Clinical Prosthetics & Orthotics

Orthotic Management of Quadriplegia

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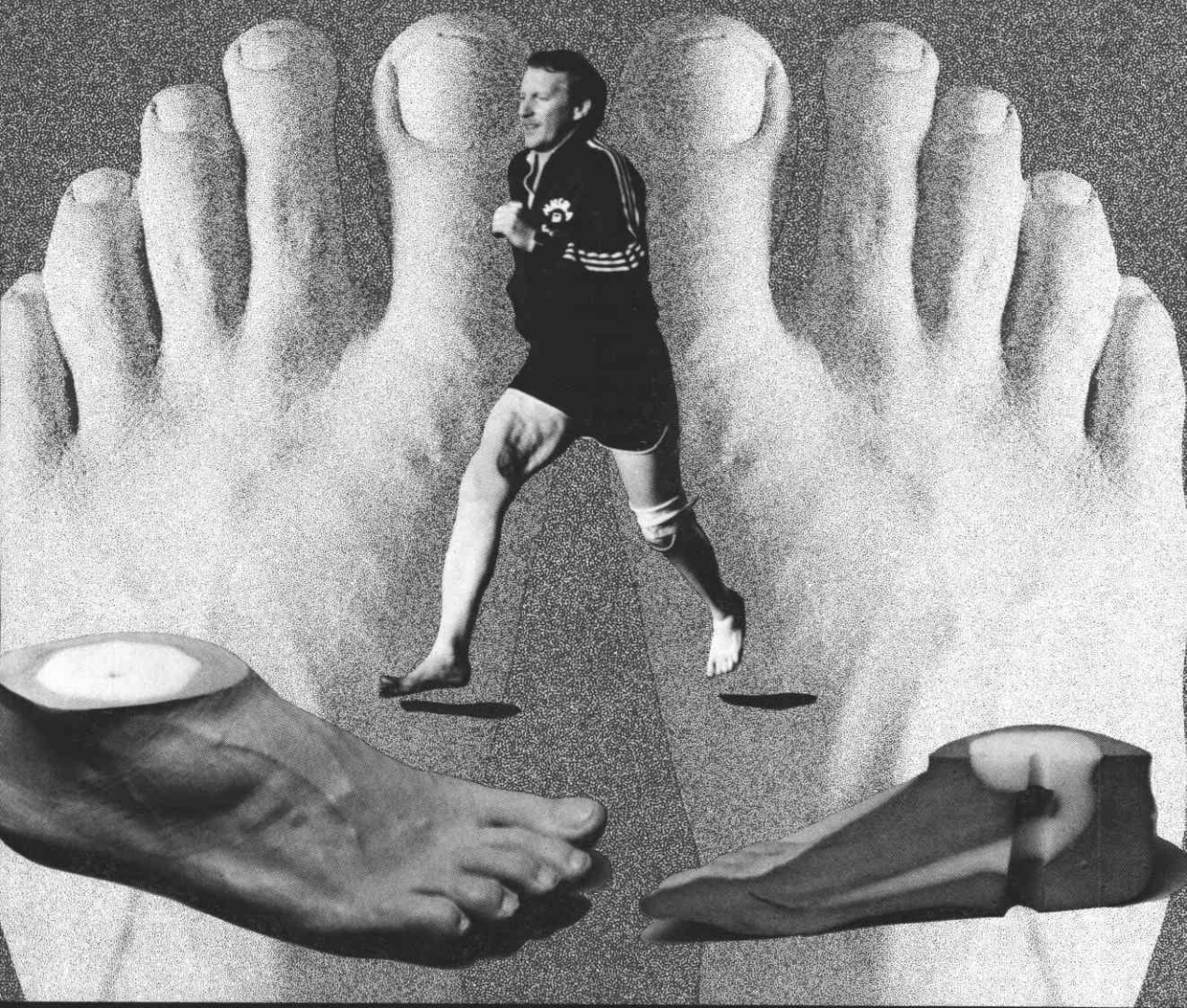

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Clinical Prosthetics & Orthotics

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.

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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 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.

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   c. Lecture or Verbal Presentation
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      2. Wagner, F.W., Jr.: "Classification and treatment for diabetic foot lesions"; Instructional Course, 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.

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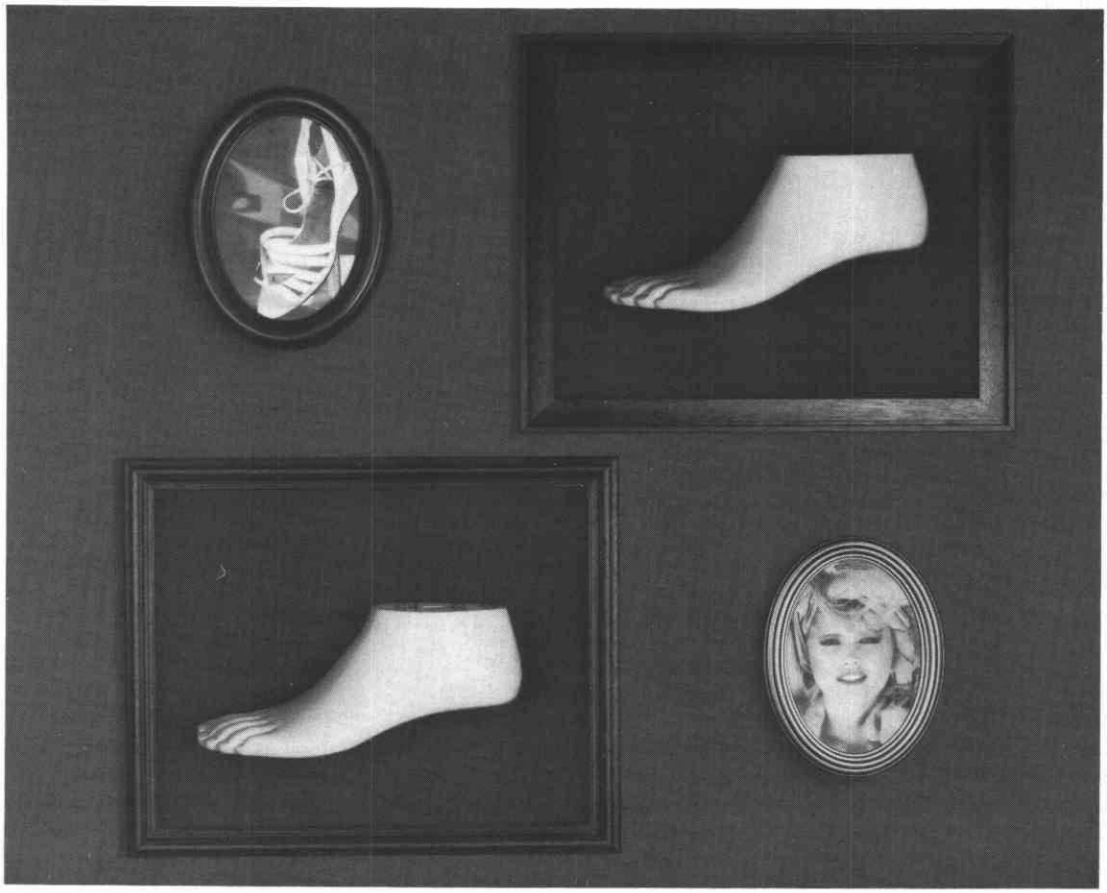

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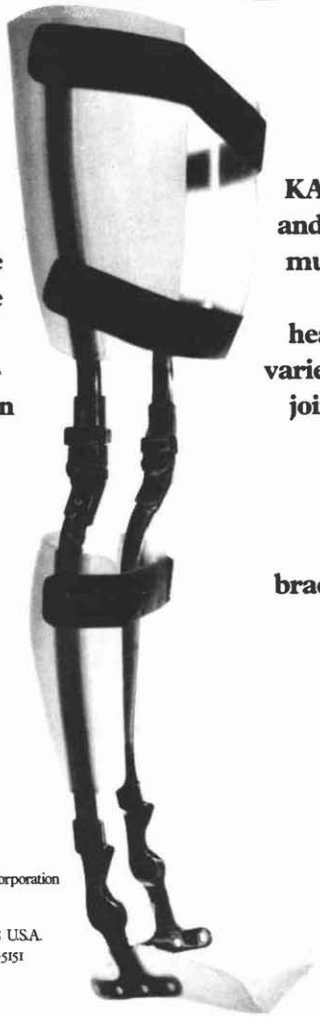

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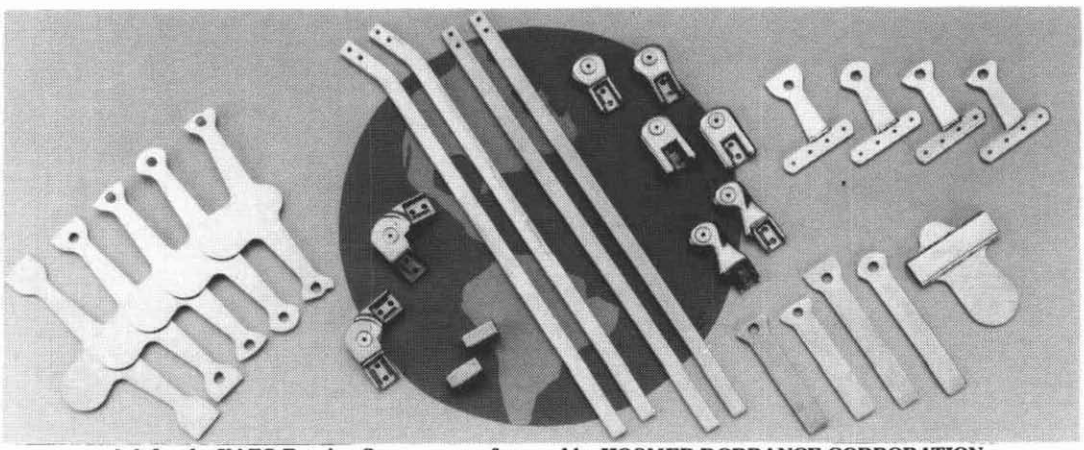

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Clinical Prosthetics and Orthotics, Vol. 11, No. 4, pp. 199–200

The Basis of Orthotic Management in Quadriplegia

by John H. Bowker, M.D.

