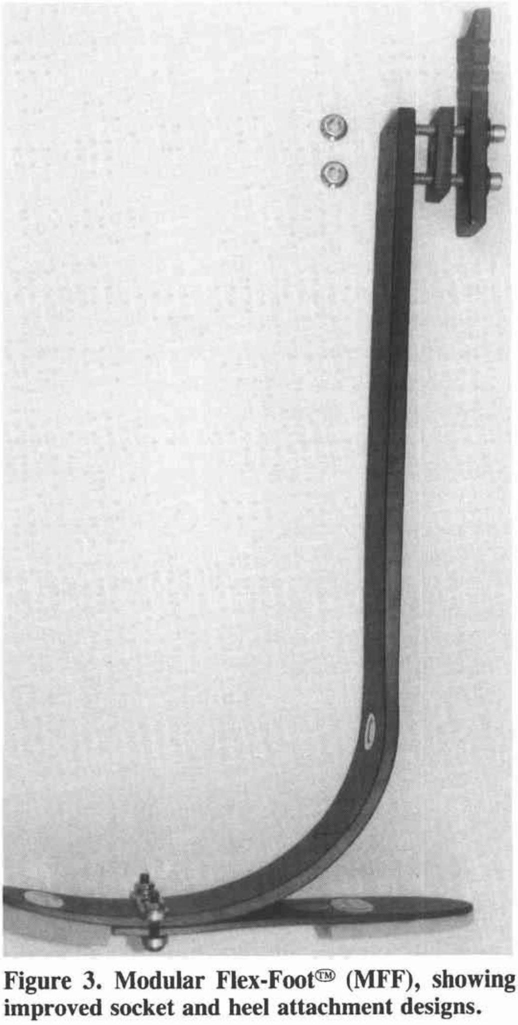


Figure 3. Modular Flex-Foot™ (MFF), showing improved socket and heel attachment designs.

Figure 4. Carbon Copy II; note rigid bolt block plus dual flexible carbon fiber deflection plates (Photo courtesy Ohio Willow Wood Co.).

vigorous activities, the auxiliary deflection plate provides additional push off. A Kevlar® glide sock prevents the plate from knifing through the elastomer shell (Figure 4).

The exterior design shows a similar attention to practical detail. The contours are lifelike, but not as starkly detailed as the Seattle Foot™. Rather, the veins and retromalleolar undercuts are softened into a more practical "humanoid" configuration. The forefoot width is a bit wider than conventional SACH feet, but less than the Seattle Foot™ version (Figure 5). Fitting narrow width shoes can sometimes be a problem.

The plantar surface is where the Carbon Copy II contour is most unique. Broad and flat (with a full-width carbon composite plate similar to Flex-Foot™), it is shaped to fit the shoe last. Analogous to a well-posted UCBL foot orthosis, this congruence between device and shoe offers maximum mediolateral stability (Figure 6).

Finally, all these practical details are contained in a package that is extremely lightweight. Significantly lighter than the conventional SACH foot, Carbon Copy II is actually slightly lighter than a geriatric "litefoot."

Currently available only in adult male sizes, Carbon Copy II should be available in female sizes in the near future. Some practitioners report that the small keel sizes are noticeably stiffer than their full-sized counterparts. In response to that observation, Ohio Willow Wood is retooling for a shorter keel block as well as narrower deflection plates for the women's style, which will initially be offered only in a 10mm (3/8") heel height.

We have experienced no failures whatsoever with Carbon Copy II thus far, even for very vigorous applications. The manufacturer reports sales of over 2,000 feet, with known failures in nine cases. Seven were rubber tears at the tips of the toes (reportedly from one particular manufacturing run), plus one split deflection plate and one broken rivet.[17] If this early reliability continues, this may be one of the most durable prosthetic feet available.

The only other problem noted is insufficient threads on the Otto Bock titanium endoskeletal foot bolt, which can be identified by its bright blue color. Placing one or two spacer washers under the head of the bolt allows it to be tightened firmly without running out of threads.

One of the key design criteria for this foot was versatility, and we have found it suitable for many levels of amputation—including unilateral and bilateral below-knee, unilateral above-knee, hip disarticulation and hemipelvectomy, as well as above-knee/below-knee bilaterals.

Overall, the Carbon Copy II and Seattle Foot™ seem to offer similar function to the patient, and the wholesale cost is comparable. At least in the larger keel sizes, most patients have preferred the Carbon Copy over the Seattle Foot™, due to lighter weight and the two-stage resistance. In the smaller keel sizes, the difference is less pronounced, and many prefer the responsiveness of the Seattle design. In general, we consider both Carbon Copy and the

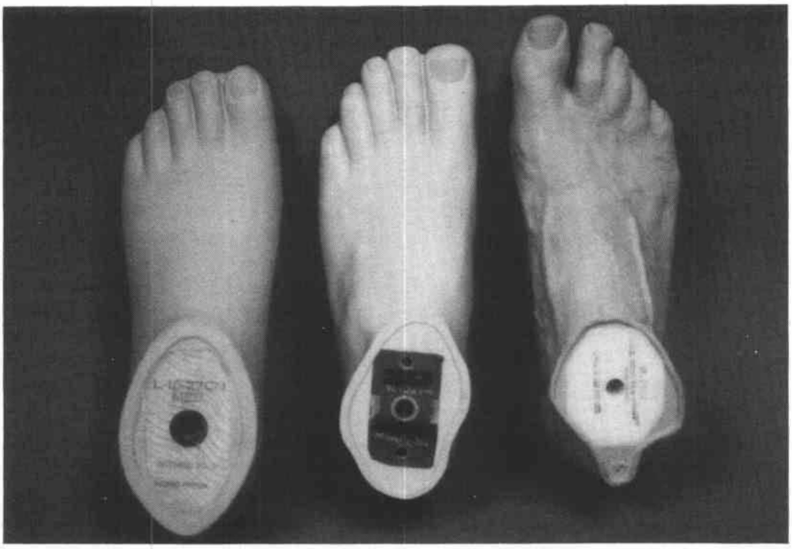
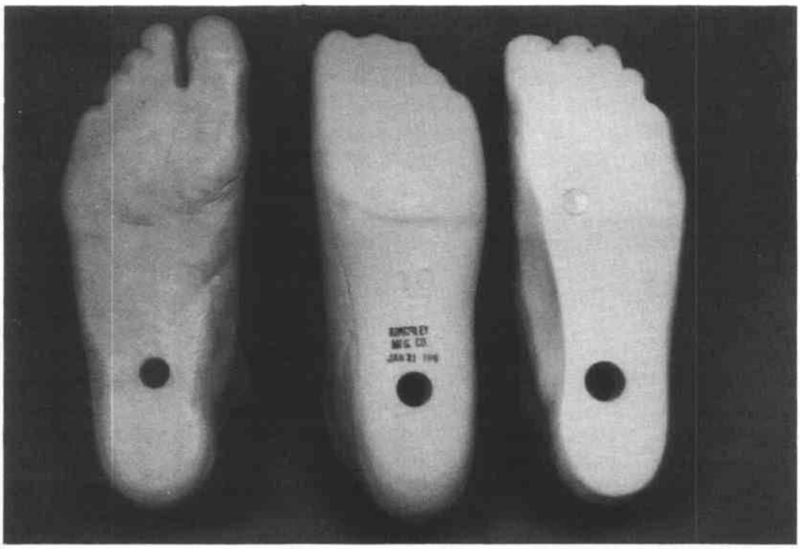


Figure 5. (Dorsal view, L to R) STEN foot, Carbon Copy II, Seattle Foot™; note retromalleolar contours and forefoot width.

Figure 6. (Plantar view, L to R) Seattle Foot™, STEN foot, Carbon Copy II; the flatter configuration enhances mediolateral stability within the shoe.



Seattle Foot™ design to be good, moderately responsive energy storing designs.

STEN Foot

STEN Foot is one of the simplest designs in prosthetic feet. Externally, it uses the familiar Kingsley foot molds and rubber. This means it is the easiest design to fit in a variety of shoe styles, and comes in the greatest selection of sizes and heel heights: from a child's 18cm keel to an adult's 30cm, including women's widths as well. Soft, medium, or firm heel durometers are available as well.[24]

Slightly heavier than a conventional SACH foot, the STEN Foot differs in its dual articulated keel. In addition to a metatarsal-phalangeal articulation, it also features a tarsal-metatarsal articulation, thus permitting a smoother,

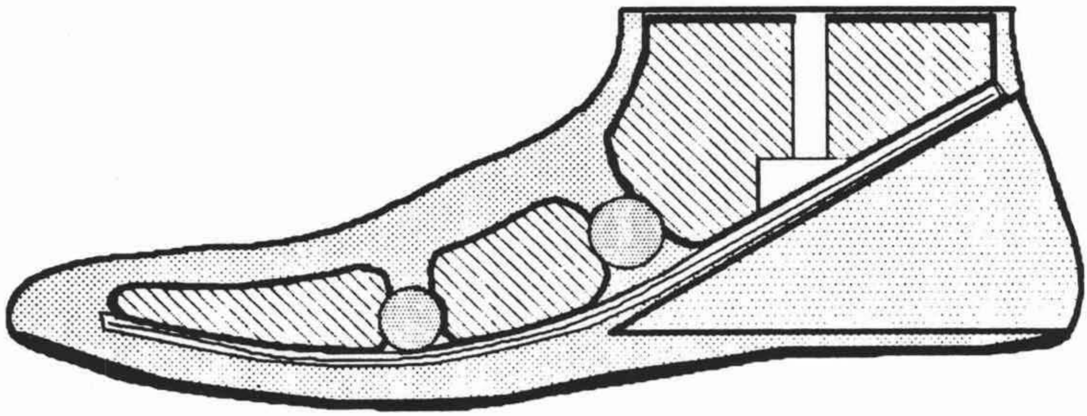


Figure 7. STEN foot; note dual keel articulations and double reinforced belting (Illustration courtesy Kingsley Manufacturing).

more gradual roll-over than a solid SACH keel (Figure 7).

Although the name stands for "STored ENergy" foot, it is our clinical impression that it does not accomplish this goal as effectively as the previous designs. The "keel bumpers" are directly analogous to the toe bumper in an old-fashioned wooden foot; both seem more to dissipate than to return energy.

We view the STEN Foot as an additional flexible keel design, similar to the SAFE foot, permitting a smoother roll-over and somewhat greater forefoot supination and pronation than the more rigid SACH design. Since it is lighter than the SAFE foot, fits the shoe more readily, and is available in a broad range of heel heights and sizes, it may offer some advantages.

Compared to a SACH foot, patient response has been predominantly favorable. Most preferred the smoother, "softer" roll-over it offers. Some higher level amputees complained of a slight increase in the tendency for the prosthetic knee to "buckle," although this could usually be minimized by plantarflexing or moving the foot more anteriorly.

Reliability was a significant problem with early versions of this design, which sometimes failed catastrophically due to rupture of the plantar belting beneath the midfoot articulation. This resulted in a sudden loss of forefoot resistance, causing the amputee to stumble. When three of our initial seven STEN Feet failed in this fashion, we stopped using this component.

It has since been redesigned with double belting reinforcements. The manufacturer reports that 3,000 feet have been sold, with no belting failures whatsoever since the reinforcement was added. With the new design, the overall failure rate from all causes is currently under one percent.[24]

At a recent Academy conference, Richard Carey, C.P. reported on over 80 successful applications of the reinforced version of the STEN Foot, and suggested it is particularly appropriate for the new amputee as the softer roll-over may facilitate gait training.[6] This also might allow an easier transition to a more sophisticated design later, since the flexible keel is a common characteristic of all current "energy storing" feet.

Other Designs

Although not a brand new design, the SAFE foot (Stationary Ankle Flexible Endoskeleton) has recently been advertised as "the original energy storing foot." In our view, this may be stretching the point, since we believe the flexible keel serves primarily to dissipate energy as it accommodates to irregular surfaces.

The SAFE foot can be viewed as a solid ankle version of the multi-axis concept, and we consider it an alternate to the well-known Greissinger foot. Both provide significant transverse rotation as well as inversion and eversion, in addition to some degree of plantar flexion and dorsiflexion.[5] The SAFE foot has the advantage of requiring no maintenance and being moisture and grit-resistant, while the Greissinger permits independent selection of the plantar flexion and other resistances.

We summarize the SAFE foot as an "accommodative" design. It is probably unparalleled for use on uneven surfaces, and many amputees report an increase in residual limb comfort because it absorbs much of the shock of everyday walking. But aggressive racquet sportsmen have complained that it takes a fraction of a second to "wind up" before permitting push off, thus lowering their score. Perhaps the SAFE foot and other soft keel designs should be viewed as offering increased shock absorption and comfort at the expense of responsiveness in a competitive situation.

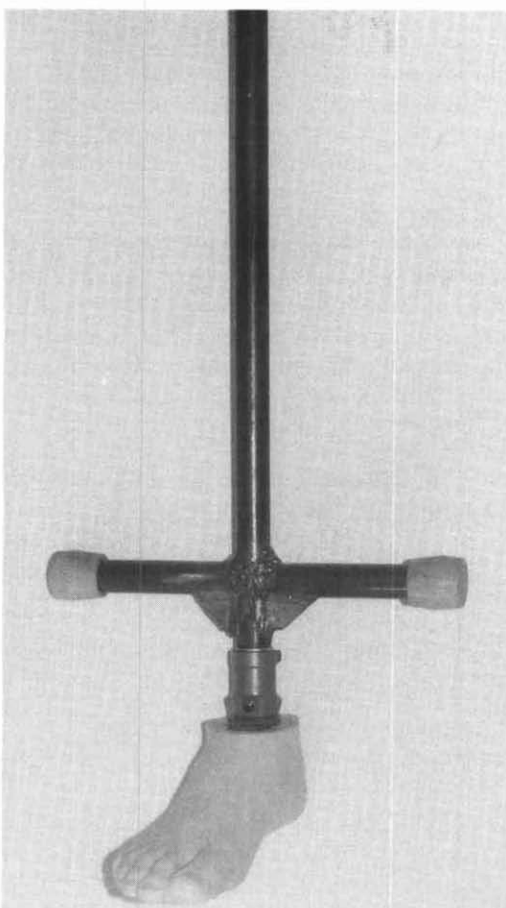


Figure 8. Pogo stick device used to test vertical spring capabilities of various feet.

Clinical Ranking

There are currently no accepted definitions of what constitutes an "energy storing" prosthetic foot. In fact, there is currently no hard data to demonstrate any energy savings at all, despite numerous anecdotal reports. Yet, there is a need to have some means of evaluating and ranking the various designs, to add some measure of rational justification for clinical use of a given component.

In reviewing slides of a unilateral below-knee amputee playing competitive volleyball, it was noted that her vertical leap appeared to be noticeably higher with the Flex-Foot™ than with the Seattle Foot™. This difference is likely due to the amount of "spring return" inherent in the components, and may represent one plausible criterion to rank their effectiveness.

To test this hypothesis, a simple "pogo stick" apparatus was constructed which permitted interchange of various prosthetic feet (Figure 8). A non-amputee subject was in-

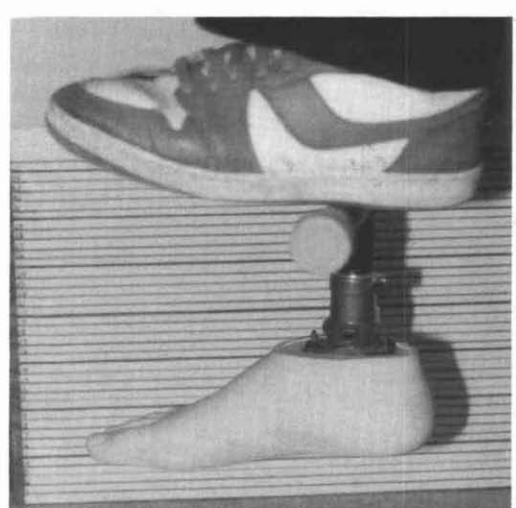


Figure 9. Frame-by-frame video analysis of ground clearance in centimeter increments.

structed to jump on the pogo stick for ten hops, trying to attain as much altitude as possible. It is believed that this measures the spring potential of the component as if it were loaded by body weight at midstance. Since the subject's feet both remained firmly on the foot pegs and did not contact the ground, this was felt to be more accurate than measuring unilateral amputees jumping, where the sound limb could partially compensate for the component's deficits.

Using frame-by-frame slow motion video analysis, the amount of ground clearance was measured to the nearest centimeter (Figure 9). This was not intended to be a controlled study, but rather a simple preliminary investigation; no quantitative judgments should be drawn from this data. Nevertheless, the trends were consistant over multiple trials, and are summarized in Figure 10.

It is interesting to note that Figure 10 coincides with our subjective clinical ranking of the effectiveness of these designs. Patients given the choice between the SACH and STEN foot, for example, generally chose the more flexible STEN, but patients perferred the Carbon Copy II or Seattle Foot™ to the STEN, because the spring keels "felt more natural." Given the choice between Flex-Foot™ and other designs, the choice was generally for the more responsive composite system.

Furthermore, the ranking also reflects the degree of sophistication of the design, and the relative wholesale cost from the manufacturer (Figure 11). The weight of the components was less straightforward. The inexpensive designs increased in weight as they increased in complexity, weighing progressively more than a conventional SACH foot. However, the two most expensive energy storing designs—Flex-Foot™ and Carbon Copy II—resulted in a lighter prosthesis than a SACH configuration (Figure 12).

Summary

Thanks to the efforts of the Prosthetics Research Study in Seattle, the concept of energy storing prosthetic feet has been widely dissemi-

Figure 10. Ground clearance after vertical leap using pogo stick apparatus; 175 pound male subject, men's size 10 feet.