Statistics indicate that there are 150,000–200,000 spinal cord injured persons in the United States.[3] Each year, approximately 10,000 newly injured are added to this figure. About 80% are males under the age of 40 years, while slightly more than half (53%) are quadriplegics, with low cervical injuries being most common.[3,4] In recent years, improved medical management has led to an increase in post-injury life expectancy in spinal cord injury to a probable 30 to 40 years.[1,2] This ever-increasing national prevalence of spinal cord injury poses major problems in rehabilitation, several of which will be addressed in this issue of *Clinical Prosthetics and Orthotics*.

When the spinal cord team first confronts a person with a cervical spine injury, the first two priorities are preservation of life itself and prevention of further damage to the spinal cord and spinal nerve roots. Immobilization of the neck, followed by traction-reduction of vertebral malalignment, is carried out concomitantly with physiologic stabilization. Special studies, including magnetic resonance imaging, are then done to determine the need for immediate surgical relief of extrinsic pressure on the cord due to residual vertebral malalignment and/or fragments of bone or intervertebral disc. Intraoperative imaging with ultrasound further aids in the identification and removal of fragments causing extrinsic pressure. The preservation or restoration of function of just one nerve root by precise surgery of this sort can make the crucial difference between a modicum of independence and total dependence in self-care. Depending on the specific injury and the surgeon's preference, stabilization of the spine may be accomplished by means of a halo external fixation system alone or by internal fixation with wires and bone grafts, supplemented by an orthosis. In either case, stabilization will expedite the rapid mobilization of the patient. At this point, a decision can be made regarding the appropriateness of orthotic fitting.

A brief mention has been made of the functional significance of each residual cervical nerve root in the quadriplegic. This may be further elaborated upon as follows:

Fourth cervical root (C-4): innervates the diaphragm, allowing independent breathing.

Fifth cervical root (C-5): innervates the deltoid and biceps/brachialis, providing shoulder abduction/flexion and elbow flexion, respectively.

Sixth cervical root (C-6): innervates the radial wrist extensors, permitting wrist dorsiflexion and a passive opposition of thumb and fingers by "tenodesis effect" of the finger flexors.

Seventh cervical root (C-7): innervates the triceps, wrist flexors and finger extensors, allowing elbow extension, wrist volar flexion, and finger extension, respectively.

Eighth cervical root (C-8): innervates the finger flexors, allowing a gross grasp.

First thoracic root (T-1): innervates the intrinsic muscles of the hand, resulting in complete hand function, including grip and a precise thumb to finger pinch.

It is important to note three features of this progressive classification to develop a clearer understanding of its relative limitations. Firstly, many muscles are supplied by two

roots. The root associated with a given muscle in the list above is that which primarily innervates that muscle. The preservation of the next lower root provides not only an additional distal function, but also greater strength in the muscle just above, due to the activation of additional motor units by this secondary nerve root. Again, this argues for preservation of every possible root. Secondly, preservation of root function is often asymmetrical. For example, a quadriplegic may have a functional level of C-5 on one side and C-6 on the other. In this case, an orthotic prescription for one side will be totally inappropriate for the other. Thirdly, with nerve fiber (axon) regrowth, improvement in strength of a given muscle may occur over time. Occasionally, even the next higher root may recover as well. Monitoring by repeated muscle testing can thus lead to a progressive change in orthotic prescription. The occupational therapist, by virtue of her close daily contact during the rehabilitation process, is often the first team member to note these changes. To aid in the prognosis of muscle return, it is now possible, by advanced biofeedback techniques, to find functioning motor units in muscles considered "paralyzed" by conventional muscle testing techniques. Following identification of working motor units, it may be possible to strengthen them with biofeedback-directed exercise. This often results in the addition of another useful upper limb function with or without the help of an orthosis.

Before an upper limb orthosis can be used, the quadriplegic must be positioned so that visual feedback allows contact between a partially insensate hand and the object to be manipulated. A properly designed and carefully fitted wheelchair can, therefore, be considered the basic orthosis for the quadriplegic. Lateral trunk supports or a corset may also be essential for functional sitting posture, freeing the upper limbs from supporting the trunk.

Throughout the process of rehabilitation, the orthotist should work closely with all members of the team, but especially the occupational therapist, physical therapist, psychologist, and physician if acceptance and use of orthotic devices is to be achieved. Successfully fitted orthoses are useful not only for self-care, but can also play a major role in achieving the ultimate goal of rehabilitation, the return to gainful employment. Many types of electronic devices, including computers, are manipulated more easily with an orthosis.

In conclusion, it is hoped that this issue will be helpful in not only delineating the unique role of the orthotist in the care of the quadriplegic, but equally importantly, in demonstrating the need for communication and cooperation among all team members, if we are to offer optimum care to our patients.

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Clinical Prosthetics and Orthotics, Vol. 11, No. 4, pp. 201–209

The Team Approach to Orthotic Management in Quadriplegia

by Wayne R. Rosen, C.O.
Janie J. McColey, O.T.R.
John H. Bowker, M.D.

This article presents the approach to orthotic intervention in quadriplegia taken at the University of Miami/Jackson Memorial Rehabilitation Center. To begin, it must be emphasized that quadriplegia implies not only loss of walking, but also loss of normal use of the hands. Since our hands are the tools with which we sustain life, a major goal of rehabilitation must be to restore the ability to independently carry out common activities of daily living such as feeding, grooming, and manipulation of devices which may allow resumption of educational and vocational goals.[9] As health care professionals in the rehabilitation field, we must be aware of advances in technique and equipment which can enhance the ever-increasing life span of this young population whose educational, economic, and social progress has been so severely curtailed.[5,6] The role of the orthotist and occupational therapist as members of the rehabilitation team is to address this very underemphasized problem of upper limb management.

When the spinal cord team is first asked to evaluate and treat a newly injured quadriplegic patient, they must take into consideration all aspects of care, not just those in their individual areas of specialization. During the acute medical phase, the emphasis is on preserving life and preventing further neurological damage. At this stage, there is little concern for joint positioning or splinting. After life-threatening problems have been addressed, however, prompt management of the upper limbs is of primary importance if we are to avoid joint stiffness and/or deformity which would interfere with the progression of rehabilitation.[13,14] This approach to the upper limbs involves a number of basic methods: frequent joint range of motion, limb positioning with and without positioning devices (temporary and permanent), dynamic orthoses (temporary and permanent), and externally powered orthoses. In our facility, spinal cord injured patients are initially placed on Roto-Rest beds. These beds, with their continuously alternating side-to-side motion, have proven to have a positive effect on the respiratory, renal and circulatory systems, as well as providing skin protection for the S.C.I. patient.[3] There is, however, potential for loss of glenohumeral and scapular mobility with its use for extended periods. We have currently adapted the bed so as to allow positioning of the shoulders in abduction and external rotation, alternating with the usual adduction and internal rotation. This change of shoulder position has been included in our regular routine of joint range of motion and should reduce the pain and stiffness that often interferes with arm placement and coordination.[13,14] Elbow flexion-forearm supination deformity is another potential problem, especially in C5 quadriplegics.[1] This may be managed by positioning the elbow in extension and pronation

between range of motion sessions. The use of thermoplastic elbow-extension splints (Figure 1), bivalved casts (Figure 2), or serial casting (Figure 3), will assist the therapist in maintaining proper position. Functional hand position should be maintained with the use of a resting hand splint (Figure 4) or a functional long opponens splint with C-bar and lumbrical bar (Figure 5), to avoid the development of a flat "simian" hand.

Once the patient is medically stable, he is able to begin a more active phase of rehabilitation, including the use of functional orthoses, if appropriate. His response to this whole process depends largely on the success of the first few days, which in turn depends on how the treatment team constructs the patient's first experiences of sitting, trunk balancing, and functional arm placement. Only when control of these factors is satisfactory will it be appropriate to introduce orthoses for function. This becomes a critical point in time for the patient and therapist, because two possible approaches to future functional activities exist. The first approach is based on the use of adaptive devices which will allow some patients to perform specific functions such as self-feeding and oral-facial hygiene. However, it is our feeling that even at this early stage, multipurpose temporary functional orthoses must be introduced if definitive orthoses are to play a useful part in the patient's life. Therapists should be prepared to fabricate and properly fit a training orthosis, which will

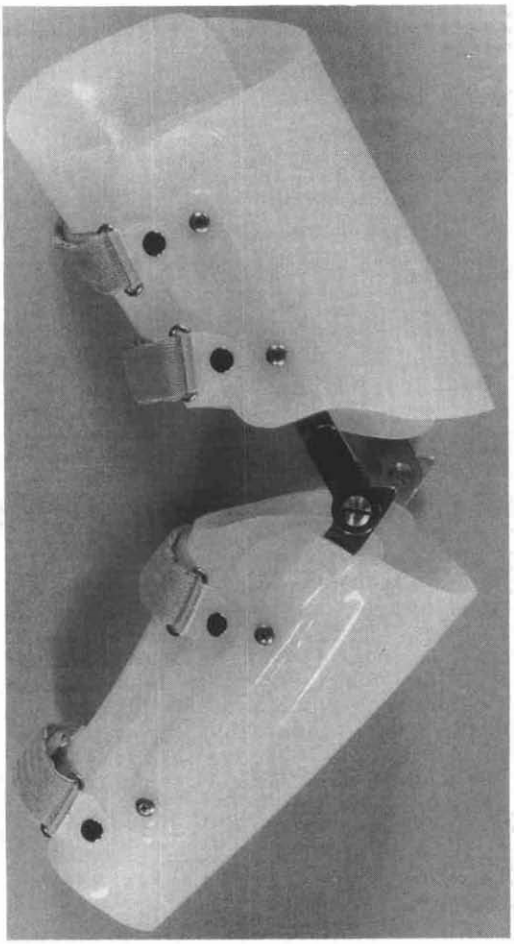


Figure 1. Elbow Control Orthosis.

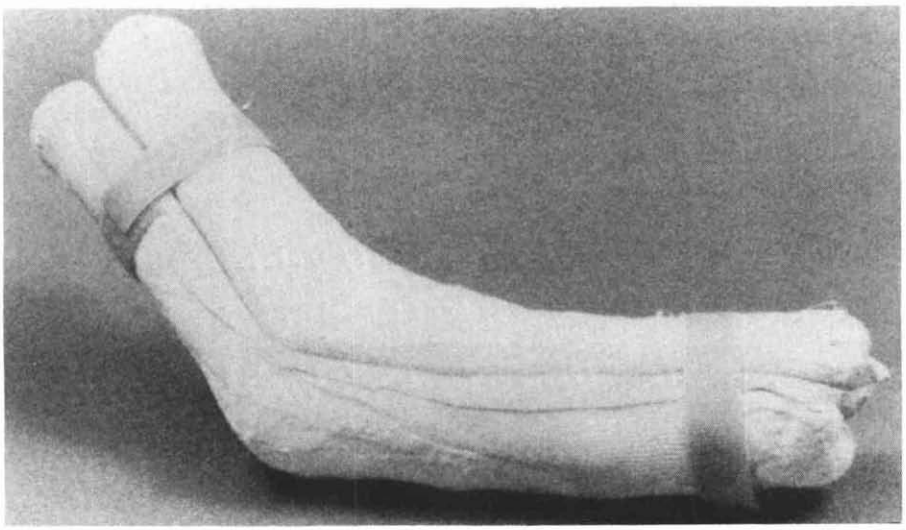


Figure 2. Bivalved plaster cast.

Figure 3. Serial casting (Plaster of Paris).

allow the patient reasonable options in developing his functional goals.[2,9,10,12]

The following chart provides guidelines for management techniques according to the level of remaining neurologic function. Many of the orthotic options listed in the "Recommended Management" column are from the N.Y.U. Upper Extremity Orthotics Manual.[7]

The guidelines listed above have been generally accepted throughout the world as the rational basis for orthotic intervention. The following variables, however, must receive equal consideration before an orthosis can be successfully fit to a patient.

Locality

The patient should reside not only reasonably close to a facility capable of adjusting his orthosis, but should have accessible transportation available if a problem arises.

Cost

Sufficient funds must be allocated to cover not only the initial cost of the orthosis prescribed but also maintenance and replacement as necessary.[15]

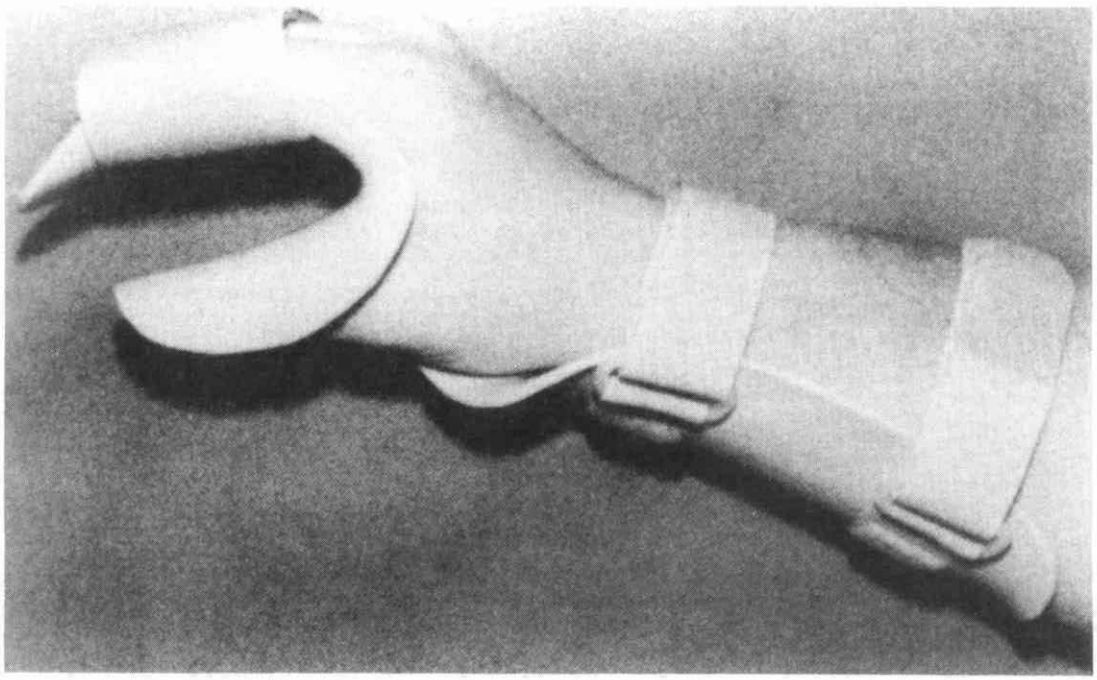


Figure 4. Thermoplastic resting splint.

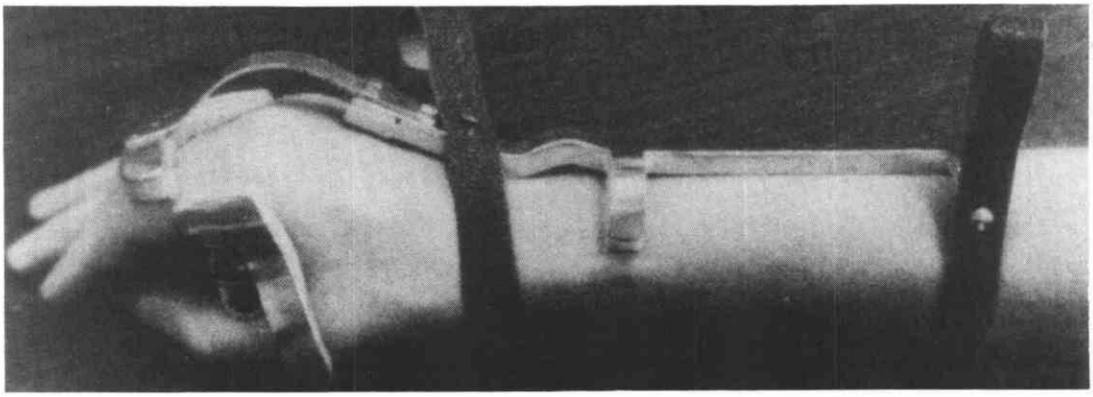


Figure 5. Long opponens with MCP extension stop.

Gadget Tolerance

The patient must have the patience to don and doff the orthosis or he will discard it because it "takes too long to apply." He may then actually prefer to sacrifice his independent performance of intricate manual tasks by either choosing a less effective piece of adaptive equipment or relying on another person for assistance. We, as practitioners, must monitor the attitude of a candidate to be sure that the function of the orthosis will be greater than the perceived inconvenience of wearing it.[2,15]

Dominance

The hand preferred prior to injury for writing and activities of daily living will usually be maintained as the dominant hand. This hand should be fit initially and the patient's progress monitored with specific activities before fitting the nondominant hand. Specific activity usage will determine whether or not the second orthosis is indicated.[9]

Vocation/Avocation

The patient's ability to perform fundamental activities of daily living is basic to maximum restoration, but it is equally important to determine additional intended uses of the orthosis, both vocationally and avocationally (i.e., manual work, desk work, telephone answering services). These data will help determine the type of materials suitable for fabrication or even the type of orthosis that would best suit the individual's needs.[12]

Psychological/Familial Roles

Assessment of the patient's psychological status is vital in establishing a treatment plan. Psychological make-up of the individual can play a very large role as to whether or not the patient will accept an orthosis. In this regard, cosmesis may play as important a role as function when dealing with a person's already altered body image. Psychological intervention is necessary to assist the patient through the stages of denial, anger, and depression to final adaptation. Indeed, the team members may need help in dealing with their own value systems regarding quality of life in relation to long term disability.