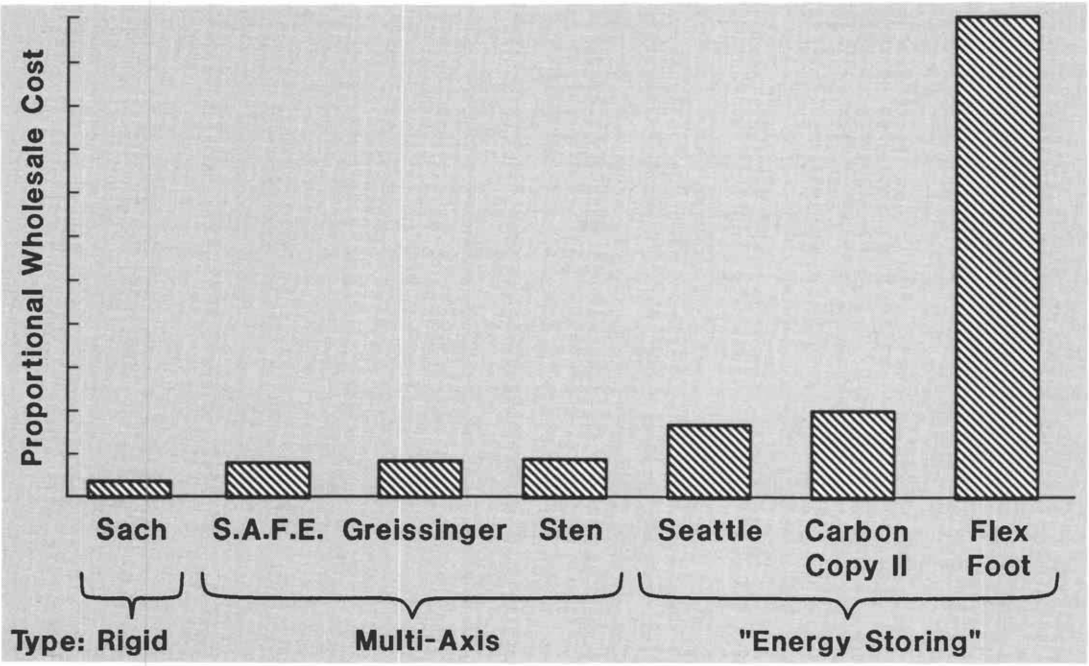


Figure 11. Relative wholesale costs for prosthetic foot mechanisms.

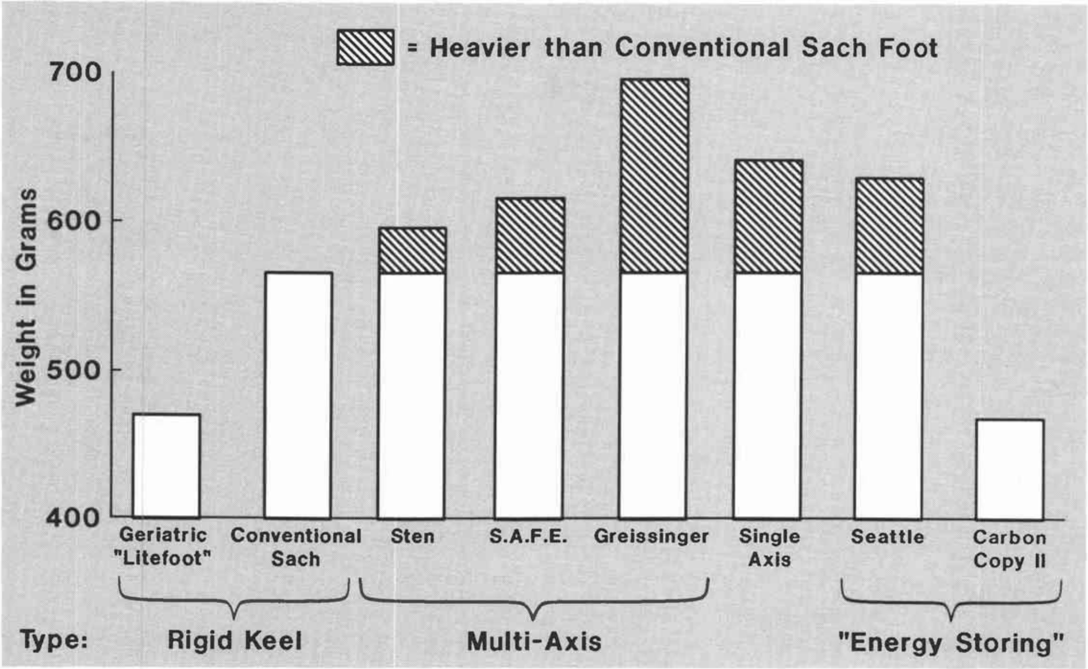


Figure 12. Weight of men's size 10 foot components, not including ankle block.

Component	Levels	Quantity	Component Failures	
			Number	Percent
Sten Foot	BK, BIL BK, KD	7	3	43%*
Seattle Foot™	BK, BIL BK, AK, HD	16	5	31%*
Carbon Copy II	SYMES, PFFD, BK, BIL BK, AK, HD, HP	35	0	0%
Flex-Foot™	BK, AK	7	0	0%

* Initial Version; Current designs are significantly more reliable

Figure 13. "Energy storing" feet through April 1987, Duke University experience.

nated.[19] Although it is fashionable to claim such benefits, no clear definition of the characteristics required has been established. The author suggests that the ability to leap vertically is one simple measurement of the "springiness" of a component, while reduced oxygen consumption during a measured task would be a more precise definition of an energy-conserving component.

All current designs seem to have merit, and have been successfully utilized clinically (Figure 13). Although limited, the Duke experience has been summarized as a first step toward more clearly delineating the indications and contraindications for each design (Figure 14).

The conventional SACH foot remains the most widely used design in North America, due to its low cost and reliability. In sports applications, it is particularly well suited for sprinting, since the rigid keel digs into the track, permitting rapid acceleration.[20]

Multi-axis feet (Greissinger and SAFE) accommodate uneven terrain and dissipate some of the shocks of ambulation, thereby increasing skin comfort. They have been widely used by amputee athletes, although the softer keel resistance may increase the lag between sudden movements. Except for limiting transverse rotation, the STEN foot offers similar function, and may be worth considering for the novice amputee in particular.

The Seattle Foot™ and Carbon Copy II are solid ankle devices that attempt to store energy via a spring keel design. They have been well received for a variety of amputation levels, and seem particularly well suited for joggers and weekend athletes.

Flex-Foot™ represents the maximum in energy storage potential, and can be individualized for a wide range of applications. It is by far the best design for vertical jumping, thereby lending itself to such sports as volleyball. It has also performed well for long distance running, as well as vigorous sports in general.

Finally, all these components have more widespread application than originally assumed. A more flexible forefoot permits an easier roll-over. For the geriatric individual, even a modest decrease in the effort required for walking can offer a substantial improvement in ambulatory potential. The more debilitated the person, the more important the weight and responsiveness of the foot component become. Virtually any lower limb amputee could benefit from the enhanced functioning that a sophisticated prosthetic foot can offer.

Although none of these designs will turn the amputee into Superman, each can add a significant dimension to the degree of restoration that can be offered. Jan Stokosa, C.P., has noted that although conventional prosthetic limbs restore mobility rather effectively, many patients feel their *function* has not been restored, so long as vigorous activities remain difficult or impossible to achieve.[23]

By increasing our collective experience with the components under discussion and pooling our impressions in forums such as this, it is hoped that we can more closely approach that elusive goal: complete functional prosthetic restoration for every amputee.

Component	Cost/Weight	Indication	Advantages
Sach	Low/medium	General use	Reliable, inexpensive, accommodates numerous shoe styles
Single axis	Mod/heavy	To enhance knee stability	Adds stability to prosthetic knees
Greissinger	Mod/heavy	Accommodate uneven surfaces, absorb rotary torques	Multi-directional motion
Safe	Mod/heavy	Accommodate uneven surfaces, absorb rotary torques, smooth roll-over	Multi-directional motion, moisture & grit resistant
Sten-Foot	Mod/medium	Smooth roll over	Moderate cost & weight; accommodates numerous shoe styles; ML stability similar to Sach
Seattle Foot™	High/heavy	Jogging, general sports, "conserve energy"	"Energy storing" smooth roll-over
Carbon Copy II	High/light	Jogging, general sports, "conserve energy"	"Energy storing", smooth roll-over, very stable ML, highest solid ankle foot
Flex-Foot™	Very high/ very light	Running, jumping, vigorous sports, "conserve energy"	Most "energy storing", most stable ML, lowest inertia, wide range of applications

Figure 14. Clinical comparison of prosthetic feet.

Disadvantages	Typical Sports Applications	Ankle Mechanism	Permits Forefoot Pro/Supination	Permits Hindfoot in/ Eversion/Rotation
Fairly rigid, limited range of motion	Sprinting	Fixed	No	No
Slightly increased cost, weight, maintenance	Limited	Articulated	No	No
Slightly increased cost, weight, maintenance less ML stability	General, to absorb stresses		Yes	Yes
Slightly increased cost, weight, less ML stability	General, to absorb stresses	←------- Fixed -------→	Yes	Yes
Slightly increased cost, weight	General, for smoother roll-over		Yes	No
Increased cost, weight, difficult to fit in shoes	General, jogging		No	No
Increased cost, difficult to fit in shoes	General, jogging		No	No
High cost, complex fabrication & alignment, not feasible for very long residual limbs	Vigorous sports jumping, running	Flexible	No	No

Author

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References

[1] Beckman, Clarence, personal communication, May, 1983.

[2] Brooke, Steve, Marketing Manager, Model Instrument and Development, Inc., personal communication, April, 1987.

[3] Burgess, et al., "The Seattle Prosthetic Foot—A Design For Active Sports: Preliminary Studies," *Orthotics and Prosthetics,* Volume 37, Number 1, pp. 25–32.

[4] Burgess, et al., "The VA Seattle Foot," *Rehabilitation Research and Development—Progress Reports 1984,* Veterans Administration Publications, 1984, p. 5.

[5] Campbell, J. and C. Childs, "The S.A.F.E. Foot," *Orthotics and Prosthetics,* Volume 34, Number 3, 1980, pp. 3–17.

[6] Carey, Richard, "The STENFOOT," Continuing Education Course 1-87, American Academy of Orthotists and Prosthetists, Portland, Oregon, March, 1987.

[7] Enoka, et al., "Below-Knee Amputee Running Gait," *American Journal of Physical Medicine,* Volume 61, Number 2, 1982, pp. 66–84.

[8] "Flex-Foot® Fitting and Alignment Procedure," Flex-Foot Inc., 19600 Fairchild, Suite 150, Irvine, CA 92715.

[9] Fosberg, Robert, President of Flex-Foot, Inc., personal communication, April, 1987.

[10] Graves, J. and E. Burgess, "The Extra-Ambulatory Concept As It Applies To the Below-Knee Amputee Skier," *Bulletin of Prosthetics Research,* Fall, 1973, pp. 126–131.

[11] Hittenberger, Drew, "Extra-Ambulatory Activities and the Amputee," *Clinical Prosthetics and Orthotics,* Volume 6, Number 4, 1982, pp. 1–4.

[12] Hittenberger, Drew, "The Seattle Foot," *Orthotics and Prosthetics,* Volume 40, Number 3, 1986, pp. 17–23.

[13] Kegal, Bernice, et al., "Functional Capabilities of Lower Extremity Amputees," *Archives of Physical Medicine and Rehabilitation,* Volume 59, 1978, pp. 109–120.

[14] Kegal, et al., "Recreational Activities of Lower Extremity Amputees: A Survey," *Archives of Physical Medicine and Rehabilitation,* Volume 61, 1980, pp. 258–264.

[15] Klenerman, Leslie, *The Foot and Its Disorders,* Blackwell Scientific Publications, London, 1976, p. 19.

[16] "A Material Change for Prosthesis," *The Orange County Register,* October 31, 1985, Sec.E, p. 12.

[17] Martin, Jeffrey, Marketing Director, Ohio Willow Wood Company, personal communication, April, 1987.

[18] Michael, J.W., "Prosthetic Feet for the Amputee Athlete," *Palaestra,* Volume 2, Number 3, 1986, pp. 37–41.

[19] Miller, Enoka, et al., "Biomechanical Analysis of Lower Extremity Amputee Running." Final Report to Veterans Administration. Contract Number V5244P-1540/VA Hospital, New York, 1979.

[20] Nobbe, Carol, personal communication, September, 1984.

[21] Rauch, Colleen, personal communication, November, 1986.

[22] Sethi, M.P., "Vulcanized Rubber Foot for Lower Limb Amputees," *Prosthetics and Orthotics International,* Volume 2, Number 3, 1982, pp. 125–136.

[23] Stokosa, Jan, "Total Surface Bearing in Lower Extremity Prosthetics," Region II-III Assembly, American Orthotic & Prosthetic Association, Atlantic City, New Jersey, April, 1986.

[24] Truesdell, James, president, Kingsley Manufacturing Company, personal communication, April, 1987.

[25] Wagner, J., et al., "Motion Analysis of SACH vs. Flex-Foot® in Moderately Active Below-Knee Amputees," *Clinical Prosthetics & Orthotics,* Volume 11, Number 1, 1987, pp. 55–62.

Appendix

SAFE Foot, Campbell-Childs, Inc., 105 East First Street, P.O. Box 120, Phoenix, Oregon 97535.

Flex-Foot®, Flex-Foot, Inc., 14 Hughes, B-201, Irvine, California 92714.

STEN Foot, Litefoot, SACH, and Single Axis Feet, Kingsley Manufacturing Company, P.O. Box CSN 5010, Costa Mesa, California 92628.

Carbon Copy II, Ohio Willow Wood Company, 15441 Scioto Darby Road, P.O. Box 192, Mount Sterling, Ohio 43134.

Greissinger, Single Axis, & SACH Feet, Otto Bock Industries, Inc., 4130 Highway 55, Minneapolis, Minnesota 55422.

Seattle Foot®, Model & Instrument Development, 861 Poplar Place South, Seattle, Washington 98144.

Clinical Prosthetics and Orthotics, Vol. 11, No. 3, pp. 169-172

The O.K.C. Above-Knee Running System

by John Sabolich, B.S., C.P.O.

For many years, above-knee amputees have been trying to run step over step rather than using the hop and skip running gait typified by Terry Fox in his run across Canada. This type of locomotion is still biomechanically defined as walking since it still contains a double support phase when both feet are touching the ground simultaneously. True running has no period of double support.

One reason that above-knee amputees have had to run in this manner is that the lower shank does not accelerate forward fast enough for true running due to inertia. While the thigh segment quickly flexes about the hip, the foot tends to stay in place, causing the knee to flex beyond a desirable position and resulting in what is commonly referred to as "excessive heel rise." This excessive heel rise causes a delay in getting the foot-shank complex to move into extension which complicates the amputee's basic problem of not having active control of the knee. It seems that the harder the amputee tries to flex his hip, the worse the heel rise becomes.

The O.K.C. system strives to solve these problems. It consists of a cable-housing arrangement (similar to that on a below-elbow prosthesis) that travels behind the hip joint and anterior to the knee axis (Figure 1). The proximal end of the cable is attached to a belt similar to a Silesian bandage by a short piece of elastic webbing and Dacron tape which is adjustable via a 4-bar buckle. The distal end of the cable is fixed to the proximal anterior shank section of the prosthesis.

When the hip joint starts to flex, just at the moment of "running toe off," tension in the cable causes a dynamic extension moment at the knee. In other words, power is being transferred to the knee joint directly from the action of hip flexion. When the thigh is fully flexed, the tension in the system is at its maximum. This turns out to be very desirable biomechanically, since the knee needs to be fully extended at heel strike. The O.K.C. system therefore supplies a dynamic force to the shank, much as the quadriceps does in the normal human leg during running (Figure 2).

It has been our experience that it is easier to start using this system on children running on grass and advance to adults later for two reasons. First, children are not afraid to try to run, especially when the practitioner tells them they are now capable of it. Second, due to lower stresses in the system, the prosthetist can use conventional upper extremity cable and housing components that are readily available rather than specially made cable and hardware which are needed for adults. It has been noted that some children are able to remove the cable after a few months, (much as training wheels on a bicycle) and still do a fair job of running step over step. They gain confidence from the system and use it to fine tune their running capabilities. However, it has been our experience that when truly fast running is required as in competitive events, the patient prefers the O.K.C. System. Parents report that their children like to keep the system in place at all times since it gives them a natural dynamic quadriceps effect. However, some adults prefer to remove the O.K.C. System for normal locomotion.

For adult running, we have found that special aircraft grade cable and terminal ends are required due to the increased stresses in the system. It has also been discovered that monofilament fishing line (300–500lb. test line)

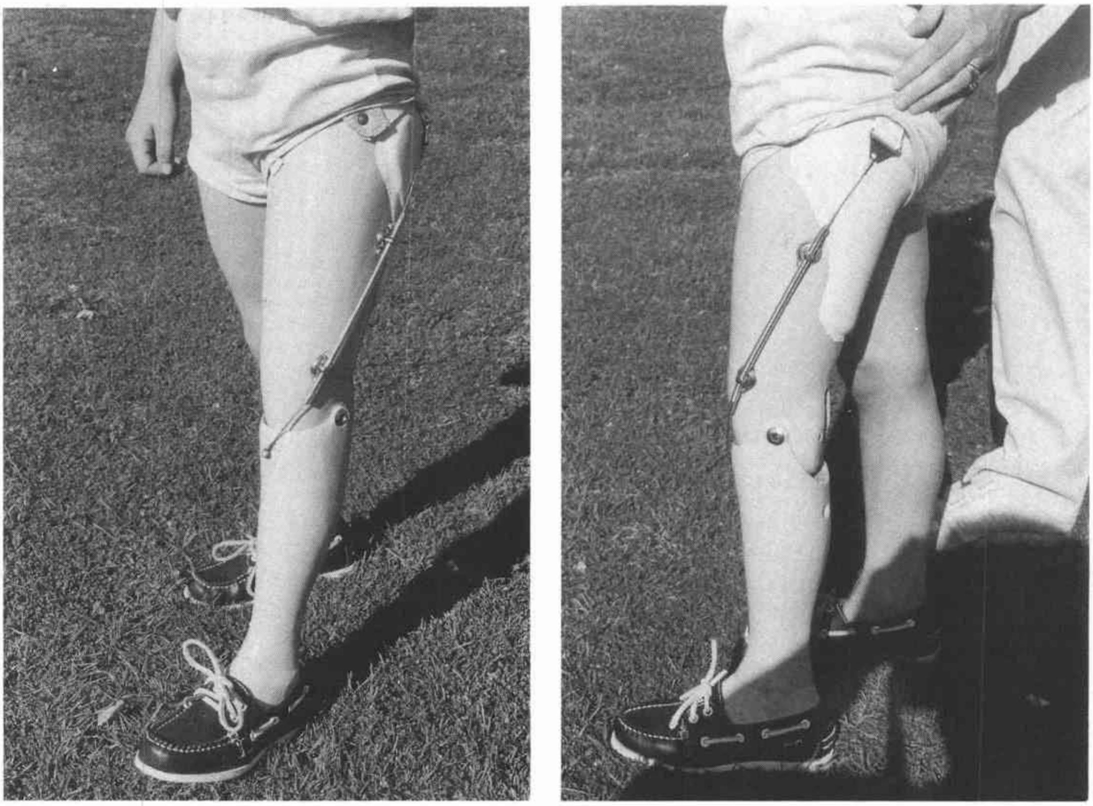

Figure 1. Lateral views of prosthesis showing path and attachment points of the OKC running cable.

works quite nicely as the coefficient of friction between the cable and housing is reduced. A plastic housing such as polypropylene tubing (commonly used in air conditioner drains) works best with this monofilament.