The personalities of the patient and family members, as well as those of the orthotist and occupational therapist, play important roles in rehabilitation after a spinal cord injury. An air of confidence emanates from professionals who are comfortable and confident with the task at hand. This confidence can be passed on to the patient, who will in turn become comfortable and confident with the orthosis being fitted. Too often, however, therapists and orthotists are not comfortable with the intricacies of fabricating upper limb orthoses, leaving the patient at a disadvantage as he begins his rehabilitation process, in that he may not be made aware of all the options available, but rather only those preferred by the professionals. Therefore, it is necessary to assemble a team of practitioners who are well versed in all aspects of their respective specialties so as to not hinder the patient in an already stressful situation. Family support is also extremely important as a

reinforcement of professional recommendations. Clear, concise instructions should be given to the patient and family members in order to increase the effective use of the orthosis.[9,10]

Economics

Since most orthotists in private practice cannot afford the luxury of skill maintenance for the small part of orthotic practice represented by upper limb orthotics, the majority of these devices are being made in an institutional setting, where an orthotist and occupational therapist on staff service the needs of quadriplegics. More time and energy can then be devoted, with less concern for monetary return, to fabrication and fitting of a complex device such as a wrist-driven prehension orthosis. Being on-site means quicker response time to the patient with no travel time for the practitioner, which also means that more time can be spent actually working with the patient as the need for adjustment arises. The expertise afforded by a qualified and skilled team of practitioners to the patient can only help an already trying and difficult situation.[9]

Through a team approach to orthotic evaluation of the spinal cord injured patient, the best orthosis for that individual should be provided. That does not necessarily mean the most complex or expensive orthosis. It means that, given a specific clinical picture, an orthosis is chosen based on all the factors previously discussed. The purpose of setting standards and guidelines is to increase the success rate of our patients, in allowing them every opportunity to return to a meaningful lifestyle. When this occurs, we as practitioners have done our job and can consider the input of our specialty a success. Conversely, our failures have a negative effect on both the patient and the practitioner. For the patient, it becomes a setback in that his hospital stay may be extended or, more importantly, the potential for independence may be lost because of rejection of the orthosis. For the practitioner, it may be not only a time of second-guessing, but a learning experience at the patient's expense.

Our approach to fitting of functional orthoses is as follows. All candidates for wrist driven prehension orthoses are initially fitted by the occupational therapist with a temporary training orthosis, namely the Rehabilitation Institute of Chicago (R.I.C.) tenodesis splint (Figure 6). The patient then trains for a period of time determined by the therapist. Once he has mastered this device, he can be fit by the orthotist with a definitive orthosis. The choice at our facility is the Engen wrist-driven prehension orthosis (Figures 7, 8, and 9). We feel this device best suits our needs because of ease of fit, adjustability, and cosmesis.[8] The occupational therapist trains the patient to use his orthosis for activities of daily living, including

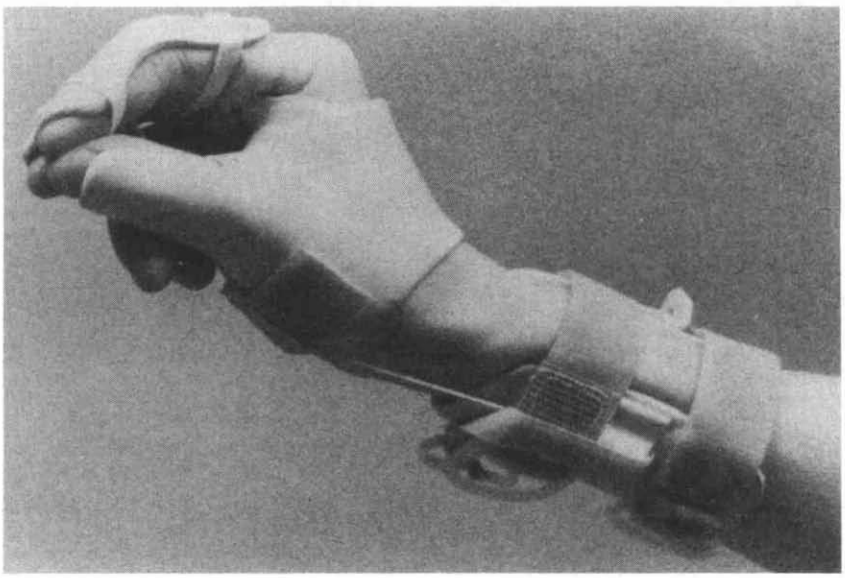


Figure 6. R.I.C., Tenodesis (temporary) splint with wrist extended and fingers apposed.

Functional Neurological Level	Residual Function (Cumulative)	Expected Deformity Without Treatment	Recommended Management
C4	Head Control Shoulder elevation	Shoulder subluxation Passive positional contractures shoulder elbow wrist hand	Complete passive range of motion 1–3 times daily (13,14) Binder, corset and/or lateral trunk supports Slings, overhead supports, lapboard, arm troughs Elbow extension or flexion orthoses Opponens orthoses with wrist control (Resting hand and/or long opponens with MCP extension stop) Balanced forearm orthoses (BFO) (may add externally powered actuator) Externally powered prehension orthoses (11) Externally powered elbow flexion assist and lock Externally powered shoulder flexion assist and lock Environmental control systems (13)
C5	Weak arm placement Elbow flexon Minimal postural compensation for trunk stability (13,15)	Shoulder abduction contracture Elbow flexion/ supination contracture (1) Passive, positional contractures wrist hand	Complete passive range of motion 1–3 times daily Power wheelchair, chin, breath or joystick control Manual wheelchair, short distance Binder, corset or lateral trunk supports Slings, overhead supports, lapboard, arm troughs Elbow extension orthoses BFO's (May delete later) Opponens orthoses with wrist control and utensil pocket assembly Externally powered prehension orthoses (May include passive or externally powered shoulder flexion assist and lock)
C6	Postural compensation for trunk stability Radial wrist extension Pronation (13,15)	Elbow flexion contracture Radial wrist deviation contracture Passive positional contractures hand	Complete passive range of motion 1–3 times daily Manual wheelchair Power wheelchair long distance only Binder, corset Elbow extension orthoses Opponens orthoses with wrist control and utensil pocket assembly Wrist driven prehension orthoses

Functional Neurological Level	Residual Function (Cumulative)	Expected Deformity Without Treatment	Recommended Management
C7	Elbow extension Wrist flexion Finger extension (13)	MCP extension/IP flexon contracture	Complete passive range of motion 1–3 times daily Manual wheelchair Possible binder, corset Basic opponens with MCP extension stop Finger driven prehension orthoses
C8	Finger flexion	Intrinsic minus deformity	Basic opponens orthoses Finger driven prehension orthoses *Note: Orthoses are rarely accepted by C8 quadriplegic patients*
T1	Intrinsic hand muscles At progressively lower levels proximal muscle function is stronger	None	None

the important function of self-catheterization of the bladder.[4] By virtue of thorough training, we feel the acceptance rate of orthoses is increased.

Unfortunately, our success rate with the Externally Powered Prehension Orthosis (EPPO) has not been as favorable as that of the wrist driven type (Figure 10). Two-thirds of all EPPOs that have been fit at our institution have not been used long-term. The feedback from our patients is that they were trained throughout the long rehabilitation process to adapt with the aid of special equipment and then, just prior to discharge, given a brace to replace the adaptive equipment. The patient who spent four to six months in the rehabilitation facility would have perhaps a week to learn to function with his new orthosis. It is hardly surprising that, in most cases, the orthosis was discarded in favor of the adapted equipment with which they were familiar. The problem has been, that for high cervical injuries, a training version of an externally powered prehension orthosis does not exist. This problem could be solved by development of a training EPPO in which the components could be reused on different patients. The only parts of the orthosis that would need to be custom-made would be the hand shells. The cost to the patient for these would be minimal and in the long run we could save the patient the cost of a very expensive "closet trophy" if he proved to be a poor candidate. We have initiated this project as a joint effort of the Occupational Therapy Department and the Department of Orthotics.

Summary

The fabrication and fitting of functional upper limb orthoses in quadriplegia requires close team work, especially between the orthotist and occupational therapist if the ultimate goal of acceptance of the orthosis as a useful aid to activities of daily living is to be achieved. We feel strongly that quadriplegics with wrist extensors should be fitted early with a functional training orthosis rather than supplied with activity-specific adaptive equipment. A confident, caring attitude on the part of the occupational therapist and orthotist can also do much toward achieving this goal. For quadriplegics with shoulder and elbow motion but no wrist extension, a training version of an externally powered prehension orthosis is badly needed for evaluation prior to ordering a definitive device. Success in the fitting of complex

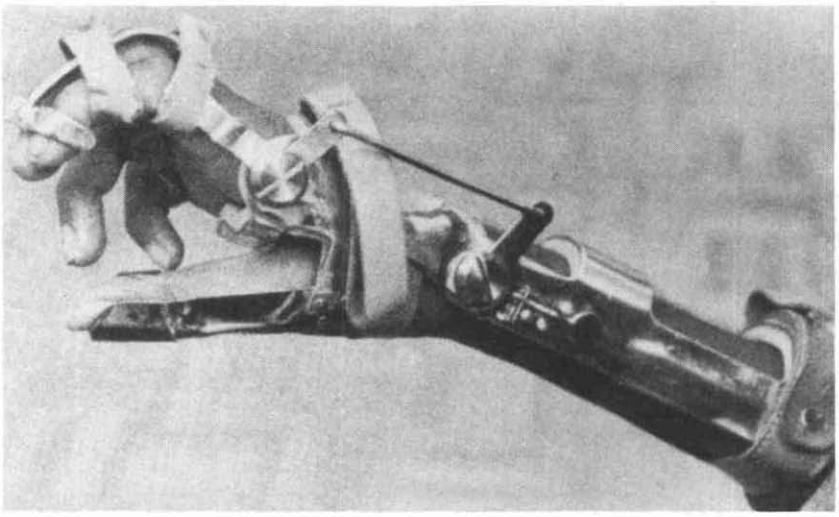


Figure 7. Wrist-driven prehension orthosis with wrist in neutral position and fingers open—Ranchos Los Amigos type.