An extension aid of surgical tubing or elastic webbing augments the O.K.C. System and provides another method of fine tuning the system. Some competitive runners also like to use a flexion limiter with the system. This consists of a ¾'' thick piece of PE-LITE® at the back of the knee joint which does not allow the knee to flex completely. This flexion limiter acts as a compressive stop which tends to bounce the knee into extension and swings out of the way during normal walking. A variety of other methods of limiting flexion can be used.

To our knowledge, the first above-knee amputee to ever run step over step on an above-knee prosthesis was in March, 1982 utilizing an O.K.C. System. Since that day, many adults who enjoy competitive running or just sports in general have been fit. The shortest residual limb fit successfully with the O.K.C. System was on a 17 year old above-knee male with a 2⅞'' femur. The longest have been knee disarticulation amputees.

It is easier to implement this system if the patient is using an exoskeletal prosthesis, since the cable and housing have a natural surface to ride and sit on. However, we have placed several on endoskeletal systems with a little creative rigging (Figure 4). It is also possible to laminate a track directly into the thigh portion of the prosthesis which eliminates the need for housing. However, this sometimes causes excessive breakage unless a section of housing is extended distally to reduce the bending radius distally about the knee.

Sitting can be a problem unless the cable or monofilament is placed in such a way as to allow the cable and housing to move posterior to the knee during sitting. This prevents the creation of a knee extension moment, which

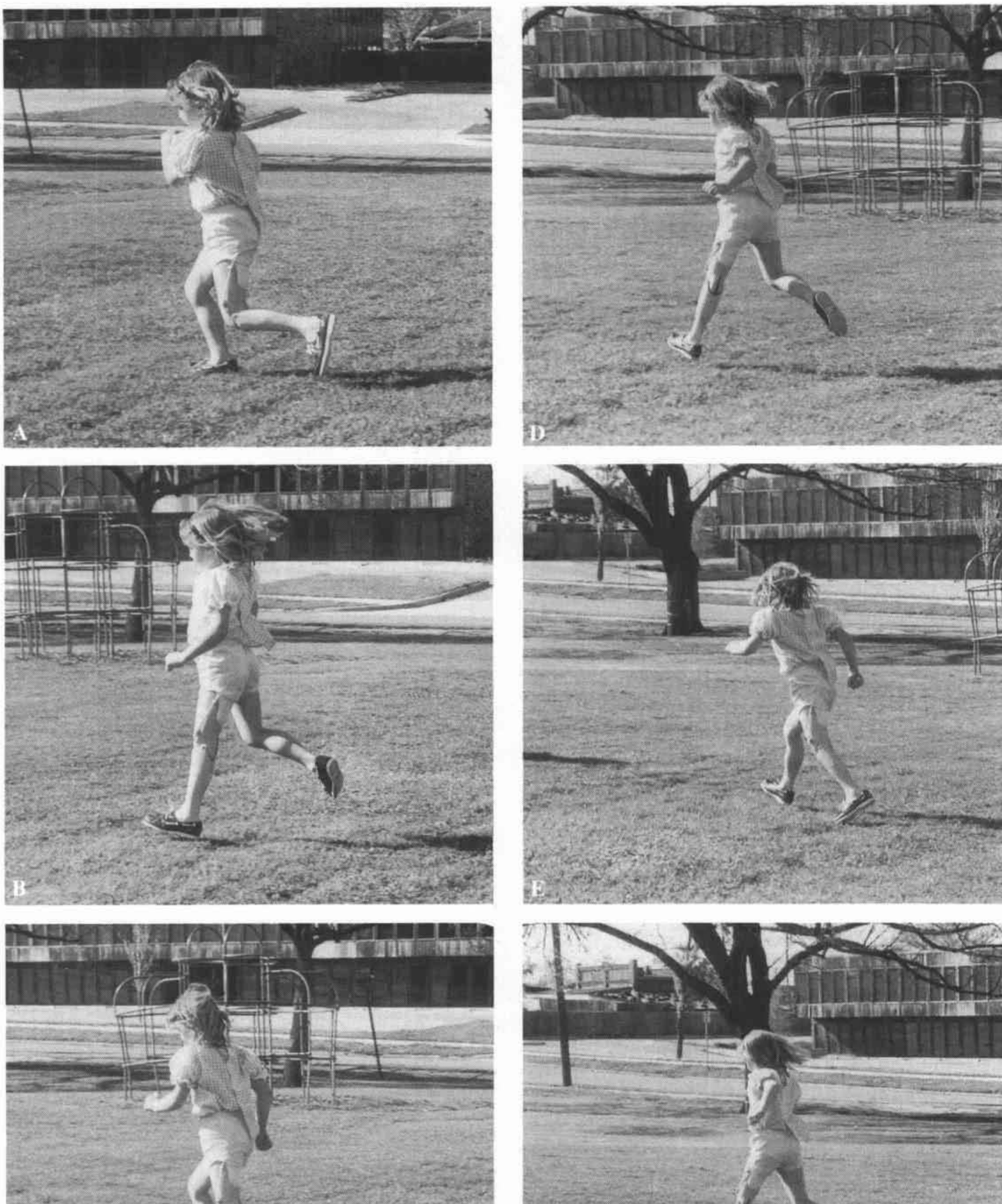

Figure 2. Running sequence showing action of the cable system.

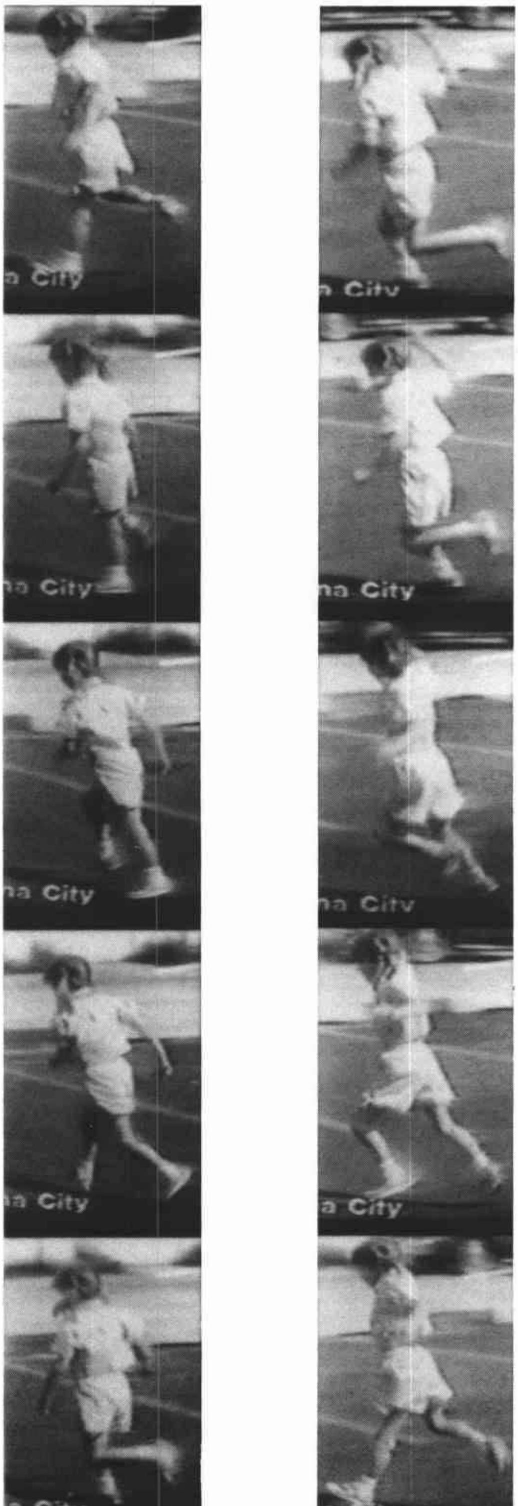

Figure 3 (left). Series of photographs taken from video screen.

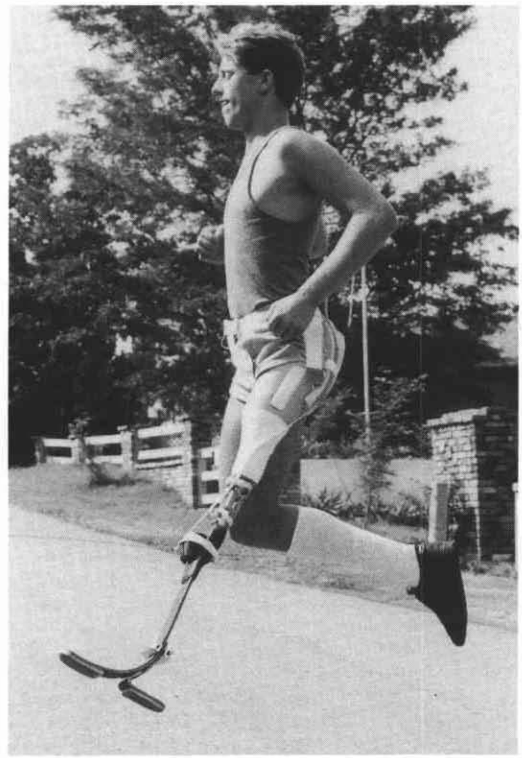

Figure 4. OKC running cable on an endoskeletal prosthesis. Aircraft cable and terminal ends were used in fabrication.

could be bothersome during sitting.

Last, we have found it most helpful that the heel portion of the prosthetic foot be soft enough to provide very easy planer-flexion so as to lessen the tendency for the knee to be forced into flexion by the ground reaction force at heel strike.

Author

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Clinical Prosthetics and Orthotics, Vol. 11, No. 3, pp. 173–175

Below-Knee Waterproof Sports Prosthesis with Joints and Corset

by Alfred W. Lehneis, C.P.

This article is concerned with the development of a waterproof below-knee prosthesis with knee joints and corset, utilizing the supracondylar/suprapatellar (SC/SP) suspension socket. A case report is described below.

The patient had a below-knee amputation due to traumatic injury with a resultant amputation length of the tibia of approximately 1″ (Figure 1). This patient currently wears a PTB type socket with leather thigh corset, polycentric joints and an SC/SP suspension socket, thus, no auxilliary suspension was necessary (Figure 2). He was doing well with this design in all activities of daily living, but desired a waterproof prosthesis for boating.

In developing the waterproof design, the following components were utilized: Kingsley beachcomber foot, Otto Bock polycentric stainless steel knee joints, and a corset fabricated from 4mm Subortholen thermoplastic. Closures were 1″ dacron straps with virgin nylon buckle closures used on scoliosis type body jackets.

Figure 1. Length of tibia is approximately 1″.

The fitting and fabrication of the prosthesis was as follows: the patient was casted (including the thigh) and the cast modified, using standard procedures for SC/SP suspension, an insert was fabricated from Pelite™, and the socket was fabricated with acrylic resin and carbon/glass reinforcements, especially at the side bar attachment sites.

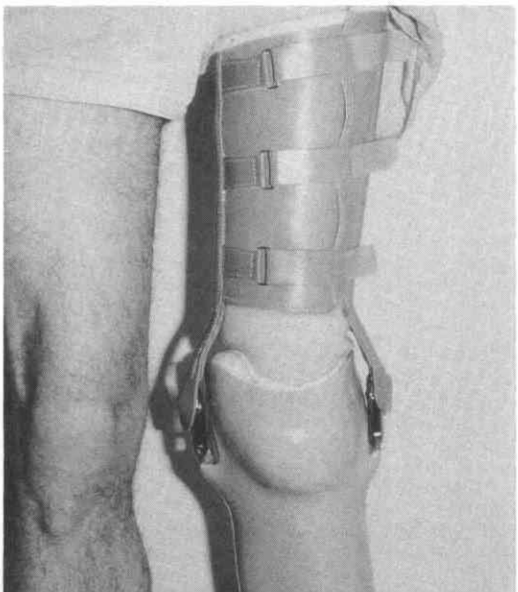

Figure 2. Patient currently wears a PTB type socket with a leather thigh corset.

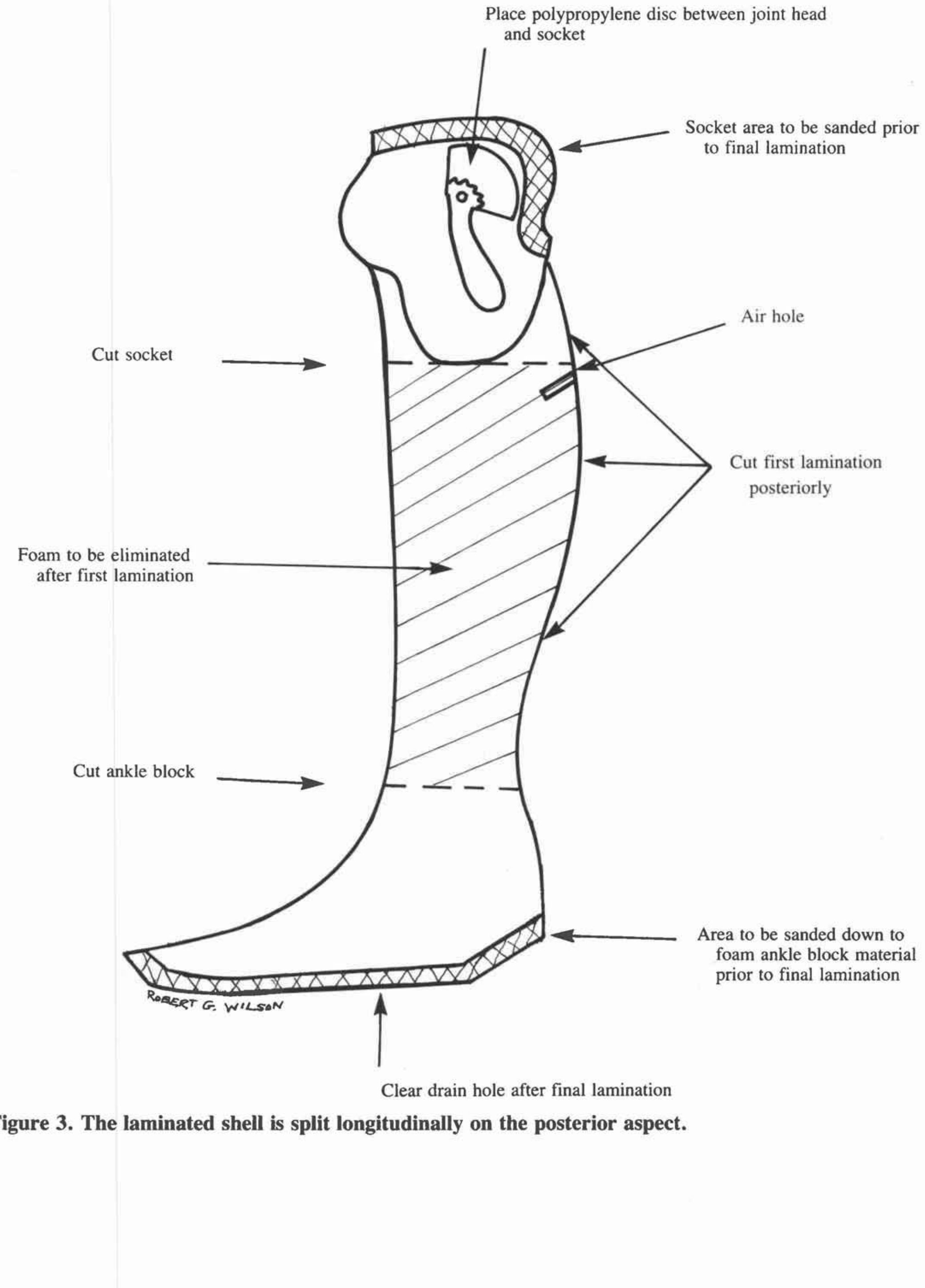

Figure 3. The laminated shell is split longitudinally on the posterior aspect.

After fabrication of the socket, the socket was foamed up and set-up on a Staros-Gardner coupling and aligned atop the beachcomber foot. The bars were then attached directly to the socket (not over the foam build-up), and the area over the bars filled with fiberglass/resin putty. The thigh bars were contoured to the modified cast, over which the Subortholen thermoplastic had been molded and attached to the corset. The patient was then fitted and aligned in the usual manner, but while wearing topsider type boating shoes.

After optimum alignment was achieved, the Staros/Gardener coupling was transferred out. This can be accomplished on a horizontal transfer device. The prosthesis was then shaped to the patient's tracing and measurements and reduced to accommodate the lamination thickness. The sole of the foot is then removed and a woman's nylon is pulled over the entire prosthesis, followed by the PVA sleeve. A lamination of one carbon-glass and two nylons without pigment is performed. After the lamination is set, the laminated shell is split longitudinally on the posterior aspect (Figure 3), taken off the prosthesis, and taped back together to retain its shape.

The shaped portion of the prosthesis is cut to allow for a 3″ ankle block and the socket is cut at the base. The foam between the ankle and socket is now eliminated (Figure 3). The foam ankle block and the foam at the base of the socket can be sealed with a resin-silica mix to prevent water penetration.

The laminated shell should be sealed with tape on the outside, and the seam should be sealed on the inside with Siegelharz. The socket and ankle block can then be bonded to the laminated shell. Once this is set, the outer shell should be sanded for a second lamination, and approximately 1″ of the proximal socket and distal ankle block perimeter should be exposed (Figure 3).