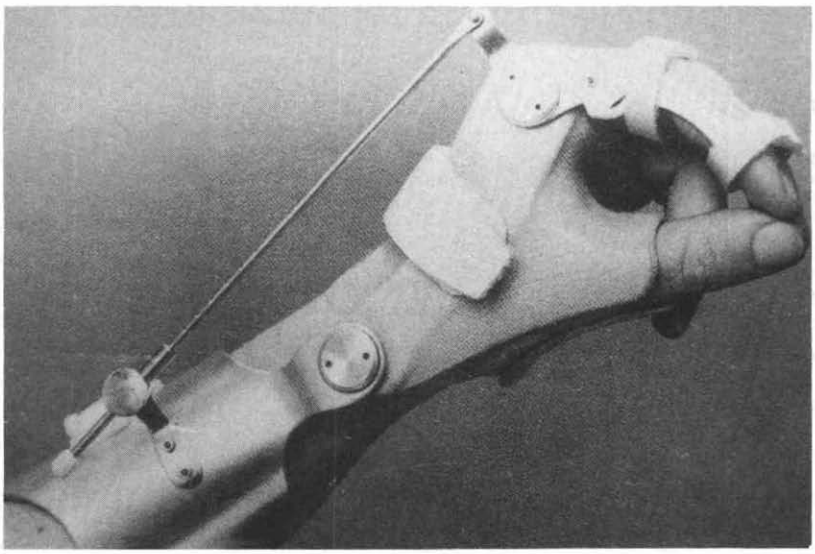
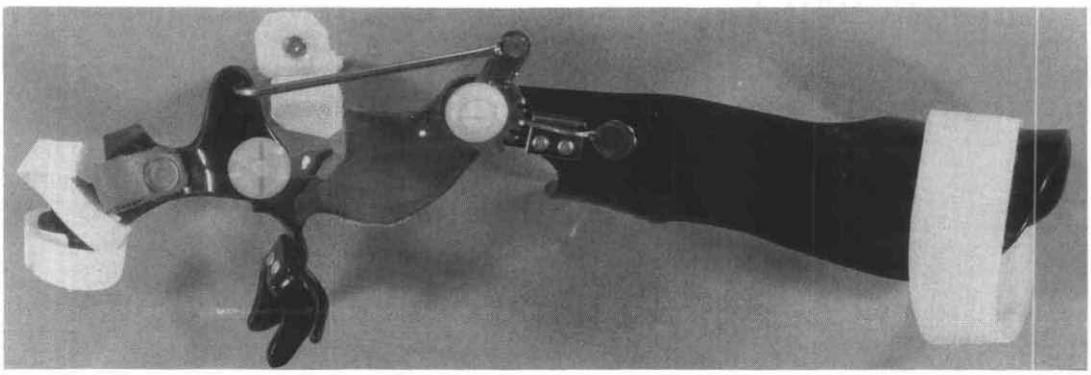


Figure 8. Wrist-driven prehension orthosis with wrist extended and fingers apposed—Engen type.

Figure 9 (below). Wrist-driven prehension orthosis (Modified N.Y.U.-I.R.M. system).



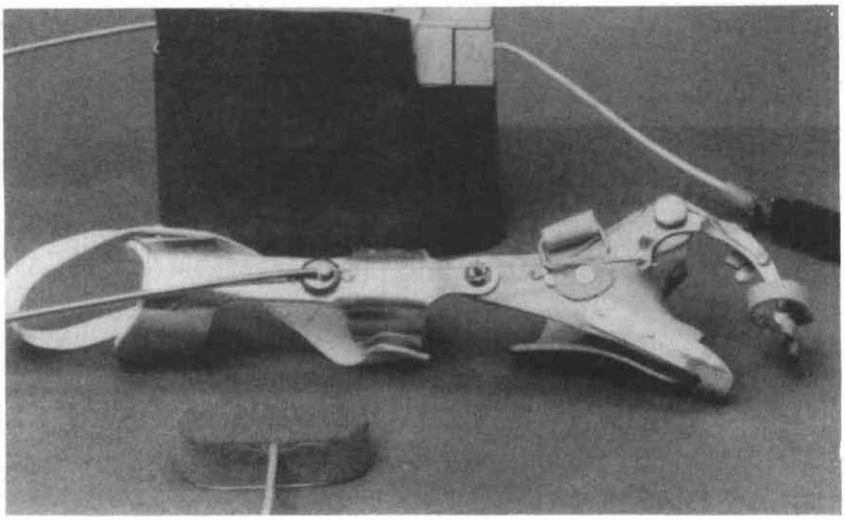


Figure 10. Externally powered prehension orthosis.

orthoses such as these requires almost unlimited "gadget-tolerance" on the part of the practitioner, if not the patient. The ultimate professional responsibility is to be equipped with both the manual skills and the objectivity to introduce all available options to our patients for their acceptance or rejection.

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Orthotic Management of the Surgically Stabilized Spine in Quadriplegic and Paraplegic Patients

by Michael MacMillan, M.D.
E. Shannon Stauffer, M.D.
Daryl G. Barth, C.P.O.

Recent developments in the diagnosis and understanding of spinal dysfunction have affected both surgical and orthotic management of post-traumatic spine instability. The diagnosis of spinal instability has been clarified by clinical study of its natural history and by application of advanced imaging techniques.[1] Biomechanical studies have defined the role of each vertebral component in maintaining structural stability.[2] Surgical techniques and instrumentation for treating this problem have also evolved rapidly. These advances have resulted in an improved approach toward operative management of spinal instability. First, because the outcome of spinal injury can be more accurately predicted, surgery can be elected earlier for disorders that certainly would fail with nonoperative management. Surgery systems are available which maximize their effect in both obtaining and maintaining optimal spine positions. These reliable instruments have allowed surgeons to apply operative stabilization to a wider range of spine problems. Therefore, the orthotist is presented with an increasing number of patients who have undergone surgical stabilization and require postoperative immobilization. The purpose of this paper is to review the rationale for surgical treatment of traumatic spine disorders. This review will identify both the neurological and mechanical factors which must be addressed. Some of the instrumentation systems available and a few of their advantages and disadvantages and disadvantages will be examined. Finally, five separate areas of the spine will be identified and the special orthotic considerations in each region reviewed.

The primary concern in all injuries to the spine is the neurologic status of the patient. There are three general categories of neurologic injury for which reduction and stabilization of the spine improves recovery.[3,4] The first group includes the Brown-Sequard, anterior cord, and posterior cord syndromes. These are collectively known as incomplete cord syndromes. Stabilization of the spine in the presence of these lesions can significantly improve neurologic recovery in a majority of cases. The second class of neurologic injury which is benefited by stabilization is nerve root compression at the cervical level. The recovery of a single nerve root at the cervical level dramatically improves the function of the patient for the rest of his life. This recovery can be facilitated by stabilization. The final lesion helped by internal fixation is the progressive neurological deficit. Often motion at a site of neurologic damage aggravates the injury. Surgical stabilization can reduce irritation and promote recovery. Thus, irrespective of the integrity of the spine, surgery can be indicated for neurologic conditions alone.

However, loss of structural integrity can itself be an indication of operative treatment. If

an area of bony disruption has resulted in significant deformity or has compromised the spine's ability to resist further deformity, surgical stabilization may be indicated. Authors have established guidelines for angulations and displacements to define this instability, but in all cases the final diagnosis of instability is largely clinical.[4] Pain at an area of compromised stability may also be an indication to reduce and stabilize a lesion. However, again the final determination is made on clinical grounds.

If internal fixation of the spine is indicated, the subsequent step is the selection of an instrumentation system and postoperative immobilization method for that patient. In dealing with quadriplegic and paraplegic patients, a major concern is skin insensitivity. Although postoperative cast immobilization provides the most rigid support and protection, it also presents the highest risk for skin and wound complications. It is generally agreed that orthoses which can be removed once or twice a day for skin inspection are best suited for neurologically impaired individuals.[5,6] The dilemma the surgeon faces is how to mobilize the patient as soon as possible after surgery, yet not use the rigid protection of casts. The solution to this problem has been the development of more rigid internal fixation systems for the spine.

Ultimately, the characteristics of the spinal column disruption determines the choice of instrumentation. Flexion, compression, and distraction are the three major mechanisms of spinal injury. Rarely does one force occur totally independent of the others. Usually one force is predominant with variable effect of the other two. The instability resulting from each of these forces, the instrument techniques used to counteract each of the deforming forces, and finally how the postoperative orthosis is also used to counter the mechanism of injury will be discussed.

Fractures which result primarily from flexion often involve crushing of the vertebral body anteriorly and distraction of the posterior elements. Generally speaking, instrumentation systems to correct this problem rely on three-point bending to reduce the fracture and maintain position. The Harrington system uses a single hook at either end of a rod to effect leverage against the kyphus and create an extension force. A long rod is required for this, so that excessive force is not generated under the single hook. In order to shorten the length of the rod and improve fixation, other systems have developed methods for attaching the rod to every segment over which it passes. The Luque, Wisconsin, and Cotrel-Dubosset instruments are examples of this segmental type fixation. These systems have three advantages over Harrington rods. By fixing the rod to each segment over which it passes, the large leverage force necessary to reduce the deformity is evenly distributed over several segments. This reduces pull-out failure. Because this force is distributed evenly, it is possible to reduce the total number of segments stabilized by the rod, thus preserving spinal motion segments. And finally, these segmental fixation systems are significantly more stable, which helps promote bony fusion of the injured segment. Another method of obtaining three-point reduction while improving instrument fixation is the use of transpedicular screws for placement of the hardware. This system uses a short plate placed over the vertex of the kyphus, and then screws placed through the plate are firmly anchored to the uninjured vertebra above-and-below the fracture. As the screws are tightened, the kyphus is slowly reduced. These devices involve the least number of normal vertebral segments to achieve reduction. They are exemplified by Steffee and Roy-Camille plates.

The segmentally fixed rods and transpedicularly anchored plates described above have excellent immediate stability. The major requirement of the postoperative orthosis is to reduce the stress on the implant by preventing repetitive forward bending of the patient. Orthotic requirements for Harrington rods systems are more demanding. With only single hook attachment, Harrington rods require an orthosis which generates a supplementary three-point bending force to reduce the possibility of hook pull-out. Because there are multiple unfixed segments where fusion is expected to occur, postoperative mobilization should be rigid enough to prevent non-unions from rotation and side-bending movements.

In fractures where axial compression is the major deformity, the vertebral body can burst both anteriorly and posteriorly. To reduce the fracture, an instrumentation system capable of distracting vertebral segments is chosen. Again, Harrington rods can be used in this situation. They have a hook in one end that can be

ratcheted against the rod to distract and pull apart the segments above and below the crushed vertebra. Segmental wiring alone is ineffective in reducing vertebral body burst fractures. However, many surgeons first use Harrington rods to counteract the compressive force, then use wires attached to the rod at every level to get the advantages of segmental wiring. This combination is lightly referred to as "Harri Luque." Plates anchored to the spine with transpedicular screws are incapable of generating a distracting force. An experimental Swiss system attaches a threaded distractor to the spine with screws and can be used to distract burst-type fractures.

Orthoses cannot effectively counteract an axial load, or the results of the compressive mechanism of injury. Therefore, the orthosis is used exclusively to protect the implants from stress while the bone graft is consolidating. Again, the orthosis is most clearly indicated when Harrington rods are the only instruments maintaining the reduction. These single hook rods are subject to dislodgement if excessive bending or torsional forces are encountered.

The loss of structural integrity resulting from distraction injuries has different implications in the diagnosis and treatment of this instability. While flexion and compression forces generally cause anterior bony collapse, distraction injuries tend to cause posterior ligament disruption. Since the injury is a traumatic tearing of ligaments and discs, the instrumentation is used to compress or pull the separated segments together. In the thoracolumbar spine, hooks enclose the vertebrae above and below the site of injury and are connected by a threaded rod. Turning of the rod slowly approximates the hooks and reduces the deformity. However, this type of injury predominantly occurs in the cervical spine. In this location, wires are usually used to draw the separated segments together. Because of the ineffectiveness of ligamentous healing, bone graft fusion is used in conjunction with internal fixation.

Postoperative orthotic management in this situation is more complementary than supplementary. Whereas the internal fixation stabilizes in flexion, it offers little resistance to extension. Therefore, the orthosis should emphasize stability in extension.

For the sake of completeness, orthotic management after anterior spinal decompression and fusion should also be mentioned. When this procedure is performed, most of the affected vertebra is removed and replaced with a block of iliac bone graft. Present anterior spine instrumentation uses a threaded rod attached to the spine with screws to afford stability. Control of motion in all planes by the orthosis is required in this clinical situation.

The previous section dealt with the indications and techniques of spinal internal fixation, with emphasis on the role of postoperative orthotic management. Next, five regions in the spine and some specific orthotic requirements for each will be identified. Particular emphasis will be placed on whether a specific injury requires an orthosis to restrict or only to reduce intervertebral motion. When an orthosis restricts intervertebral motion, less than ten percent of normal motion is possible at that segment with the orthosis in place. An orthosis which restricts motion is used when either no or minimal internal fixation is used to provide stability. When up to 30% of motion at an intervertebral segment is possible while wearing an orthosis, the orthosis is said to only reduce intervertebral motion and not restrict it. A reduction orthosis is indicated to protect inherently stable fractures or spines internally stabilized secondary to surgery.

The first anatomic area to be discussed is the upper cervical spine. In this area, instability can result from fractures of the atlas, from fractures of the odontoid process, and from disease processes such as rheumatoid arthritis and tumors. Orthoses generally are inadequate in restricting intervertebral motion between the occipito-atlanto-axial segments. Therefore, for virtually any upper cervical disorder requiring restriction of intervertebral motion, application of a halo and vest is indicated.[7] One possible exception is the SOMI brace, which can be used to effectively restrict instability from ruptures and attrition of the transverse ligament of the atlas.[7]

The second anatomical area is the lower cervical spine. This extends from C3 through T1. Restriction of motion in this region is required in at least three situations. One is a flexion injury which compresses the vertebral body anteriorly and disrupts ligaments posteriorly. A second need for restriction is for extension injuries which avulse both the anterior longitudinal ligament and the intervertebral disc. A final sit-

uation is postoperative management of lower cervical fusions in which no internal fixation is used. In these situations, a cervicothoracic four-poster device should be used. If only reduction of intervertebral motion is required, then application of a Philadelphia collar is all that is necessary. The usual clinical situation needing reduction of intervertebral motion is immobilization after posterior cervical stabilization with wires.

The third anatomical region lies between T3 and T10. The thoracic region possesses the most inherent stability of the entire spine. For this reason, the bracing requirements are minimal. If no internal fixation is performed, the stabilization afforded by the thoracic cage need only be supplemented by a thoracolumbosacral orthosis (TLSO) to ensure maintenance of position. Segmental type operative fixation is especially suited for the thoracic spine. When this is performed, often no postoperative orthosis is required. Postoperative immobilization is still required in the thoracic spine when Harrington instrumentation is employed.

In the fourth region, the thoracolumbar junction, the use of orthotic management is dependent on whether or not surgical stabilization is performed and if so, which instruments are used. In this area, from T11 through L3, the typical fracture occurs from a combination of flexion and compression forces and is termed a "burst" fracture. Nonoperative management of this lesion relies on bracing to create an extension moment to reduce the amount of collapse during healing. Operative treatment has a combined goal: to reduce and hold the fractured segments while leaving mobile as many normal lumbar segments as possible. For this reason either segmentally attached rods or transpedicularly applied plates are used in this area. Since these systems possess significant inherent stability, the TLSO provides effective postoperative immobilization. This orthosis has been demonstrated to be effective for the upper lumbar spine.[8]

The final anatomical area, the lumbosacral spine including L 4, is least subject to traumatic fractures. It does, however, present some interesting challenges to obtaining effective immobilization. Operative treatment in this area should also preserve as many mobile lumbar segments as possible. With L 4 fractures, the lumbosacral articulation can often be maintained. However, the more rare L5 fractures usually require fusion to the sacrum. Because of the need for short but extremely rigid spinal instrumentation, systems using transpedicular fixation are favored for lumbosacral fusions. Although this fixation method is rigid, the high stresses at the lumbosacral junction dictate that external immobilization be used, especially if two level fusions are attempted. The TLSO has almost no ability to immobilize the lumbosacral motion segment. Therefore, the use of a one-half spica cast is recommended for use after lumbosacral surgery.[8]

In summary, the role of orthotics in the postoperative management of spinal instability is critical. Because the lack of normal sensation precludes the use of casts in quadriplegics and paraplegics, the proper fabrication and application of an orthosis is essential. Knowledge of the original fractures forces, as well as an understanding of the principles of operative stabilization, can assist the orthotist in managing the postoperative immobilization of the injured spine.

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Mobility and Mobility Devices for the Spinal Cord Injured Person

by Samuel R. McFarland, MSME

Introduction

In the dictionary, the preferred definition of mobility is "the quality of being movable."[13] A second definition, more sociological in scope, defines mobility as "the movement of people in a population, from place to place, or job to job, or social position to social position." The second concept captures the significance of mobility as it relates to the life of a spinal cord injured individual. Spinal cord injury is a condition that most commonly affects young, physically active adults who have already established a social pattern in their lives. Certainly, spinal cord injury (SCI) causes impairment of movement, but more importantly, it may constrain a person's capacity for self-directed, purposeful movements, which are important to almost all activities. Much of the medical rehabilitation of a SCI patient involves therapeutic interventions aimed at increasing the range, strength, and coordination of body movements that have been impaired by an insult to the central nervous system. To fully appreciate the scope of mobility impairments encountered by SCI patients, we must examine the entire spectrum of activities that can be affected by limitations of movements. Independence, social and personal interactions, career development, and access to public facilities are some of the freedoms that can be adversely affected by mobility impairment.[9]

A thorough discussion of the methodology for reestablishment of mobility for SCI patients must include topics such as therapeutic interventions, orthotic appliances for stabilizing and enhancing the performance of musculoskeletal components, devices for extending the range or speed of movements, and substitutions for lost or severely limited functions. This article will not dwell on therapy, which is more appropriate for other authors, nor on orthotic appliances, since that subject is covered well in the accompanying articles on spinal stabilization and upper limb orthotics. Rather, it will attempt to represent some of the mobility considerations that are common to SCI and to discuss the application of products and techniques associated with ameliorating movement limitations. For the sake of simplifying the myriad array of details that can be covered under the general heading of mobility, this article will survey a sequence of activities that start with static support of the body and proceed to increasingly more complex movements in terms of range, speed, and energy demand.