The prosthesis is then filled with sand through the hole at the bottom of the ankle block. The hole is then sealed with play dough. Lay-up of the prosthesis consists of six alternating layers of nylon and nyglass. Two pieces of polypropylene with 120° arcs (Figure 3) should be placed between the joints and the socket after the first two layers to allow attachment of the joint clevis after lamination. These pieces are removed after lamination. The foot drain hole is then reopened to release the sand. A second ½″ hole should be drilled posterior and distal to the socket end to allow air to enter and escape the inner hollow of the leg. This allows water to enter and escape the foot drain hole and prevent bouyancy of the prosthesis.

The thermoplastic corset is finished with a polyethylene tongue and dacron strap closures as described earlier. When assembling the prosthesis, bonding of the foot should be as recommended by Kingsley, Mfg. or using Devcon two-part epoxy.

Acknowledgments

The author gratefully acknowledges the technical contribution of Roger Losee, C.O., and Robert Wilson, M.S., for the illustration in Figure 3.

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Seating for Children and Young Adults with Cerebral Palsy

by J. Martin Carlson, M.S., C.P.O.
John Lonstein, M.D.
Karen O. Beck, R.P.T.
David C. Wilkie, B.F.A.

Introduction

This paper will reflect the experience, perspective, and design rationale of one institution rather than attempt to give a comprehensive survey of the full spectrum of experience and designs.

Several examples are given and references made to Duchenne muscular dystrophy (D.M.D.). The D.M.D. examples are used when they are particularly good illustrations of a general principle which helps complete our understanding of seating for children with cerebral palsy. For more information on our experience and rationale relative to seating boys with Duchenne Muscular Dystrophy, refer to the reference section.[2]

The study of seating has many facets (cosmetic, functional, economic, etc.) and many professional perspectives (engineer, therapist, orthotist, physician, manufacturer, etc.). Engineers tend to relate to biomechanics and the economics of standard design. Therapists are concerned with function, development, inhibition of spasticity, etc. Each medical specialist has a different predominant focus. In different settings, it is inevitable that availability of professionals, availability of funds, age and severity of client population culture, etc., vary, and these factors will direct the seating program. Another important factor is that orthotists have not traditionally been trained in the provision of special seating, most are not active in special seating, and in most communities, there is a shortage of orthotists. These realities are a major reason why pre-manufactured, easy to assemble, and adjustable designs have predominated in many regions. The potential for commercial success and profit for the manufacturer, the ability to provide a system without the involvement of orthotic professionals (who are scarce and often inexperienced in seating), and the need to minimize costs, all seem to be best served by the wide distribution of premanufactured designs. In many communities, that is the best option available at this time. However, there are communities and settings wherein the circumstances make it possible to have the advantages of custom fabricated designs.

To help you put this paper into perspective, we need to provide some information on the history of our seating program. The Orthotic/Prosthetic Laboratory at Gillette Children's Hospital became involved with seating in 1974. Our seating program developed out of almost ideal circumstances. Orthotic services were strong and there was a close working relationship between our orthotists, therapists, and medical specialists. Weekly clinics brought a steady stream of clients through our outpatient clinic where the team members worked together to solve both general and individual problems. Also extremely important was our strong tradition and mechanisms for follow-up, which provided us with excellent feedback. Our early entry into seating, and the growth of the program, quickly gave us a significant volume so that specialists could be assigned and efficient procedures developed.

Another factor bearing positively on our program is Gillette's extensive experience in spinal orthopedics. Spinal support to resist the development of spine deformities is therefore an ever-present consideration.

Although we have some experience with people of middle and advanced age, our experience at Gillette Children's Hospital is primarily with people from birth into young adulthood. This younger age group will be the focus of this paper. Our client population with cerebral palsy includes the full spectrum of severity, but the very severe cases far out number the less severe.

It is important that we all endeavor to recognize and respect the various aspects, perspectives, and variable circumstances mentioned earlier. Two very different seating programs may offer equally excellent care, but both can be even better if they "compare notes." This paper is a compilation of our "notes."

Fundamental Goals

The seating systems we provide must benefit the impaired person, those who care for that person, and society. Balanced against that, every piece of equipment inherently carries costs and disadvantages. Our systems cannot be all things to all people, but we will most nearly approach the ideal by keeping our sights aimed directly at the fundamental benefits and goals, while we endeaver to minimize the negatives.

What are the fundamental goals? The main categories are outlined below.

1) Function
2) Orthopedic/Neurologic
3) Cosmesis
4) Safety
5) Economy

Function is primary. It affects a range of activities and benefits which can be best explained by examples: recreation for the child and family; making it easier for a care worker to feed a youngster; improving the child's field of vision; increasing his comfort; increasing the level of independence, etc. A functional seating system improves the child's development, decreases the amount of work required to take care of the child, and promotes a more enjoyable existence for the entire family.

From an orthopedic/neurologic standpoint,

Figure 1. A typical example of sitting alignment control in a young person with severe cerebral palsy provided with only minimal propping aid (wide spaced arm rests). He is much more able to control his head and neck position than his pelvis. (Also see Figure 5, an example of an x-ray taken under the same conditions.)

the ideal would be to prevent the progression of hip and spine deformities, and maintain body positions which reduce spastic reflex patterns. The expected benefits are better voluntary control, less severe deformity, less surgery, and a corresponding decrease in the work and cost of daily care. The advantages are perhaps most apparent to those of us who have visited state hospitals and have seen severely involved adult patients who were maintained only in recumbent positions during their earlier years. Positioning options for these adults are so severely limited that constant and expensive care is required to prevent ulcers and maceration. Also, hospitalization for those problems and pneumonia tend to be more frequent.

Cosmetically the ideal is a well camouflaged, hidden, or attractive seating system which helps the youngster sit upright with the

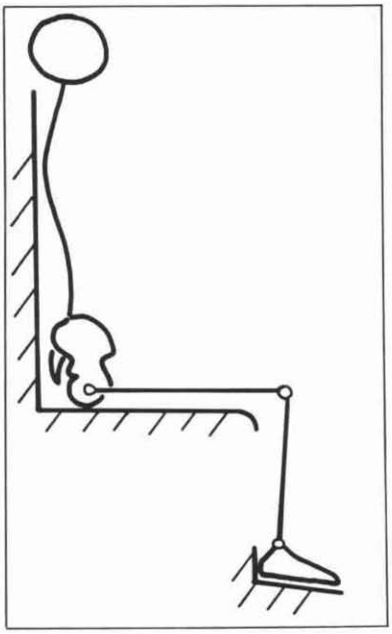


Figure 2. Sagittal view of "standard" sitting posture. In most cases, seats should be designed to biomechanically urge the sitting posture toward this configuration, with variations as necessary to inhibit spastic reflex patterns.

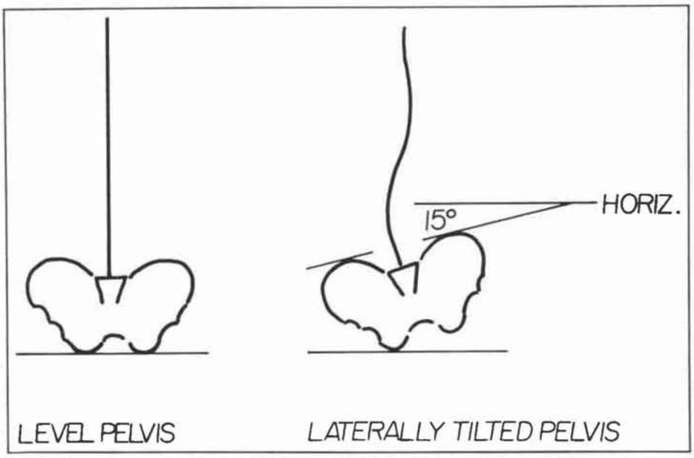


Figure 3. Proposed nomenclature to describe seated pelvic misalignment in the frontal plane.

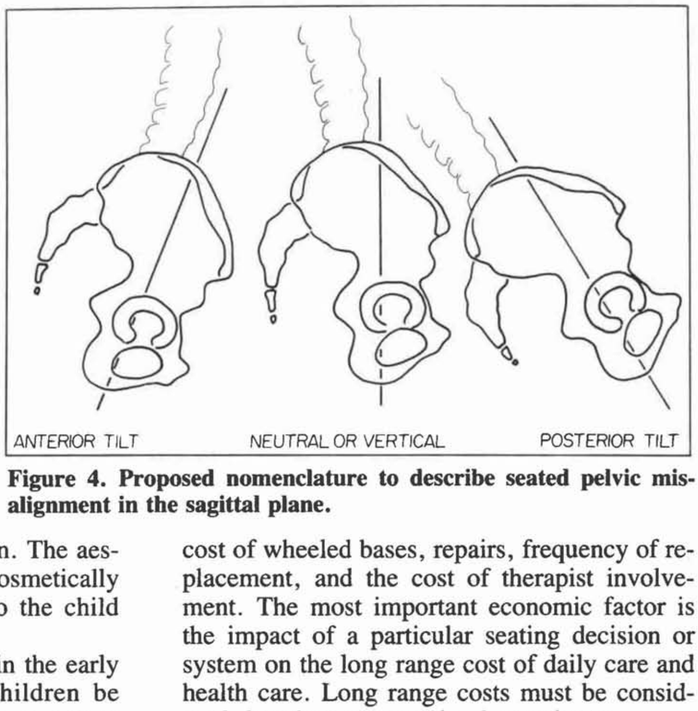


Figure 4. Proposed nomenclature to describe seated pelvic misalignment in the sagittal plane.

head in a position to see and be seen. The aesthetic and emotional benefits of a cosmetically appealing seating system accrue to the child and everyone in his environment.

Federal laws passed in the U.S. in the early and mid 1970's mandated that children be transported from their living environments to educational settings. Safe transportation necessitates secure seating. Ultimately, society benefits, both tangibly and intangibly.

Comparing the costs of various seating approaches is difficult because of the many costs which should be taken into account and the complexity of the various alternatives. We must take into account the cost of the seat, the cost of wheeled bases, repairs, frequency of replacement, and the cost of therapist involvement. The most important economic factor is the impact of a particular seating decision or system on the long range cost of daily care and health care. Long range costs must be considered, but they are very hard to estimate.

Biomechanics of Seating

The unimpaired human trunk-neck-head complex receives its stability partly from the spinal column acting as a controlled stack of compression elements and partly from a multitude of muscles acting in several different

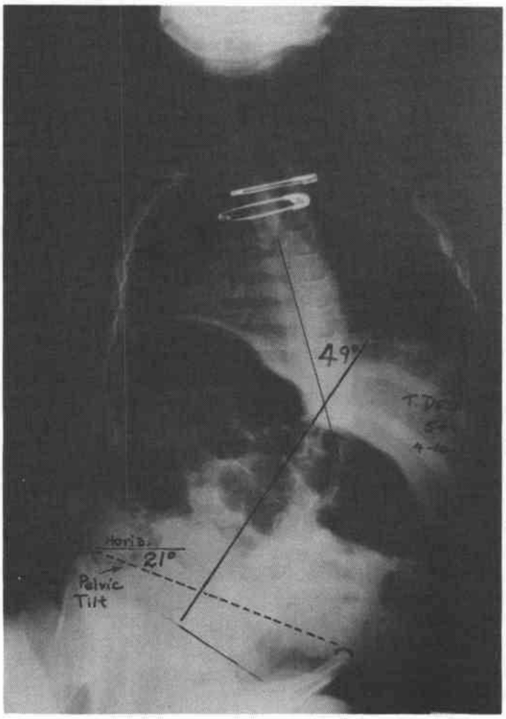


Figure 5. This is an x-ray illustrating the typical tilt of the pelvis in the direction of the convexity of the major scoliosis curve.

ways. The paraspinal muscles have a direct action on the configuration of the spine through extension, lateral flexion, and rotation. The abdominal (and to some extent, costal) muscles, in addition to being direct skeletal motors, affect the spine's stability and configuration indirectly, but importantly, through their action on the viscera. Muscle action to constrict and control the circumference of the abdomen and thorax allow compressive body weight loads to be taken partly down through the fluid filled abdomino-thoracic cylinder rather than all acting down through the spinal column. This adds significantly to the stability of the torso. We must note that recent research by Nachemson, et al.[6] (indicating that the Valsalva maneuver fails to lower pressure in the intervertebral disks) challenges this classical explanation of Morris,[5] but does not propose a new analysis of abdominal muscle function in trunk stabilization. Swedish data suggests that we don't fully understand what the Valsalva maneuver consists of and how it functions biomechanically. (The Valsalva maneuver is a general tensing of abdominal muscles.)

The normal activity of sitting consists of a series of frequently changed postures. Each of those postures would be non-functional, uncomfortable, and even injurious if it were the only posture available to us and maintained for hours. It is the frequent voluntary change which makes those postures collectively safe, acceptable and tolerably comfortable for more than ten minutes. It is quite an undertaking to design a seating system in which our client can safely and comfortably sit, with little or no change, for a matter of hours. In the case of a person with cerebral palsy, the abnormally high muscle tone about the pelvis and thighs is the major reason this an be accomplished.

It is important to note that when a child has some limited postural alignment capability, that capability is greatest at the head and neck. There is less ability to control the pelvis (Figure 1). (This capability reflects the early developmental stages of an infant, but when we see it in the older child, it represents delayed or arrested development.) Arm-propping is typically used to stabilize the upper thorax for effective

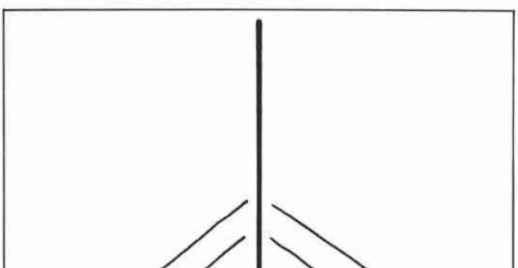


Figure 6. When abdominal and lower costal muscles are flaccid, a simple corset, providing snug circumferential constraint helps to create a hydraulic load bearing column. This reduces the collapsing load on the spinal column.

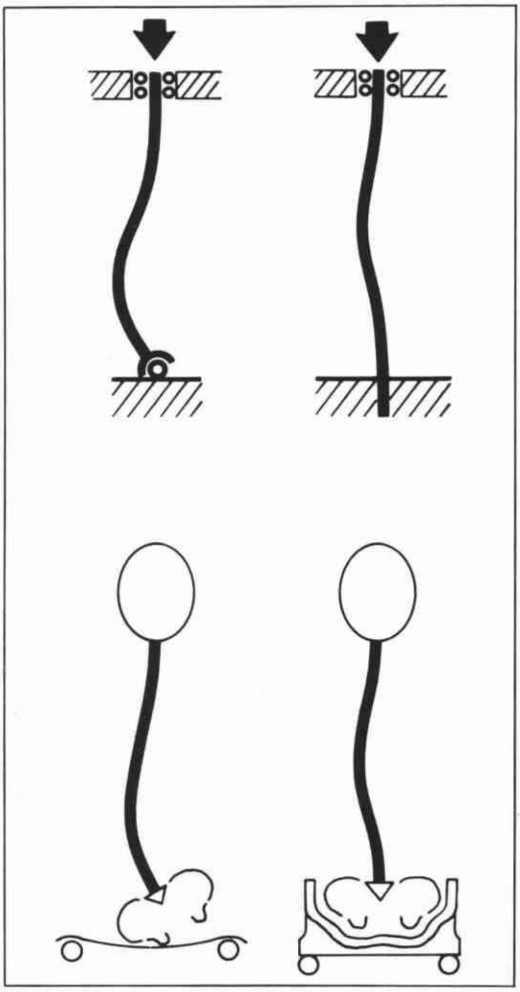


Figure 7. The unconstrained-pelvic condition illustrated on the lower left is similar to the pin jointed base end-condition represented above it. The constrained-pelvis condition illustrated on the lower right can be compared to a built-in base end-condition. The column with the built-in end is approximately twice as stable as the column with the pin jointed end.

neck and head control. This illustrates two seating principles. The first is that the postural control and use of the superior body elements is dependent on the stability of body elements inferior to them. Second, the seat should bring the stability from the pelvis upward to meet the descending/decreasing voluntary stability of the client. Terminating stability too low will fail to maximize the child's function. Carrying stability too high will deprive the client of his full voluntary movement capability.

Since "normal" sitting postures are so variable and changeable, we cannot relate supported sitting postures to a specific normal posture. We must reason and choose a sitting posture which has the most advantages, and propose it as a "standard."

We choose the "sitting at attention" sagittal configuration (Figure 2), because it represents a mid-range spine configuration, it allows significant weight bearing on the proximal thighs as well as the bottom of the pelvis, it is a cosmetic posture (chest and head upright, facing outward), and it is a functional posture (head in a position to observe and thorax and shoulders forming a secure base for the neck and arms to move). In the sagittal plane, the sacrum is tilted anteriorly a moderate amount. There is moderate lumbar lordosis, thoracic kyphosis, and cervical lordosis. We would further propose that the "standard" posture consists of a pelvis level and the spine straight in the frontal plane. When the left side of the pelvis is elevated, the pelvis is said to be "tilted rightward," and when the right side is elevated, it is "tilted leftward" (Figure 3). Likewise, in the sagittal view, the pelvis is "tilted posteriorly" or "tilted anteriorly" depending on which direction the upper parts of the pelvis are oriented relative to "standard" (Figure 4). In the transverse plane, if the right side of the pelvis is rotated forward relative to the shoulders, we would say the pelvis is "torqued leftward." We do not present this nomenclature as the most correct, but offer it for use in the absence of standard nomenclature.

Cerebral palsy is a disease that expresses itself in a wide variety of static and dynamic patterns, and we cannot go into the mechanics of all those variations. We will limit ourselves to a discussion of what, in our experience, is the most common combination.

Fortunately, even some of the children with severe cerebral palsy do not have a significant deformity or collapse in the frontal plane. This is not to say, however, that scoliosis is rare in this group. Scoliosis is quite common, and we see very severe cases. When we examine a child with scoliosis, we should evaluate whether or not the scoliotic collapse is aggravated by asymmetric trunk muscle spasticity.

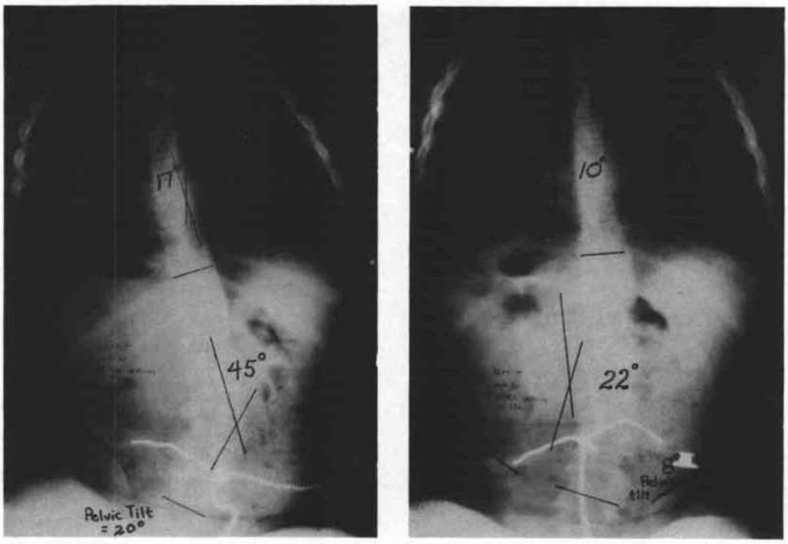


Figure 8. Photos of x-rays taken before (left) and just after (right) the child's pelvis was leveled in the sitting support orthosis illustrate the stabilizing benefit of pelvic control.

Figure 9. Left and center x-rays show the deterioration which occurred during a time period when the pelvic leveling procedure was not used. The x-ray on the right shows the immediate effect of leveling (to the extent then possible) and controlling the pelvis.

Figure 10a. S.T., a 12 year old boy with Duchenne muscular dystrophy, seated as he was presented to us.

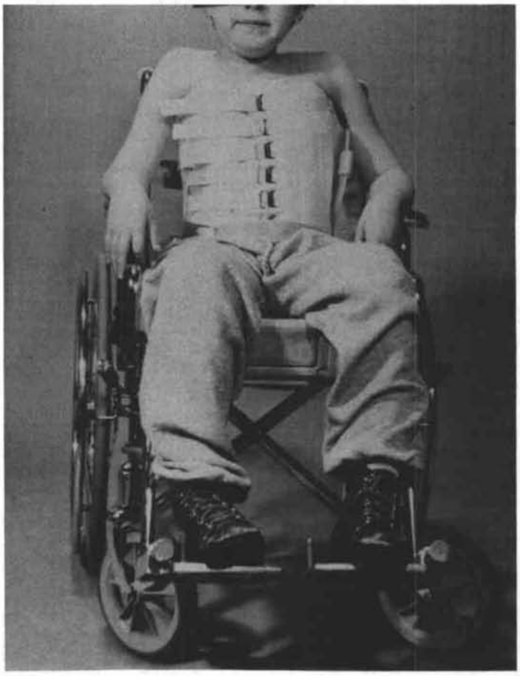


Figure 10b. S.T. in the sitting support system we provided.

We can expect to be much more effective at controlling a scoliosis deformity when asymmetric trunk muscle spasticity appears *not* to be a significant factor.

One of the usual characteristics of scoliosis in neuro-muscularly impaired sitters is lateral tilting of the pelvis in the direction of the convexity of the major scoliosis curve (Figure 5). This is not surprising when we consider that pelvic orientation is usually not under voluntary control. This characteristic will become more interesting later as we discuss the various methods for generating spine stability.

There are several distinct biomechanical schemes for providing spine stability to resist scoliosis. These schemes do not, of course, operate exclusively in the frontal plane. Also, the employment of one scheme does not preclude the simultaneous employment of one or more other schemes. The first and most familiar of these is "three-point-force." We need not explain the principles of this scheme since they are so well known. However, it is appropriate to note that three-point-force schemes are much less effective at stabilizing a multi-joint, multi-axis system such as the spinal column, than stabilizing a single-joint system such as the elbow or knee. The application of the three-point scheme in a spinal support system, which includes a seat, has some advantage over a traditional spinal orthosis in that the most inferior force can be located at greater distance from the more superior forces to give a longer moment arm. However, the more the client functionally moves in his seated position, the less the seat is able to apply three-point support, because it doesn't move with the client. Furthermore, a spinal orthosis can be worn 23 hours per day, if necessary. These latter considerations make the spinal orthosis a stronger orthotic treatment of progressive spine deformity.

The second scheme we will discuss has to do with the Valsalva maneuver, given earlier, in which the abdominal and costal muscles function to relieve the spinal column of compression and bending loads. No matter what exactly happens during the Valsalva maneuver, the Morris explanation is a valid biomechanical analysis of how a snug corset contributes to

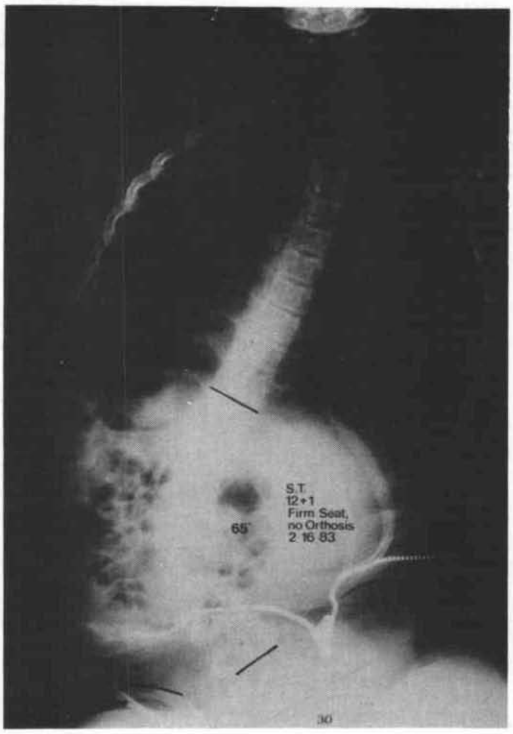


Figure 10c. Spine x-ray of S.T. sitting unsupported as presented, showing a scoliosis of 65° and a lateral pelvic tilt of 30°.

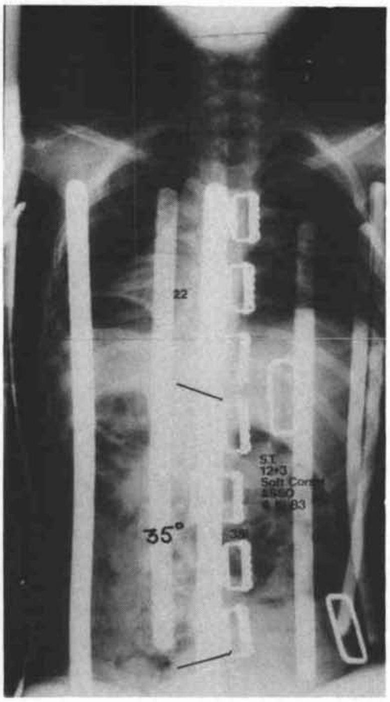


Figure 10d. Spine x-ray of S.T. sitting in the support system we provided. The scoliosis is reduced to 35° and the lateral pelvic tilt to 14°.

trunk/spine stability in the presence of flaccid paralysis of abdominal and costal muscles. Engineering analysis and empirical evidence indicate that when we passively apply circumferential abdominal constraint (ie. a snug corset), a hydraulic load bearing column is created and we reduce the magnitude of flexible collapse (Figure 6). In our experience, the corset is seldom used for children with cerebral palsy, but is virtually always useful for children with muscular dystrophy.

The third scheme for enhancing spine stability derives from the fact that the sacro-pelvic complex forms the foundation on which the flexible spinal column rests. Voluntary pelvic control is an important component of spine stability in the unimpaired trunk. If, by a conforming design about the pelvis and a proper donning procedure, we can increase the foundation (bottom end) constraint conditions, much is added to spinal stability. The pair of diagrams on the left side of Figure 7 illustrates the similarity between the spinal column in the case of an uncontrolled pelvis and the slender column pin jointed (free to tilt) at its lower end. The two diagrams on the right in Figure 7 illustrate the similarity between the controlled pelvic case and the built-in base end condition. Elastic column buckling equations for the two beams indicate that the built-in beam will withstand almost twice as much load as the other before buckling.[4] To achieve this end condition stability, we need a well made seat, as well as a procedure to level the pelvis each time the child is seated.

To fully appreciate the strength of this scheme in practice, compare the two x-rays in Figure 8. Figure 8a is the x-ray taken just before the pelvic leveling procedure was performed and Figure 8b is the x-ray taken a few minutes later, after the pelvic leveling procedure was performed. The Cobb angle is reduced from 36 degrees to 20 degrees by this quick procedure, which is normally performed as a routine part of positioning the child in the sitting support orthosis. These x-rays are of a

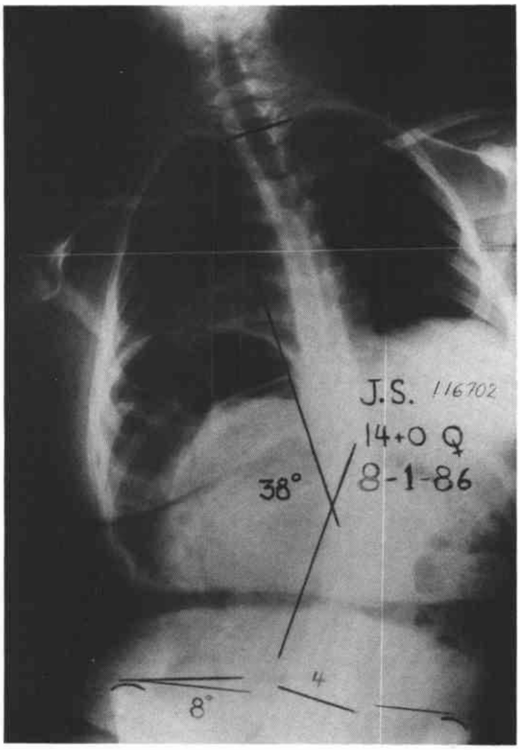


Figure 11a. This x-ray of J.S., a 14 year old girl with cerebral palsy, presented with a pelvic rightward tilt of 8° and a convex-right thoraco-lumbar scoliosis of 38°. Her shoulders were tilted 13° degrees toward the left. Her clinical appearance verified the features noted on the x-ray. She occupied her right arm almost constantly as a lateral prop.

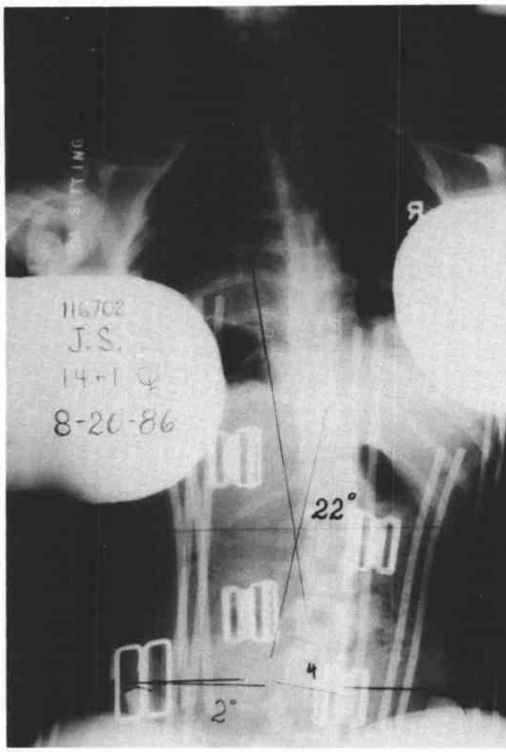


Figure 11b. J.S. was provided with a sitting support system consisting of soft corset worn under her clothing and a somewhat abbreviated S.S.O. Her system was almost identical to that provided to S.T. (see Figure 10b). This x-ray shows a pelvic tilt reduced to 2°, the scoliosis curve reduced to 22°, and her shoulders level. She liked the system because her hands were free and she found breathing easier.

boy with Duchenne muscular dystrophy; he was not wearing a corset.

A second example is given in Figure 9. The left and center x-rays show the progression which occurred in the eight months following fitting. During this period, the parents did not use the pelvic leveling procedure. The x-ray on the right was taken a short time after the center x-ray, with the only difference being the pelvic leveling procedure was performed before the last film. Note: once a spine deformity has become partially structural, the pelvis can be leveled only to the degree that the deformity is still flexible.

In summary, maintaining a level pelvis makes it easier to control the spine. Pelvic control and orientation in the frontal plane also relates strongly to the uniformity of pressures in weight bearing areas and minimizing the progressive deterioration of sitting comfort.

Let us now look at two examples where these stabilizing schemes have been simultaneously applied. Figure 10a is a photo of a 12 year old boy with muscular dystrophy, sitting as he was presented to us. Figure 10b shows the sitting support system properly applied. The corset is entirely independent; it is not attached to the seat. Figures 10c and 10d compare his A-P spine x-rays with and without the orthotic system. The lateral tilt of his pelvis is reduced from 30° to 14°. The Cobb angle of his scoliosis was reduced from 65° to 35°. Curve control of this magnitude is not unusual as long as the deformity is still flexible. Figure 11a is the x-ray of J.S., a 14 year old girl with cerebral palsy. She presented a right thoraco-lumbar scoliosis of 38° and a rightward pelvic tilt of eight degrees. Her shoulders were tilted 13° to the left partly because she used her right arm for propping to avoid falling to the right. We provided her with a soft corset and the Gillette Sitting Support Orthosis. The Sitting Support Orthosis was to provide pelvic control and bilateral "propping" support. It had no head rest or anterior support. The x-ray taken just after fitting shows pelvic tilt reduced to two degrees (Figure 11b), the Cobb angle of the scoliosis reduced to 22°, and shoulders leveled. Both hands were free to function, and she said she could breathe deeper.

Figure 12. Example of a Sitting Support Orthosis designed to accommodate a right hip extension contracture.

Figure 13. A diagram of a sitting posture caused by overactive hip extensors and inadequate thoracic extensors.

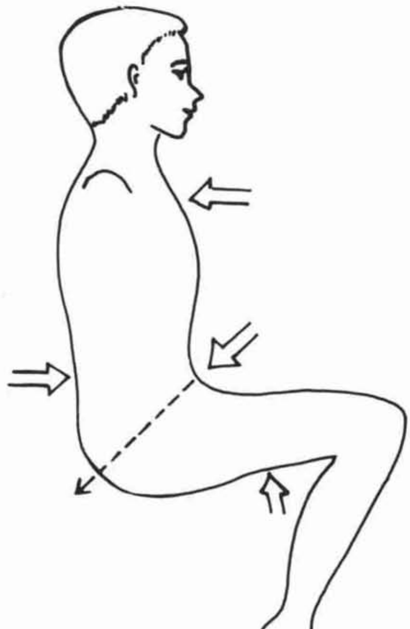


Figure 14. A diagram showing the thigh, pelvic, and lumbar forces essential to flex the hips, reduce pelvic posterior tilt, and restore lumbar lordosis. It also shows a fourth force, at the upper thorax, sometimes necessary to aid thoracic extension.

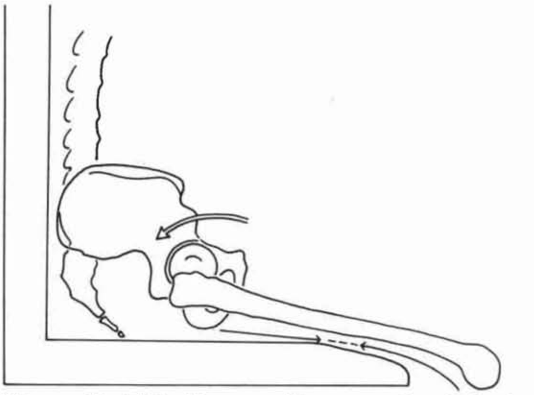


Figure 15. This diagram illustrates the skeletal alignment which actually occurs when someone with over-active hamstrings sits on a horizontal, lightly padded seat.

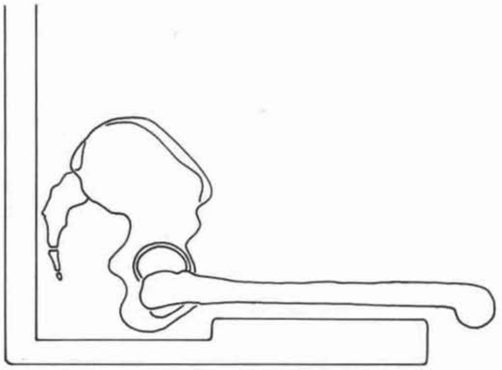
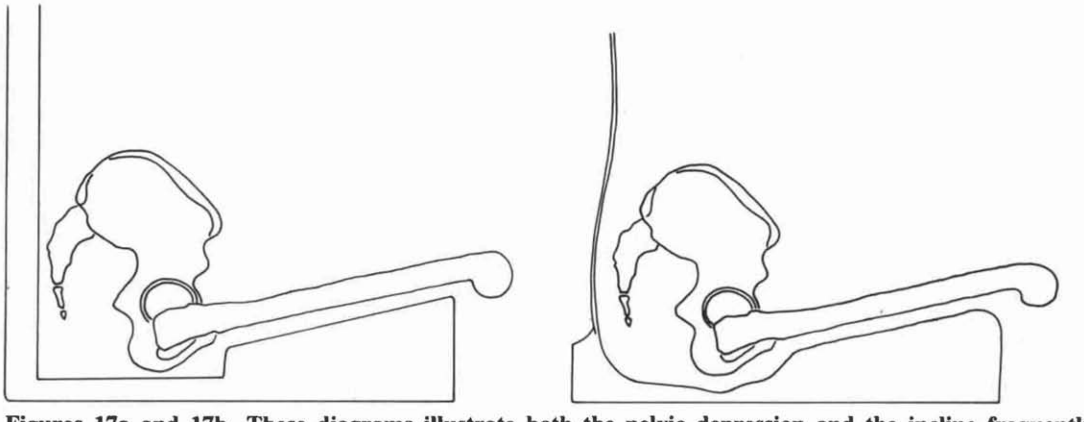


Figure 16. A depression under the pelvis is necessary to maintain horizontal thighs.



Figures 17a and 17b. These diagrams illustrate both the pelvic depression and the incline frequently needed in, (a) an upholstered seat and, (b) a contoured seat.