The author admits to a bias toward devices and technologies, which will be reflected in the discussions that follow, but he wishes to emphasize his belief that the only successful technical solution to a mobility problem is the one that integrates well with other rehabilitation interventions and withstands the test of time and use by the patient. Simplicity, cosmetic design, and reliability are essential to the immediate and long-range acceptance of adaptive technology by the user.[8]

Background

Spinal cord injury commonly results in permanent paralysis of some of the large and pow-

erful skeletal muscles of the body. The location of the injury along the spine correlates roughly to the cumulative amount of paralysis that results. The closer the injury site is to the head, the greater the involvement. Trauma incurred at the spinal column can affect the transmission of the nerve signals to all parts of the body served by the injury site and beyond. However, functional deficits incurred by SCI are almost always incomplete, meaning seldom is there complete loss of function or bilateral symmetry of effects below the site of the injury (lesion). For the sake of this paper, however, it will suffice to consider only two general types of functional paralysis: paraplegia and quadriplegia.

Impaired voluntary control of skeletal muscles is not the only significant impediment resulting from SCI. Other organ functions can be affected as well. Bowel elimination, bladder voiding, sexual function, sweating, bone strength, and peripheral vascular circulation can all be altered in response to spinal cord insult. A common and troublesome side-effect is involuntary contraction of a muscle, spasm. Not only is the motor function of a nerve network affected, but also the sensory aspect. The combination of loss of sensation and reduced tissue blood circulation resulting from everyday bumps and pressures incur a high risk of undetected soft tissue damage. In insensate tissues, such seemingly minor injuries can easily progress into massive tissue death in the form of a decubitus ulcur. "Decubiti" are immensely threatening to a spinal injured person, not only because of the irreversible tissue damage, but also due to the extensive time loss and expense incurred in the treatment. All of these conditions must be kept in the forefront of planning for mobility and will be mentioned from time to time in the text that follows.

Transfer

The initial and simplest tasks of SCI mobility begin with rising from a reclining position, from which seated tasks, ambulation, or wheeled mobility can proceed. If starting from a bed, the person must first be able to sit up. A paraplegic or quadriplegic with good shoulder strength, may be able to sit up without assistance. Some may prefer to use an overhead handle, often called a trapeze, or a looped strap, to pull up into a sitting position. Sometimes a hospital type bed, with a powered drive to the articulated back section, can raise the person to a sitting position from which he can turn and let his legs off the bed in preparation for standing. A standing transfer, even with an attendant assisting is desirable because the weight is borne on the legs, but not by the attendant or a transfer device. If the legs are capable of supporting body weight, with or without bracing, the person may develop greater independence.

When the quadriplegic or high paraplegic is not able to stand without braces, the transfer from a sitting position to another seat is somewhat more complicated because of the physical strength required to lift the body, change levels between sitting surfaces, and traverse the distance. Transfer aids foster independence and supplement the work of an attendant. For wheelchair transfers, it may be helpful to use a sliding board (also called a "transfer board"), a short length of wood or rigid artificial material that bridges the gap between two sitting surfaces, such as the bed and wheelchair. A paraplegic, and some low level quadriplegics, can momentarily life his weight and move in short, sideways increments from one surface to another. A strong and active paraplegic will probably vault by pushing downward with his hands or swing from an overhead handle, in lieu of being burdened with a transfer board. Even a person who cannot transfer himself can be aided by sitting on a piece of sturdy fabric which may be pulled sideways across the sliding board by an attendant.

If a sliding transfer is not possible, a person can be lifted while sitting in a fabric hammock by a mechanical patient life that incorporates an electrical motor or hydraulic jack mechanism to provide the lifting force. The hammock is attached overhead to the lifting device which is usually operated by an attendant. Some can be self-operated if appropriate fail-safe or emergency mechanisms are built in to compensate for equipment failure. Elaborate custom installations of overhead tracks can allow a person to be transported from bedroom to bathroom and beyond. Overhead lifts are also available for transferring from a wheelchair into a car, but with the advent of van adaptations, they are losing acceptance among users.

The lifting and sliding principles used in transfer aids are applied in many products used

in home and institutional settings, especially in the bedroom and bathroom. A common application of the sliding-lifting principle is the bathtub transfer aid, a device used to help a person transfer safely into the bathtub and lower himself into the tub for bathing. Some products are completely passive, incorporating a sliding pathway for the user to traverse across the tub rim. Some are powered seats, often driven by faucet water pressure, that raise and lower the seated occupant relative to the tub bottom.

A more expensive form of lifting aid for the home is the vertical shaft home elevator that is used to give mobility between vertically separated living areas. Installation usually requires alterations to the structure of the building. A somewhat less expensive approach, where applicable, is the stairway elevator, which can be added to an existing staircase. Available as a chair for ambulatory persons and a platform for wheelchair riders, it typically follows the path and incline of the stairs and usurps a portion of the walking path. The least expensive adaptation for moving between levels, especially from outside, is the ramp. Ramps have been well defined in standards produced by the American National Standards Institute.[12] Outdoor elevators that are added on, rather than built into a building, usually called porch lifts, are made primarily for wheelchair users where ramp construction is impractical and a landing platform can be placed next to an outer door. Home elevators of all forms are usually sold and custom-installed by specialty vendors that are associated with vendors of other mobility aids.

Standing Aids

Paraplegics and quadriplegics, although unable to stand unassisted, can derive both physiological and psychological benefits from standing.[1] Being able to stand allows a wheelchair user to reach work surfaces and interact with standing people at their level. There are static devices, called standing frames, that hold a person in a standing position by binding him to an upright, rigid structure. The user must pull himself up from a seated position into the device and secure the binding straps or close and latch a supporting gate. The manipulations involved may require the assistance of another person.

A more complicated device that allows more independent operation by the user is the mobile stander that uses a power source to raise the person to a standing position and support him there. This principle has been incorporated into two forms of wheeled mobility. In the one form, the person may move slowly around for short distances on smooth surfaces after he rises to the standing position by controlling an electrically powered drive mechanism. In the other form, the assistive force standup mechanism has been added to a wheelchair. When the occupant is standing, the device is immobile. When the occupant is seated, it functions as a regular wheelchair.

Another standing device, but one that provides a modicum of mobility is the swivel walker, or "parapodium," that is used by a very few paraplegic adults.

Ambulation

Walking is the most common form of mobility for humans and the mode most desired by people who have limitations that diminish or eliminate their ambulation abilities. Where there is any possibility of a mechanism to regain the ability to walk or move about in a standing posture, even if it is slow and requires great expenditure of energy, a person often prefers to ambulate rather than use wheeled mobility. Even temporary standing, without walking, can be used to enable a person to get through narrow entryways, such as toilet compartments, bathrooms, and closets. The desire to remain upright has sustained the development and application of torso and leg braces, standing aids, and even artificial stimulation of paralyzed muscles by externally supplied electrical signals. At a lesion level around high thoracic, the instability of the torso suggests that ambulation may be less secure and more demanding of energy than wheeled mobility.

Stability

One of the more important considerations in assuring the fullest functional mobility of the SCI patient is stabilizing the proximal parts of the body in order to facilitate the most controlled movements of the distal portions. The person fitted with the finest of upper limb orthoses or supplied with the most elaborate

vehicle control system will be substantially incapable of adequate performance if the body is not appropriately stabilized. Securing the proximal portions of the body is a critical consideration and can easily be both underestimated and overdone. It is quite common that a patient will be trained to substitute certain spared muscle functions for those that have been impaired. If a substitute muscle is occupied with stabilizing the torso, it will be effectively unavailable for its substitute function. Similarly, if the proximal base of distal limb segments has been too severely confined, the distal functions will be limited. In general, the SCI patient will be concerned with use of the upper body for control and work tasks, so the primary concern should be focused on providing a secure base for the torso, while retaining a sufficient range of upper body motion to allow the arms and hands to perform functional tasks. These principles will be restated more specifically in the sections that follow.

Wheeled Mobility

When walking is not an option, or when the upper limits of speed and range of ambulation are too low for the mobility needs of the person or the occasion, the indicated mobility aid is the wheelchair or any one of a variety of wheeled devices. The basic, most familiar form of the wheelchair is a shiny, tubular metal, open-framed structure that has four wheels, two small casters in front and two large drive wheels in the rear. Details of implementation vary slightly, but the design remains essentially the same from brand to brand. They are intended to fit an average sized person, withstand heavy use with minimal maintenance, and be propelled primarily by an attendant. A wheelchair produced for these purposes is known in the industry as a commodity wheelchair and is intended for temporary use by any one person but repeated use by many people. This is the type of wheelchair that insurance companies and government-based reimbursement programs provide for nursing home and convalescent use.