In cerebral palsy, we occasionally see a case of lateral pelvic tilt and scoliotic posture secondary to a unilateral hip extension contracture. A right hip extension contracture, if not accommodated, will cause the right side of the pelvis to be elevated. The pelvis will be tilted leftward and a compensatory convex left scoliosis will be produced. When we see this problem, it is usually an older child or adult. Figure 12 is an example of a rather extreme case of how the deformity was accommodated to minimize pelvic and spinal malalignment and stress.

In the sagittal view, we commonly see a posture dominated by the powerful, very active hamstring muscle group. The gluteals are often helping to resist adequate hip flexion for an ideal sitting alignment. To a greater or lesser degree, the pelvis is maintained in a posterior tilt position with weight bearing shifted posteriorly toward the sacrum. This pelvic alignment

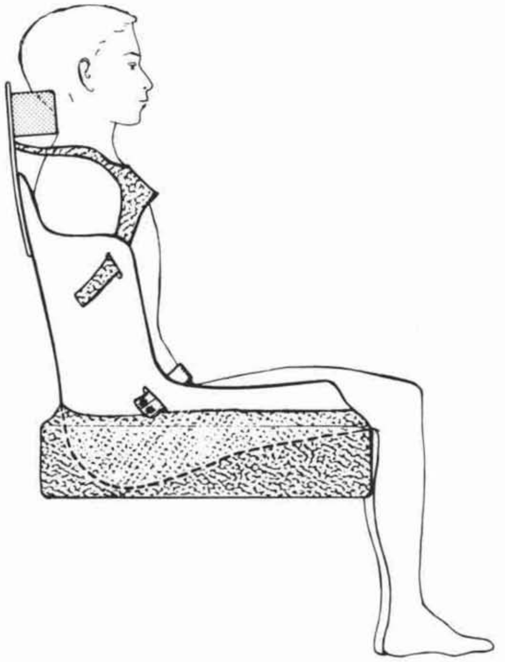


Figure 18. A diagram of the contoured plastic shell Sitting Support Orthosis (S.S.O.)

Figure 19. Anterior view of the child in his S.S.O. This photo illustrates how the thin polypropylene shell can achieve high bilateral thoracic support without interfering with arm position.

tends to reduce lumbar lordosis and convert it to a kyphosis (Figure 13). The loss of lumbar lordosis makes it more difficult for the thoracic extensors to maintain a vertical upper thorax. This explains why a flexible spine, maintained with a pelvic belt and lumbar bolster to restore lumbar lordosis, often produces better active alignment of the upper thorax and head. (We would caution you that different solutions are necessary for people with rigid hyperkyphosis.)

The three forces needed to maintain the position of the pelvis and lumbar spine are the thigh support, lap belt constraint, and lumbar support (Figure 14). Attention must be given to properly provide all three. The seat bottoms must be configured specifically to provide optimum thigh support. A flat horizontal seat bottom will never maintain hip flexion against active extension (Figure 15). The anatomy itself calls for a depression under the pelvis to bring the femurs to a horizontal position (Figure 16). More importantly, the hip flexion required to "break through" the extensor spasticity varies from child to child, but we usually find that some degree of seat bottom incline (pelvis to knees) is needed for the more severely involved children (Figures 17a and 17b).

The pelvic belt force is perhaps the most critical. The pelvic belt must be perfectly anchored: close to the body posterolaterally for good "wrap around" and at the correct level to achieve a good downward force component (Figures 18 and 19). The most common mistake is to anchor the lap belt too high. We have never seen one anchored too low. (We must remember that none of the hip/lumbar support forces function properly in service unless the caretakers know why and how to put the pelvis in position and snug up the pelvic belt. Without education and training of the users, our designs are worthless. We must train and retrain on every return visit.)

A fourth support force is sometimes needed in the area of the upper thorax or shoulders to maintain adequate thoracic extension. This is accomplished with a vest or shoulder straps which must be adjustable for grading the amount of support to fit the need, which may vary through the daily routine of activities.

Seating misalignment and deformity problems in the transverse plane are not uncommon among the severely involved cerebral palsy population. The problem consists of the pelvis being torqued right or left by deformities

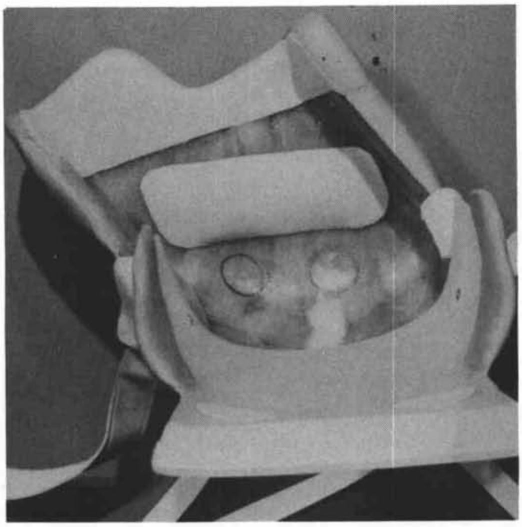


Figure 20a. Top view of a Sitting Support Orthosis for B.K., who, with a diagnosis of cerebral palsy, has a "windblown hips" deformity.

Figure 20b. Top view of B.K. sitting in the orthosis. Direction of the thigh section is designed to minimize the rightward torque of the pelvis and the corresponding spinal twist.

of one or both hips. A severe adduction contracture of the right hip will, for instance, cause a seated misalignment which includes leftward direction of the thighs (with respect to the pelvis), a rightwardly torqued pelvis, and an apparently (not actually) short right femur. This misalignment has been well diagrammed in an article by Mercer Rang, et al.[7] A severe abduction contracture of the left hip will cause a similar misalignment. These deformities are often referred to as "wind blown hips." We can see that when such a condition exists, forcing the thighs to be aligned straight forward will obligate the client to sit facing to one side, or the spine will be continuously twisted. In most cases, the direction of the thighs may be altered enough to avoid much of the spinal twist. Figure 20a is a photo of a top view of a Sitting Support Orthosis we provided for such a client. Figure 20b is the same view of the client in the orthosis.

It is of utmost importance, as we treat these clients, that we keep function and quality of life issues uppermost in our mind. Biomechanics and deformity prevention ideals often must be compromised to avoid undue impingement on any aspect of the child's development or function.

Client Evaluation

Seating evaluations at Gillette always include an orthotist, a therapist, and a physician in addition to the client, parents or caretakers, and, if available, a community therapist. The physical evaluation includes an assessment of orthopedic deformities, spastic reflex patterns, voluntary sitting capability, and other functional abilities. To assess sitting ability, two people manually control the child's thighs, pelvis and lower trunk. If, with this amount of stabilizing assistance, the child still cannot manage an upright sitting posture, we would grade voluntary sitting capability at non-existent to poor. If the child can, with that assistance, struggle to an upright sitting posture and maintain it for fifteen seconds, we would grade voluntary sitting capability at poor to fair. Better performance would be graded accordingly as better than fair.

A thorough interview of parents and others with the child is immensely valuable. We want to find out about the child's daily routine, mode of family transportation, what they feel are positive and negative features about their present

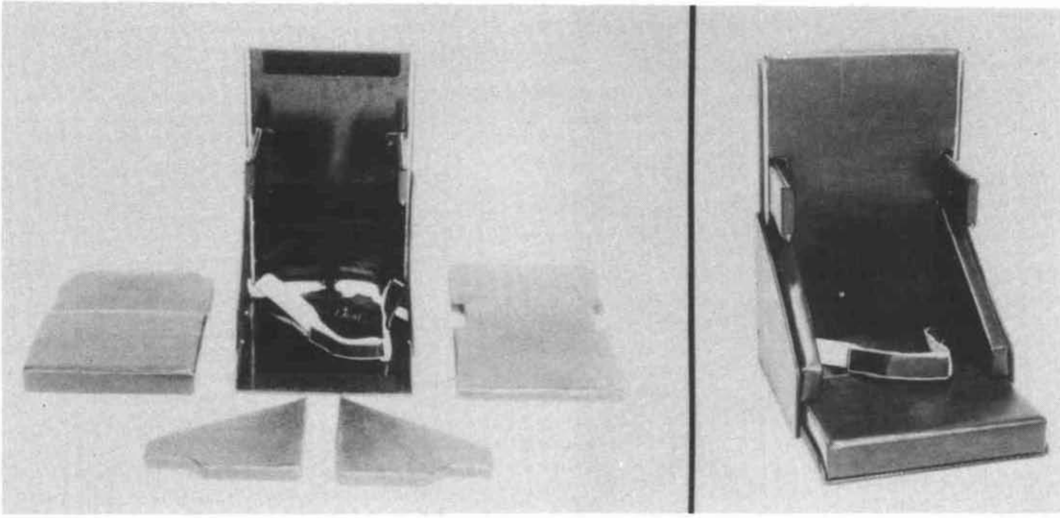


Figure 21. The current design for the Upholstered Sitting Support Orthosis combines an ABS frame and removable, firm upholstered components.

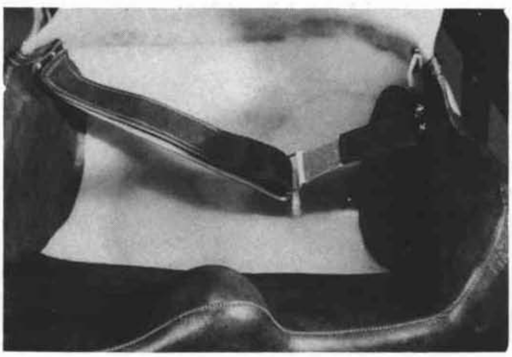


Figure 22. This photo shows the bilateral pelvic growth pads which can be removed later to accommodate an increased pelvic width.

equipment and routine, and the child's usual status compared to what we are observing. We also seek all concerns and ideas they may have for optimum seating. The interview should gradually become more of an educational session and finally a discussion of options. The child and parents or caretakers should, as much as possible, feel they were heard, were educated, and have participated in the decisions made on the seat, mobility base, accessories, etc.

Seating Design

We currently solve the majority of the seating problems we encounter with variations

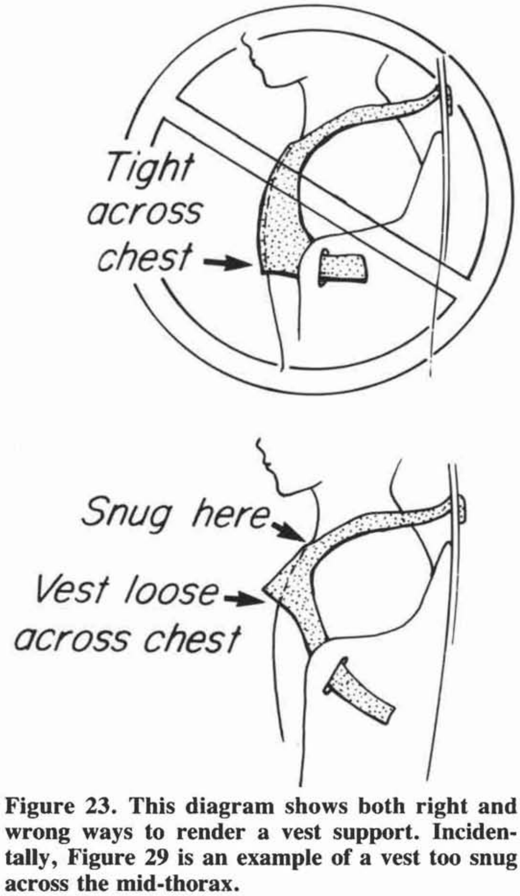


Figure 23. This diagram shows both right and wrong ways to render a vest support. Incidentally, Figure 29 is an example of a vest too snug across the mid-thorax.

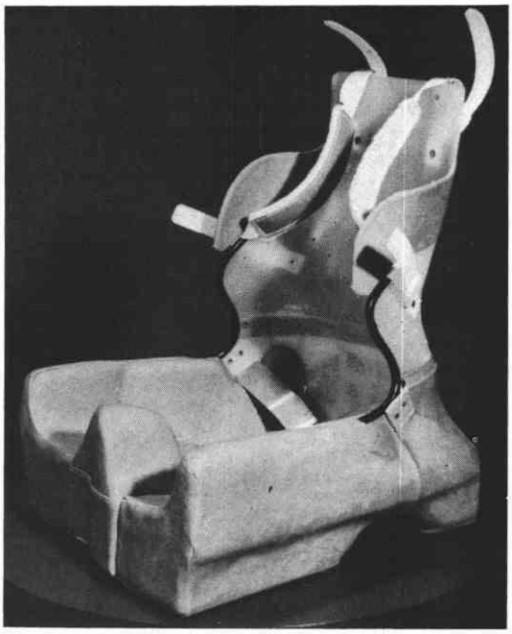


Figure 24. This is an example of an S.S.O. design utilizing the shoulder strap type anterior support. This S.S.O. also has a removeable pommel for easier entry and exit. It also has modifications to the base for recessing into the wheelchair.

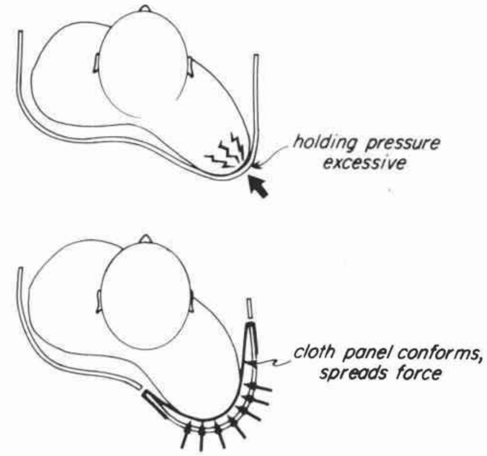


Figure 25. This diagram illustrates the difficulty in safely supporting spinal deformity prominences and how a denim fabric panel may be installed to provide a "wrapping-around" support which is more conforming. The flexible panel also accommodates some positioning errors and some movements without increasing the support pressures.

Figure 26. We call this the "over-shoulder, bend-down" type head rest. It is especially helpful for those children who consistently pull to one side as the head falls forward. Later, when they voluntarily extend the neck again, the extension is in place to guide the head toward mid-line.

on two basic designs. Both are custom made.

Although there have been many very significant design changes along the way, the Gillette style Sitting Support Orthosis (S.S.O.) has continued, from 1974 to the present, as a portable system utilizing a custom molded unpadded plastic shell mounted in a plastic foam base (Figures 18 and 24). We have provided approximately 1,100 of these Sitting Support Orthoses. Our present rate of S.S.O. production is about 140 per year.

In the early years, we also constructed upholstery and plywood seats. In 1983, we converted that rectangular design to one that used upholstered removeable components attached to the inside surfaces of a plastic seat frame as shown in Figure 21. (We first saw a design similar to Figure 21 at the Royal Ottawa Rehabilitation Center. In addition to our own changes, the present design incorporates features also learned from the Rehabilitation Engineering Center at Children's Hospital at Stanford.) To distinquish this design from the contoured plastic shell type S.S.O., we call it an Upholstered Sitting Support Orthosis (U.S.S.O.). We currently construct and fit about 200 of these units annually.

A more specific discussion of the design of the S.S.O. must start with noting that the main structure is an unpadded, thin plastic shell. Because of the thinness of the supporting shell, the seat is less bulky, less visible, and lighter than other seats. It allows us to provide close thoracic support up to the axillary level and wrap around the thorax, between the arms and chest, and well past mid-line, without impinging on the arms (Figures 18 and 19). When properly contoured, the shell can be left almost totally unpadded. The unpadded shell is easier to clean and requires less maintenance. The pelvic portion is contoured and sized to fit the hip/pelvic area quite close, but not snug. At fitting time, we leave adequate space to push our fingers between the gluteus medius and the seat bilaterally. About 18 months ago, we began providing room in the shell to install bilateral pelvic growth pads (visible in Figure 22), which are removed later as the pelvis grows wider.

There is complete freedom within the design to reduce the level and amount of support to match the client's need: it may not include a head support, vest, or shoulder straps, and bilateral thoracic support may be terminated at a lower level and leave more room for movement as appropriate.

Anterior upper thoracic support is provided by either a special vest (Figure 23) or shoulder straps (Figure 24). The shoulder straps are more efficient at keeping the thorax in an extended, upright posture. However, when the child has some arm function, we prefer to use the vest because it can be configured to impinge less on the anterior deltoid muscles. Note that the lower attachment points for the vest or shoulder straps should be in the sub-axillary area to provide good wrap-around and a posteriorly directed holding vector. Some commercially available seats anchor the shoulder straps to the lap belt. That design is seriously flawed because the shoulder straps then pull the lap belt up out of proper position and pull down on the shoulders.

When the S.S.O. is used for people with severe scoliosis or hyperkyphosis, the polypropylene shell accommodates to the contours of the deformity. However, sometimes our best efforts fail to create sufficiently precise contouring to spread pressure evenly over the entire rib prominence. Figure 25 diagrams how we sometimes solve that problem: an adjustable denim cloth panel is installed through vertical slits in the shell. The panel wraps around the prominence, conforming to the contour.

Head support varies from nothing to a simple occipital prop to a variety of designs, depending on the particular challenge presented. A few of the many designs we have contrived over the years are shown in Figures 26, 27, and 28. We do not have a good solution for the child who persists in actively bringing the head forward and down. In seating children with hydrocephalus, the sheer weight of the head presents special safety and weight bearing problems (Figures 29 and 30).

Figure 27. This is a variation which incorporates a cranial support above the ear for greater leverage if there is more forceful tendency to laterally flex the cervical spine.

Figure 28. If there is a tendency for the child's head to drop forward and she has very little or no ability to bring it back up, a firm, padded neck collar can sometimes give significant improvement. The collar is sometimes anchored to the S.S.O. behind the neck.

Figure 29. This headrest for a hydrocephalic child has a safety bar which hinges upward for entrance and exit.

Figure 30. This cradle type headrest is mounted so that it can be pivoted by means of a small wheel-crank. The child turns the wheel-crank to change weight bearing areas and to change the direction of her gaze.

We haven't the space to show and explain the wide variety of accoutrements which are variously added for shoulder protraction, arm positioning, etc. We work closely with the therapists so that they can help design the final configuration for best functional positioning.

As emphasized earlier, a seating program must consider the sitting functional environment. The seating orthoses we produce are removeably mounted in wheelchairs, strollers, buggies, and other bases as the circumstances indicate. Being portable, they are also utilized as car seats, or to place the child very near the floor to facilitate peer interaction (Figure 31). We have found that a seating program, to be effective, must address the full spectrum of life activities. It must also address related equipment in the sitting environment. Footrests, wheelchair upholstery, laptrays, and control boxes are some of the most common things which must be modified, moved, or completely replaced with special designs. It seems to us that the "standard" wheelchair was designed to be "slouched" into (Figure 32) rather than to be sat erect in. Those chairs are not adequate, as manufactured, for extended use by anyone. In spite of the newer, more enlightened designs coming along, those "standard" wheelchairs are still part of the scene and must be dealt with. When we sit a client erect on a firm seat, and then place that seat in a wheelchair, the client's shoulders are far from the center of the drive wheels (Figure 33). For clients who self-propel, the seat must be sized or shaped to sit between the upholstery mounting bars. The standard upholstery must be removed and replaced with straps so that the seat can be recessed down and back between the bars (Figures 34 and 35).

At semi-annual follow-up visits, we accommodate the child's growth by adjusting the size of the S.S.O. Thigh length is added as necessary. The bilateral pelvic growth pads are thinned or removed when appropriate. The back and sides of the shell can be heated to widen the shell width across the chest. Axillary extensions are welded on as necessary to accommodate increase in thoracic height. Head rests and the anchor points for vests and shoulder straps are also elevated as necessary. Presently, the basic S.S.O. shell is serving for an average of 37 months for children between three years and 14 years of age. We expect the use of the pelvic growth pads to push that service life even higher. For adults, the average useful life of S.S.O.s is much greater.

We recommend the S.S.O. for children who have non-existent to poor voluntary sitting capability. Other factors which would indicate a need for the S.S.O., in our program, would be significant orthopedic deformities (of the hips and spine) and moderate to severe spastic reflex patterns. Completed physical growth may also be an indication for the S.S.O., because the polypropylene shell is very durable. It requires less repair maintenance than the upholstered systems.

Provision of a good quality S.S.O. requires a relatively high level of specific orthotic skill and practice. This may be considered a disadvantage, but we feel the adaptability and quality which results more than justifies the necessary investment.

The structural components of the Upholstered Sitting Support Orthosis are made of ABS plastic. The upholstered firm inserts are removable to facilitate cleaning and adjustments for growth. Thoracic supports are thin (of metal) and can be easily adjusted to change height and spacing. The pelvic belt is used on every U.S.S.O. Lumbar bolsters, vests or shoulder straps, and head rests are used when appropriate. Figure 31 shows some of these design features. During therapy sessions, and for certain daily time periods, therapists or parents may wish to work specifically on improving upper trunk or head control. For this reason, shoulder straps and vests are designed for partial or complete loosening. Head rests can be easily removed from the unit (true of the S.S.O. as well as the U.S.S.O.).

The U.S.S.O. is most appropriate for children with poor-to-fair voluntary sitting capability, minimal orthopedic deformities, and less severe spastic reflex patterns. The easy size-adjustability of this design gives it some advantage over the S.S.O. for younger, rapidly growing children. For children under two years, we often utilize one of the commercial infant seat or car seat frames to which we can add support bolsters, lap belt, etc. (Figure 36).

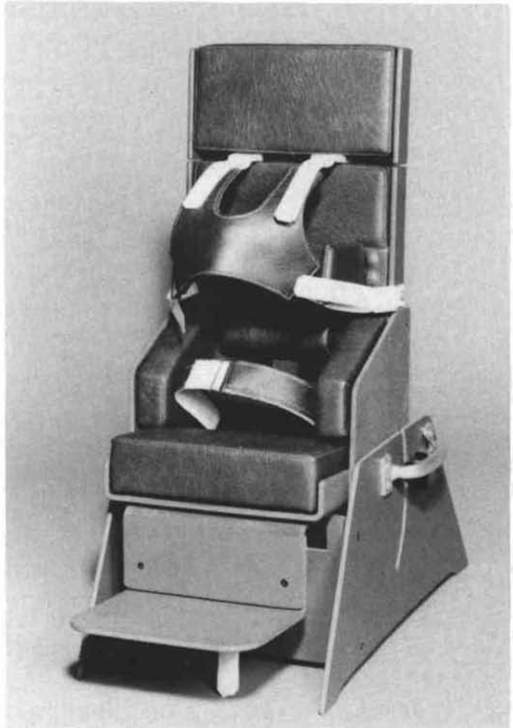


Figure 31. Both types of seating orthoses can be mounted in this type of base for use at near-floor levels for greater interaction with other young children. The base allows a variety of recline angles. This photo also shows many of the components which may or may not be part of a U.S.S.O. provided for a specific child.

Fabrication

Much about the fabrication of these orthoses can be inferred from the photos and design information given earlier. Some information on fabrication of the "Gillette" S.S.O. has been discussed in earlier articles on that orthosis.[2,9] However, there are some serious errors in the S.S.O. fabrication process we made in the very beginning. Other orthotic labs might repeat those errors unless we reiterate a couple of the procedural steps and more clearly explain the rationale for those steps.

The polypropylene shell is obtained by covering a pattern developed from an impression of the child. To obtain the impression, we position the child, on a supporting fixture (Figure 37) in a face-down, hips-flexed, knees-flexed configuration (Figure 38). We use the weight relieving (horizontal) trunk alignment, support under the knees, and a waist belt for the precise purpose of achieving an impression which does

Figure 32. The "hammock" style upholstery on standard wheelchairs encourages a "slouched" sitting posture. That posture is almost necessary for a good hand-on-wheel power stroke.

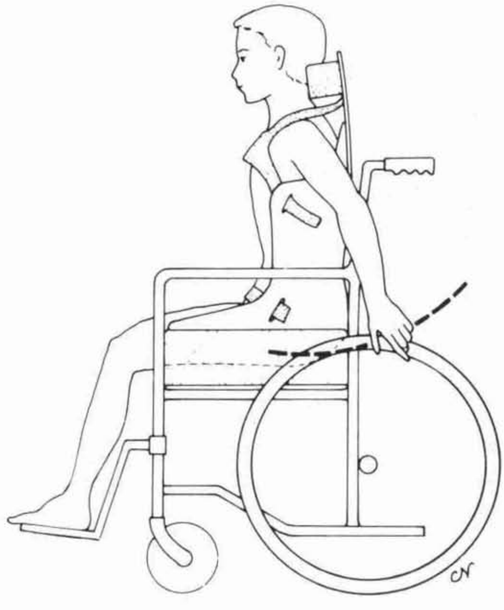


Figure 33. If the client sits erect in a seat orthosis which rests on the upholstery mounting bars, the shoulders are elevated. The hand-on-wheel power stroke is unacceptably shortened. Also, the excessively high forward position of the center-of-gravity causes the client/wheelchair combination to be dangerously susceptible for forward upset.

not possess the poor alignment characteristics we are trying to avoid. The support under the knees allows us to locate the pelvis as directly as possible in alignment with the spine. For the child with tight hamstring muscles, a waist belt on the fixture helps reduce lumbar kyphosis and perhaps achieve a little lumber lordosis, if possible. The contrasting diagrams in Figures 39a and 39b illustrate the critical role of knee support. The hip flexion angle of the fixture can be varied and is adjusted according to the amount of hip flexion we want in the seat shell. On the positive model, plaster is added to create the bulges and contours needed to avoid pressure on bony prominences (Figure 40). Plaster is added across the back of the upper thorax to give room for extension. Figures 41a and 41b are posterior and lateral views of a positive model fully modified and ready for covering. The resulting polypropylene seat shell is mounted in a polyethylene foam base (Figure 42). Final trim lines, lap belt and vest attachment points, head-rest placement, etc. wait until the child comes for fitting.

The molded "Chailey Heritage" supportive seat,[8] which also utilizes vacuum dilatancy to obtain an impresson, creates a positive model, and vacuum forms the seat materials over that

Figure 34. Diagram showing improvement in hand-to-wheel accessibility when the orthosis is recessed into the wheelchair.

Figure 35. This photo shows an example of how to shape the base of a seat and use straps instead of standard upholstery to recess the seat into the wheelchair for better access to the wheels.

Figure 36. For children under about two years of age, we can save expense by building appropriate sitting support into one of the commercial infant or car seats.

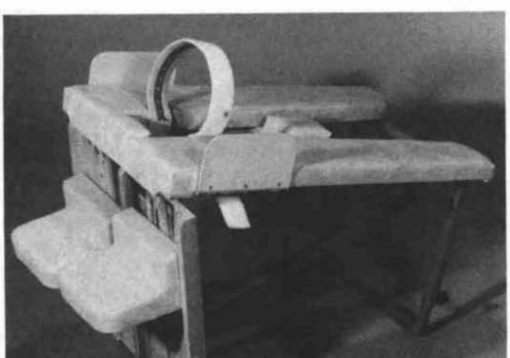
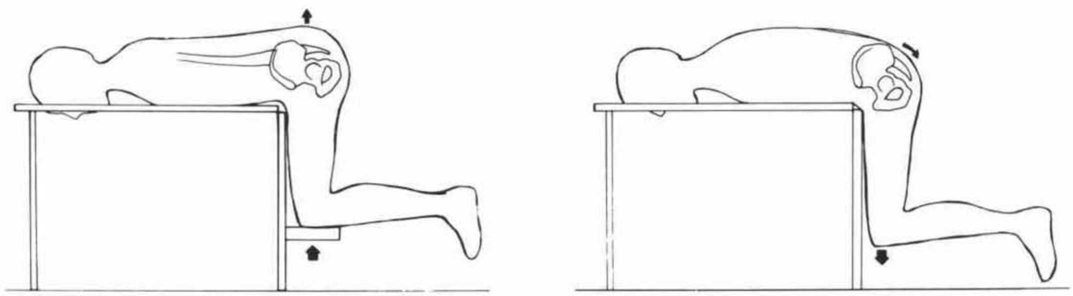


Figure 37. This is the positioning fixture which helps us obtain an impression with the alignment characteristics we hope to achieve in the finished S.S.O. The hip flexion angle can be varied. The knee supports are moved to the proper position for each child's impression. The waist belt helps to reduce lumbar kyphosis.

Figure 38. When we have achieved optimum alignment of the child on the fixture, bony prominences and landmarks are covered with masking tape and outlined with lipstick. A bag of polystyrene beads is packed around the child and when a vacuum is drawn on the bag it becomes a firm impression which may be removed and filled with molding plaster.



Figures 39a and 39b. These diagrams illustrate the critical value of proper support under the knees during the impression-taking process.

model. With the exception of those general similarities, the procedures, materials, and design of the Chailey Heritage seat is very different from the Sitting Support Orthosis developed at Gillette Children's Hospital.

Fabrication of the U.S.S.O. does not require a pattern and is therefore free of the potential problems inherent in obtaining and modifying a model.

Conclusions

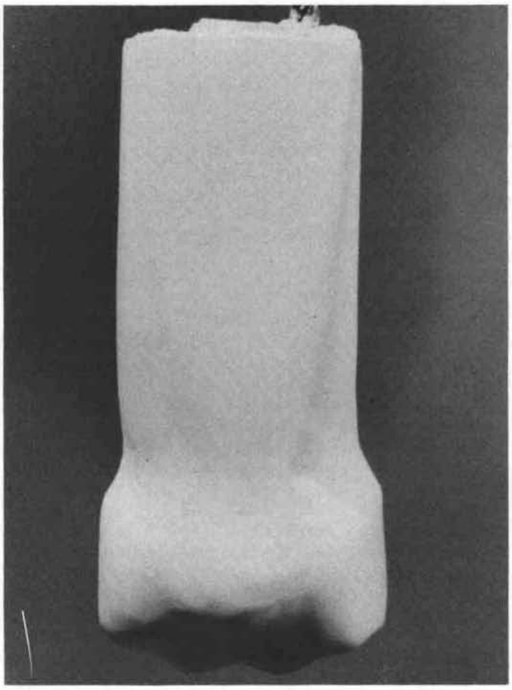
This paper has dealt most heavily with biomechanics and design, but many other programmatic components have been mentioned. Devices do not solve seating problems. A program is required. A truly successful seating program, one that approaches the fundamental goals discussed at the beginning of this paper, must contain at least the following components:

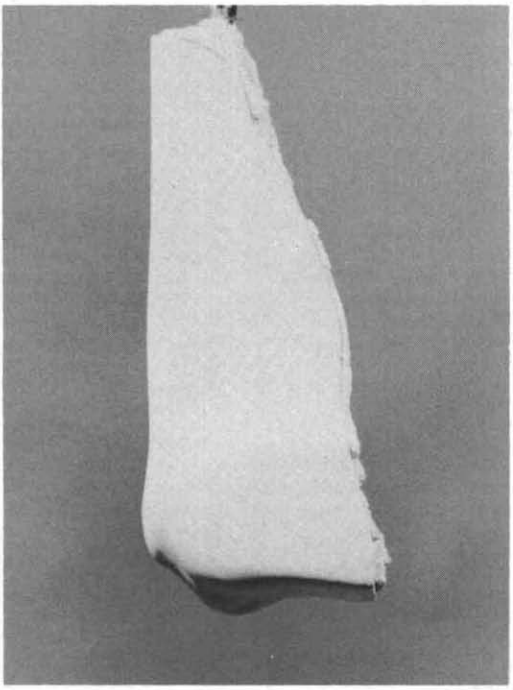
1. Involvement of all appropriate and available professional disciplines.
2. Comprehensive discussion with, and education of, the client (when possible), the parents and/or other caretakers, and other available community-based professionals.
3. Attention to finding and solving the family-specific functional (including play, recreation, and transportation) problems and opportunities.
4. Provision of effective equipment with thorough instructions on its use.
5. Tenacious follow-up to uncover and solve the inevitable problems and opportunities brought on by growth and functional changes; to obtain feedback necessary to the efficient evolution of the program; and to reinforce, as necessary, the education of the users.

Figure 40. Plaster is added to the positive model as appropriate to provide pressure relief in the locations of bony prominences (lipstick marks transferred from the masking tape to the plaster vacuum bay were re-marked with indelible pencil on the bag to get the transfer to the plaster positive).

Acknowledgments

The important roles of some individuals and institutions have been cited earlier and will not be repeated here. Our experience with Duchenne Muscular Dystrophy has come





Figures 41a and 41b. Posterior and lateral views of a finished molding pattern for an S.S.O. shell.

primarily through Dr. Lowell (Hap) Lutter, chief of the Growth and Development Clinic at Gillette, and orthopedic surgeon for the Muscular Dystrophy Clinic at Fairview Hospital. The seating systems were provided at Gillette by Team Leaders, Mark Payette and David Wilkie, and the people they supervise. Those people include (currently, and in the recent past) Tracy Lillehaug, Joe Bieganek, Dannel Friel, John Spielman, Katie Voss, Lee Hegfors, Bruce Tew, Wendy Schifsky, Rick Weber, Paul Swanlund, Paul Lemke, and Marcia Munson. Gene Berglund is orthotic group manager at Gillette. Former Therapy Supervisors, Diane Twedt and Jan Headley were very involved and important during the early years of the program. Gillette therapists significantly involved with the program currently (or in the recent past) include Rebecca Lucas, Lynn Bowman-Bathke, Cindy Theisen, Patricia Mathie, Gail Graff, Marilyn Kochsiek, and Ellen Kratz.

Over the years, we have been privileged to work with many outstanding individuals and institutions in various communities in our referral area. Five institutions which have been especially cooperative and capable are the Cambridge Regional Human Services Center (formerly Cambridge State Hospital), People's Child Care Residence, Homeward Bound, Brainerd State Hospital, and Moose Lake State Hospital.

We have significantly learned from (in addition to centers cited earlier) the professionals associated with seating programs at the Rehabilitation Engineering Center of the University of Tennessee, the Hugh MacMillan Center in Toronto, and the Winnipeg Rehabilitation Center for Children.

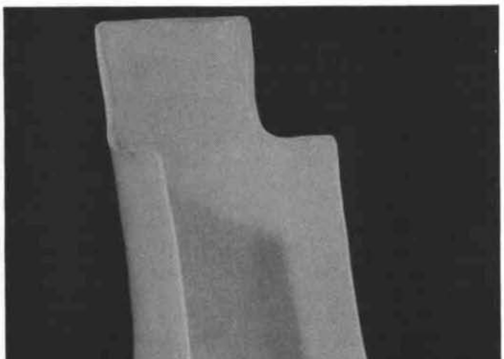


Figure 42. The polypropylene S.S.O. shell is matted to a polyethylene foam base by using foam-in-place material. The foam is shaped and becomes the distal portion of the thigh support.

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Karen O. Beck, R.P.T., is a Senior Physical Therapist at Gillette Children's Hospital.

David C. Wilkie, B.F.A., is an Adaptive Equipment Team Leader at Gillette Children's Hospital.

References

[1] Bowker, John H. and Reed, "A Vacuum Formed Plastic Insert for Neurologically Handicapped Wheelchair Patients," *Inter-Clinic Information Bulletin,* 12:10, July, 1973, pp. 7–12.

[2] Carlson, J. Martin and Payette, Mark, "Seating and Spine Support for Boys with Duchenne Muscular Dystrophy," Program and Proceedings of the Rehabilitation Engineering Society of North America, Memphis, Tennessee, June, 1985.

[3] Carlson, J. Martin and Winter, Robert, "The Gillette Sitting Support Orthosis," *Orthotics and Prosthetics,* 32:4, December, 1978, pp. 35–45.

[4] Crandall, Stephen H. and Dahl, Norman C., "Stability of Equilibrium," *An Introduction to the Mechanics of Solids,* McGraw-Hill, 1959, Chapter 9, p. 420.

[5] Morris, J.M., Lucas, D.B., and Bresler, B., "Role of the Trunk in Stability of the Spine," *The Journal of Bone and Joint Surgery,* 43-A:3, April, 1961, pp. 327–351.

[6] Nachemson, Alf L., Andersson, Gunnar, B.J., and Schultz, Albert B., "Valsalva Maneuver Biomechanics: Effects on Lumbar Trunk Loads of Elevated Intra-abdominal Pressures," *Spine,* 11:5, June, 1986, pp. 476–479.

[7] Rang, M., Douglas, G., Bennet, G.C., and Koreska, J., "Seating for Children with Cerebral Palsy," *Journal of Pediatric Orthopedics,* 1:3, 1981.

[8] Ring, N.D., Nelham, R.L., and Pearson, F.A., "Moulded Supportive Seating for the Disabled," *Prosthetics and Orthotics International,* 2:1, April, 1978, pp. 30–34.

[9] Winter, Robert B., and Carlson, J. Martin, "Modern Orthotics for Spinal Deformities," *Clinical Orthopedics.* 126:5, July–August, 1977, pp. 74–86.

Calendar

1987

August 6, GRAPH-LITE Orthotics, DAW Advanced Continuing Education Seminar. Contact DAW Industries, 5360-A Eastgate Mall, San Diego, California 92121, 1-800-824-7192.

August 7–8, Texas Association of Orthotists and Prosthetists and the Texas Chapter of the American Academy of Orthotists and Prosthetists Combined Meeting, Corpus Christi, Texas. Contact: Mike Allen, CPO, 2504 West Ohio, Midland, Texas 79701; tel. (915) 683-5280.

August 7–8, Anatomical Design/Narrow ML Casting Brim, Advanced Modular Prosthetics. DAW Advanced Continuing Education Seminar. Contact DAW Industries, 5360-A Eastgate Mall, San Diego, California 92121, 1-800-824-7192.

August 20, GRAPH-LITE Orthotics, DAW Advanced Continuing Education Seminar. Contact DAW Industries, 5360-A Eastgate Mall, San Diego, California 92121, 1-800-824-7192.

August 21–22, Anatomical Design/Narrow ML Casting Brim, Advanced Modular Prosthetics. DAW Advanced Continuing Education Seminar. Contact DAW Industries, 5360-A Eastgate Mall, San Diego, California 92121, 1-800-824-7192.

August 21–22, Academy Continuing Education Conference, "Sports Injuries and Recreational Prosthetics," Amway Grand Plaza Hotel, Grand Rapids, Michigan. Contact: Academy National Headquarters, (703) 836-7118.

August 21–22, Charleston Bending Brace Seminar, Radisson Plaza Hotel, Orlando, Florida. Contact: Julie Sayago, Charleston Bending Brace Seminars, P.O. Box 1070, Apopka, Florida 37204-1070, or call 1-800-327-0073.

August 17–21, Motion Control course, "Fitting Procedures for the Utah Artificial Arm and Hand Controller," 916 Area Vo-Tech Institute, White Bear Lake, Minnesota. Contact: Harold Sears, Ph.D., 95 South Elliot Road, #105, Chapel Hill, North Carolina 27514; (919) 968-8492.

September 6–10, International Seminar on Prosthetics and Orthotics, Dan Accadia Hotel, Herzliya, Israel. Contact: ISPO 1987, P.O. Box 50006, Tel Aviv 61500, Israel; tel. (03) 654 571; TELEX: 341171 KENS IL, Fax: 972 3 655674.

September 11–12, Ohio Orthotics and Prosthetics Association/Ohio Chapter, American Academy of Orthotists and Prosthetists combined meeting, "Bridging the Profession," Dayton, Ohio. Contact: Norma Jean Finissi, Executive Director, O.O.P.A./Ohio A.A.O.P., 4355 North High Street, #208, Columbus, Ohio 43214; tel. (614) 267-1121.

September 28–30, Hosmer Electric Systems Workshop and Seminar, Hosmer Dorrance Corporation, Campbell, California. Contact: Catherine Wooten, Hosmer Dorrance Corporation, 561 Division Street, Campbell, California 95008; tel. (800) 538-7748 or (408) 379-5151.

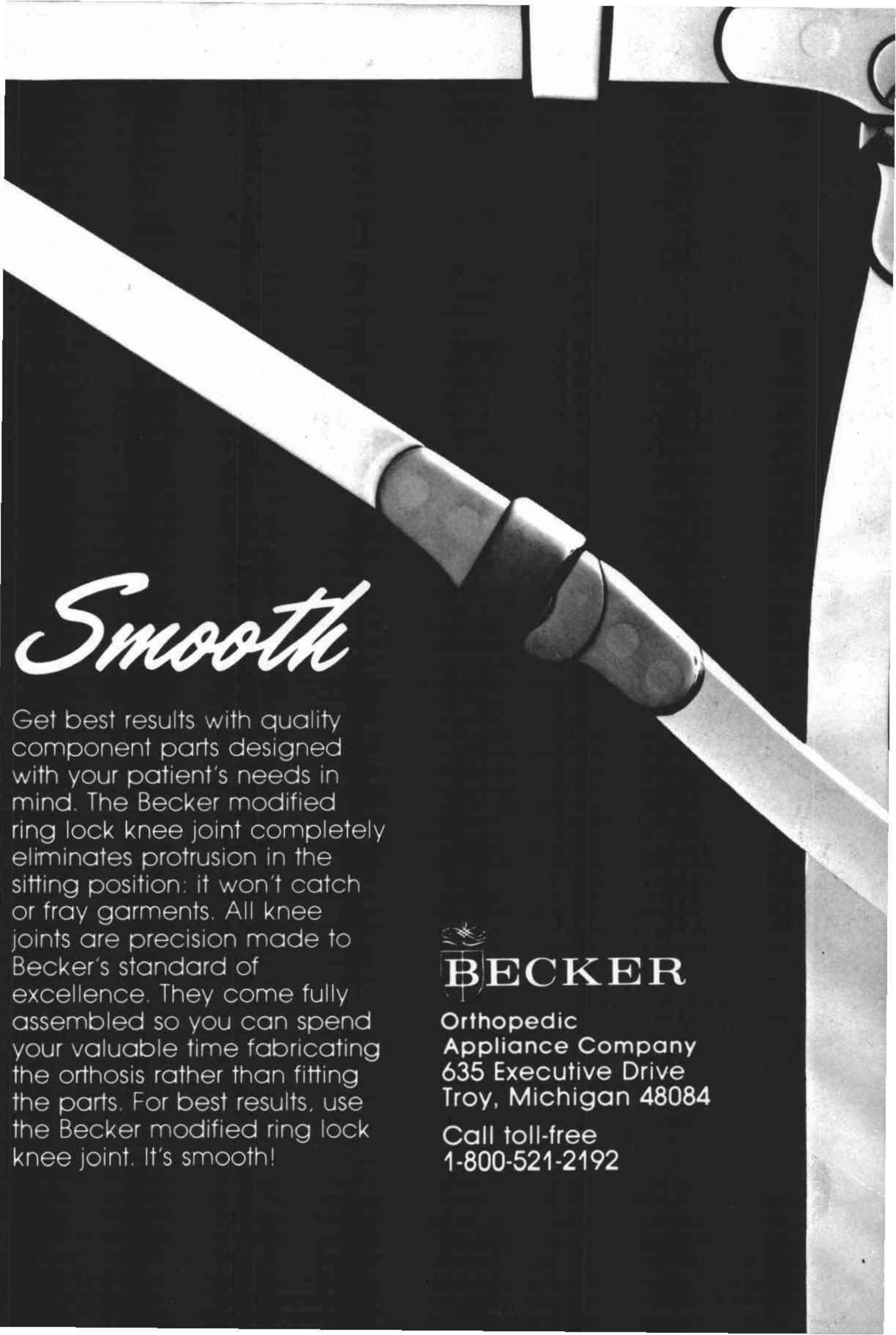
October 2–3, New York State Chapter AAOP Fall Seminar, Sheraton Inn and Conference Center, Utica, New York. Contact: David Forbes, CPO, (315) 736-0161.

October 9–10, Freeman Two-day Orthotic Fitters Workshop, Reno, Nevada. Tuition free. Contact: Cameron Brown 1-800-253-2091, in MI 1-800-632-2015.

October 12–15, Middle East Medicare 87 Exhibition, Exhibition Centre Bahrain, Bahrain. Contact: Garald G. Kallman, Kalman Associates, 5 Maple Court, Ridgewood, New Jersey 07450; tel. (201) 652-7070.

October 23–24, Academy Continuing Education Conference, "Hi-Tech in Prosthetics and Orthotics," The Lincoln Hotel, Dallas, Texas. Contact: Academy National Headquarters, (703) 836-7118.

October 24, Academy Northern California Chapter Seminar, San Jose, California. Contact: Robert A. Bangham, CO, c/o Hittenbergers, 1117 Market Street, San Francisco, California 94103.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November 15–18, All Americas Health '87 International Conference and Exhibition of Medical and Hospital Equipment, Curtis Hixon Convention Center, Tampa, Florida. Contact: John Sellers, City of Tampa International Trade Fair Advisory Committee, 600 Ashley Drive, Tampa, Florida 33602; tel. (813) 223-8421.

November 26–29, Medical/Hospitech 87, Bangkok International Exposition Center, Bangkok, Thailand. Contact: SKA International Services Ltd., 22/F. Tian An Centre, 151 Gloucester Road, Hong Kong.

December 7–11, Motion Control course, "Fitting Procedures for the Utah Artificial Arm and Hand Controller," UCLA Prosthetics Education Program, Los Angeles, California. Contact: Harold Sears, Ph.D., 95 South Elliot Road, #105, Chapel Hill, North Carolina 27514; (919) 968-8492.

1988

January 25–31, Academy Annual Meeting and Scientific Symposium, Newport Beach Marriott Hotel and Tennis Club, Newport Beach, California. Contact: Academy National Office, (703) 836-7118.

February 4–9, American Academy of Orthopedic Surgeons Annual Meeting, Atlanta, Georgia.

March 12, Academy Northern California Chapter Seminar, Oakland, California. Contact: Robert A. Bangham, CO, c/o Hittenbergers, 1117 Market Street, San Francisco, California 94103.

September 5–9, 16th World Congress of Rehabilitation International, Keio Plaza Inter-Continental Hotel, Shinjuku, Tokyo, Japan. Contact: Secretary General, 16th World Congress of Rehabilitation International, c/o the Japanese Society for Rehabilitation of the Disabled, 3-13-15, Higashi Ikebukuro, Toshima-Ku, Tokyo 170, Japan.

September 24, Academy Northern California Chapter Seminar, San Francisco, California. Contact: Robert A. Bangham, CO, c/o Hittenbergs, 1117 Market Street, San Francisco, California 94103.

1989

January 31–February 5, Academy Annual Meeting and Scientific Symposium, Wyndham Hotel, Orlando, Florida. Contact: Academy National Office, (703) 836-7118.

February 9–19, American Academy of Orthopaedic Surgeons Annual Meeting, Las Vegas, Nevada.

November 12–17, International Society for Prosthetics and Orthotics VI World Congress, Kobe Convention Center, Kobe, Japan. Contact: VI ISPO World Congress, Secretariat, c/o International Conference Organizers, Inc., 5A Calm Building, 4-7, Akasaka 8-chome, Minato-ku, Tokyo, 107 Japan.

1990

January 22–28, Academy Annual Meeting and Scientific Symposium, Hyatt Regency Hotel, Phoenix, Arizona. Contact: Academy National Office, (703) 836-7118.

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Clinical Prosthetics and Orthotics, Vol. 11, No. 3, pp. xix–xx

Academy College Fund Survey Results

John C. Lewis, Ed.D.

We were fortunate to have received 190 surveys in response to the American Academy of Orthotists and Prosthetists College Fund survey. Many of the surveys returned to us were accompanied by letters including suggestions, approvals, and sharp criticisms. The following highlights are presented.

DEMOGRAPHY

155* Orthotics or prosthetics practitioners
7 Institutional practitioners
4 Researchers
24* Patient care facility owners
4 Work with patient care facility owner
3 Instructor, teacher, professor
3 Institutional head
0 Supplier firm owner
0 Work with supplier firm owner

* Denotes primary affiliation of respondent, although several checked more than one category.

PREPARATION

34 High School
39 Associate Degree
113 Bachelor Degree
24 Other: Masters (14), Ph.D. (2), Post B.S. Credits (5), Post high school college credits (4)

CERTIFICATION

159 Yes
1 No

CERTIFICATION AREA

44 CP
52 CO
96 CPO
8 Unknown

NUMBER OF YEARS SERVICE

39 0–5 (15 who would be willing to enroll)
52 6–10 (21 who would be willing to enroll)
32 11–15 (10 who would be willing to enroll)
33 16–20 (7 who would be willing to enroll)
13 21–25 (1 who would be willing to enroll)
10 26–30
9 31–35
8 36 and over
4 Unknown

STATEMENTS CHECKED WHICH WERE BELIEVED TO BE TRUE

185 Aware of Academy's efforts to promote degree
15 Never heard of project
189 Feels need for more understanding of Orthotics
180 Feels need for more understanding of Prosthetics
77 Interested in developing, promoting or teaching in the doctoral program

127 Interested in taking some of the courses
58 Interested in enrolling to secure degree
31 Little to be gained in the field by this project
122 Great deal to be gained in the field by this project
105 See O & P personnel to be regarded on same plane as are physicians

AUTHOR INFORMATION

Clinical Prosthetics & Orthotics

As professionals, we are obligated to do what we can to advance the state-of-the-art and share new developments with our colleagues. The most efficient way to transfer information, and the way that has the greatest impact, is through the written word. But, for many professionals, writing is a task that often becomes monumental to the point that we succumb to inertia. Writing, however, is not such a monumental task if we break it down into smaller, simpler tasks which we can complete one at a time.

The initial and most difficult problem every writer faces is how to organize the material. The quickest way to organize material is through the use of an outline. In its most basic form, an article is divided into three parts—introduction, body, and conclusion. The introduction states the subject and gives pertinent background information that is necessary in order to understand the topic. The main body of the article is the intent to inform and answer a variety of questions. The body can include subheads, such as review of literature, method, clinical materials, discussion, and results. The conclusion restates the main points presented in the article.

Clinical Prosthetics and Orthotics addresses broad, philosophical issues, and as such invites a more subjective style. Each issue of *C.P.O.* centers on a main topic. Usually, an issue will contain a lead article, an editorial, and one or more technical articles pertaining to the topic. Authors are solicited by the Academy editorial board; however, *C.P.O.* also accepts unsolicited articles. Unsolicited articles need not cover the topic at hand and may be of a more technical and objective nature. All articles are submitted to the editor, a professional in the field, who checks every article for accuracy, terminology, format, and references. The articles are then forwarded to the publications staff at the Academy National Office for production and printing.

The chosen topics for *Clinical Prosthetics and Orthotics,* Volume 11, Number 4 through Volume 12, Number 3, and deadlines for submission are as follows:

Volume 11, Number 4	"Quadraplegia" Deadline: July 1, 1987
Volume 12, Number 1	"Prosthetic Management of the Partial Foot and Symes Amputations" Deadline: September 1, 1987
Volume 12, Number 2	"Orthotic Management of the Foot" Deadline: December 1, 1987
Volume 12, Number 3	"Disarticulation Amputations" Deadline: March 1, 1988

Please remember that although these are the chosen topics for these particular issues, we gladly welcome submissions on other topics. Please feel free to contact the National Office if you have any questions on whether your article would be appropriate for *C.P.O.*

If you have an article that has been previously published in another scientific journal and think it may be appropriate for *C.P.O.,* please let us know.

Submit articles to: Charles Pritham, CPO, Editor, c/o Durr-Fillauer Medical, Inc., Orthopedic Division, P.O. Box 5189, Chattanooga, Tennessee 37406.

Questions should be submitted to: Sharada Gilkey, Managing Editor, Academy National Office, 717 Pendleton Street, Alexandria, Virginia 22314; or call (703) 836-7118.

P.S. Author's kits are made available upon request, free of charge. Kits include manuscript guidelines, a patient permission form, reprint information, a reprint permission form, and information on prizes for published articles.

C.P.O. MANUSCRIPT GUIDELINES

1. Manuscripts must be typewritten, double-spaced with wide margins.
2. Indicate bibliographical references by means of Arabic numerals in parentheses (6).
3. Write out numbers less than ten.
4. Bibliography should follow the correct forms as shown below.
   a. Book
      Murphy, Eugene F., "Lower-Extremity Component," *Orthopedic Appliances Atlas,* Vol. 2, J.W. Edwards, 1960, pp. 217–224.
   b. Journal Article
      Panton, Hugh J., "Considerations for Joints and Corset," *Newsletter . . . Amputee Clinics,* 8:3: June, 1975, pp. 1–3, 6–7.
   c. Lecture or Verbal Presentation
      1. Holmgren, Gunnar, "The PTB Suction Prosthesis" from the written material of a lecture delivered at the third of the "Strathclyde Bioengineering Seminars," 8–11 August, 1978.
      2. Wagner, F.W., Jr.: "Classification and treatment for diabetic foot lesions"; Instructional Còurse, American Academy of Orthopedic Surgeons, New Orleans, Louisiana, February, 1976.
   d. Personal Communication
      Irons, George, C.P.O., Personal communication, June 1977. Presently, Director of Research, United States Mfg., Glendale, California. Formerly, Research Prosthetist, Patient Engineering Service, Rancho Los Amigos Hospital, Downey, California.

   Arrange all references alphabetically.
5. Illustrations
   a. Write authors name on the back of each illustration.
   b. Number all illustrations to correspond to references from the text.
   c. Submit either an original or a photographic black & white reproduction of illustrations.
6. Photographs
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   b. Identify by number to correspond to references from the text on a piece of paper taped to the back of each print.
7. List all captions in order on a separate sheet of paper, typed.
8. Must include with the manuscript signed copies of releases from patients who are photographed and referred to in the text. For pictures of patients for which permission cannot be obtained, the eyes must be masked out.
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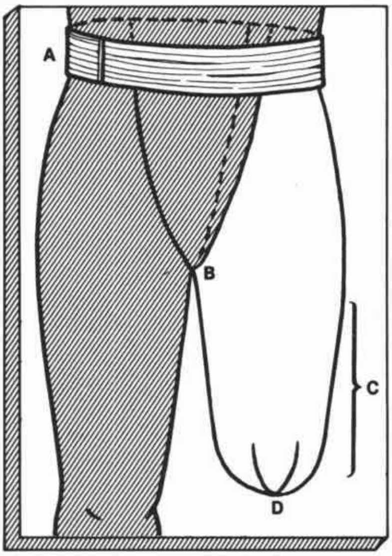

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				13"	2HPH9513	2HPM9513	
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				13"	2HPH8613	2HPM8613	
6"	9"		23½"-25½"	7"	2HPH9607	2HPM9607	
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				13"	2HPH9613	2HPM9613	
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