Chronic users of wheelchairs should not use a commodity chair, but should be guided toward the use of a prescription wheelchair, which looks similar to the commodity chair, but is available in a variety of dimensions that can be more carefully sized to the user and embodies some optional features that better suit the demands of everyday, independent usage. Prescription wheelchairs tend to be lighter in weight, more durable, and offer less resistance to rolling than the commodity type because of the use of more specifically suitable materials and components and more exacting tolerances in their manufacture. Available options include variations in wheel and tire size and type, variable seating dimensions and configurations, removeable armrests and footrests, and selection of frame and upholstery material and color.[15] The diameter of the wheel and type of tire affect the maneuverability, rolling resistance, and riding comfort. Hard rubber or polymeric tires offer less rolling resistance than pneumatic tires, but transmit more of the shock of pathway irregularities to the rider than the softer, pneumatic tires. Similarly, small diameter wheels offer less inertial resistance to rolling than larger diameters, but the greater curvature imparts higher impact forces to the rider and inhibits movement over rough surfaces.

For a chronic user, a wheelchair should be very carefully sized and the components and accessories selected to assure efficiency of operation, postural support, and prevention of medical complications of disability. In general, a wheelchair should be as narrow as possible without pressing against the hips, thereby allowing the greatest freedom of access through narrow passageways and the maximum of mechanical advantage for propulsion and control. The back height should provide good postural support, but minimize interference with the arms during a propulsion stroke. Low level, active paraplegics may prefer a very low back to maximize freedom of arm and upper body movements. The height of the seat bottom is governed by three dependent variables; arm access to the pushrims, footplate clearance above the ground, and even distribution of the sitting load along the underside of the thighs and buttocks (taking the compressed thickness of any cushion into consideration).[3]

The wheelchair seat cushion is a crucially important accessory component for a person who does not have sensation in the lower body and legs.[16] A cushion is intended to help distribute the gravitational loading forces of the

occupant over the broadest possible area of the sitting surface and minimize the point pressure that occurs near the bony prominences of the pelvis and hips. There are many types of cushions that utilize a broad variety of materials and configurations, such as polyethylene foam, air and fluid-filled pillows, and semi-rigid and custom contoured devices. Each design has proponents who claim it is the best universal solution to the problem of pressure sores (decubitus ulcers), a major health problem for paralyzed persons with diminished or absent sensation. Since the formation of decubiti is related to many factors, such as pressure distribution and duration, temperature, moisture, diet, activity level and seating geometry,[10] it follows that no cushion can serve as a universal preventative measure. However, it is generally accepted by clinicians and users that there is a type of cushion best suited to each individual and careful selection for each person is important.

It has also become increasingly more common for wheelchair seating experts to recommend that the hammock-style seat be replaced with a rigid member to provide a solid support structure for the type of cushioning material that is chosen. Hammock seats tend to wrap around the buttocks, creating a squeezing and shearing force pattern that tends to restrict tissue circulation. Also, the hammock is inherently unstable as a support for a high center of mass.

The prescription wheelchair has recently undergone a rapid evolution in materials and design, resulting in lighter weight, smoother operation, greater durability and a change of image for the user. Wheelchairs are now offered in a mosaic of materials, colors, frame styles, and applications.[4] Largely because of the demand and innovations arising from the wheelchair sports movement, a new breed of daily use wheelchair has been developed and the market has accepted it with enthusiasm and buyer support. The new breed of wheelchair, now being labelled the "ultralight," embodies higher performance materials and design innovations including radial, rather than crossed (bicycle style) spoke patterns, aluminum alloy rims and hubs, die cast metal or injection molded polymeric wheels, adjustable position (fore/aft and up/down) and angle of axles, rigid (non-folding) and take-apart frames, and designer colors in anodized and polymeric finishes. The new product is less medical in appearance, more energy efficient to use, and more reliable and durable to the user. Although most of these changes have been directed at the manually propelled wheelchair for active adult paraplegics, some of the same innovations are beginning to be applied to powered chairs as well.

The addition of mechanisms that propel the vehicle using electric motor power has provided a means of independent mobility for previously dependent users with quadriplegia. The most commonly used powered wheelchairs are supplied from the manufacturer as an integrated product that combines conventional frame and seating design with motorized propulsion. The power drive wheelchair (also called "electric" and "battery powered") was originally the result of relatively minor design improvements to the basic tubular metal wheelchair.

Beginning in the early 1970s, the concept of a wheeled device, especially for severely disabled users, was reexamined by designers in North America and Europe. The result of that scrutiny was a proliferation of design ideas and clinical studies, some of which have resulted in commercially viable products. Out of that innovation revolution, stimulated in part by government supported research programs and workshops,[14] have come significant changes in propulsion and control of the electrically powered vehicle, an understanding of the health and performance benefits of carefully seating and positioning the occupant, and two new distinctly different types of powered vehicles.

The first thrust of innovation dealt with obtaining new control modes for the user who could not operate the conventional joystick controller. One of the most common modifications of the powered wheelchair, and most important to the independence of the user, is the relocation or other alteration of the operator control device (typically an electromechanical joystick). It is now possible, with the purchase of options from the wheelchair manufacturer, or modifications developed by separate suppliers, for a severely impaired person to drive a powered wheelchair using any available physical movement on the body, including the head, chin, eyes and feet. It is also possible now to control a powered wheelchair with oral modulation of the breath and pneumatically powered

electronic switching (the "sip and puff" control).

The second most noteworthy trend in the redesign of the basic vehicle has been the separation of the seating function from the vehicular function. Conventional wheelchairs had been designed so that the chassis of the vehicle and the frame supporting the seat were the same. Therefore, changing the seat meant changing the total unit. The current focus on separating the functions has freed the vehicle designers and body positioning designers to pursue independent courses of study, resulting in both improved vehicle performance and enhanced comfort and health for the user. Scientific knowledge of the biomechanics and physiology of the wheelchair occupant is now being more appropriately applied to the development of specialized seating systems that position the body statically, and periodically reposition it, to promote improved vascular circulation and breathing, pressure relief and posture, leading to greater comfort, health, and prolonged periods of functional independence for the user.[5]

An entirely different form of vehicle, the powered cart, has also been developed during the past decade, primarily for people who are ambulatory, but limited in speed and range of ambulation. The cart does not look like the basic wheelchair, rather a scaled-down, one person version of the familiar golf cart. Intended primarily for public use by less severely disabled people, the cart is available in a variety of three and four-wheel versions with either tiller or joystick control. People who might otherwise use ambulatory aids or manually-propelled wheelchairs may choose a cart to gain greater speed, range, and (in some models) rough terrain travelling capabilities. Use of the cart should be confined, however, to areas where motor vehicles are not likely to travel. On the road travel for wheelchair users should be limited to persons riding in specially adapted automobiles, trucks, and buses.

Adapted Motor Vehicles

As a passenger or as an operator, a spinal cord injured person can greatly extend his range of travel by using a motor vehicle. The motor vehicle, whether a passenger car, a truck, or a mass transit vehicle, presents some significant impediments to use by an SCI person and typically must be modified to accommodate him. The impediments can be roughly grouped into three categories: access, securement, and control. In order to safely and comfortably use a motor vehicle, a person must be able to get into (and out of) the vehicle, be seated comfortably and secured against any hazards that are presented by vehicle motion, and, if feasible, he must be able to exercise guidance or accessory control over the vehicle.

Access to the vehicle is the pivotal concern, for if the individual cannot enter the vehicle, securement and control functions are moot. Entry into a vehicle is affected by the size and shape of the doorway, the height and slope of the ground just outside the vehicle, and the amount of time consumed in the boarding process; these parameters can be effectively controlled with an adapted personal vehicle.

Mass transit vehicles, which are designed to quickly transport large numbers of people, present a great challenge to people who use ambulation aids and wheelchairs because transit systems typically operate on hurried schedules and boarding occurs in tight spaces. Access to busses, trains, and airplanes is a problem if the person cannot enter the vehicle where it is normally available for boarding without displacing other passengers or delaying the route schedule. Despite these conflicts, many of the modern mass transportation systems have incorporated accommodations for mobility limited people and their mobility devices.[2] Older systems are typically not accessible and not feasible for retrofit. Personal vehicles and small busses for groups of mobility impaired people, however, can be selected and effectively adapted with structural modifications and add-on products.

Personal vehicles are more adaptable. Many people prefer to use a passenger sedan, rather than a van or bus, simply because it is smaller and less costly to own and operate. Paralyzed people, except for those who ride power drive wheelchairs, can get into a sedan without using special access equipment, but may need a little more time than able-bodied people. They must learn to be selective about the place on the sidewalk, at the curb, or in the garage where they board, because the height and slope of the ground often affect the ease of boarding. Generally desirable features in a car include a tall, wide door opening, a door that swings open to

a large angle, and a seat at chair height with firm padding and low friction upholstery. A broad driprail or handle located overhead near the door opening can give a person something to hold or pull against during the transfer process. Large interior leg space is important, especially to someone who wears a long leg brace.

Seating is only part of the access problem, since once the person is seated, the mobility aid must be stowed. A crutch or cane can be stowed inside the car, but a walker may be too bulky unless it is the type that folds up for storage. A wheelchair creates a special problem which will be discussed later.

The person who can enter a passenger car, even with difficulty, may find entry to a van or bus to be impossible because the height of the seat from the ground is typically too great to enable direct sitting from outside the van. The person must enter the van before sitting. Van seats more nearly resemble a chair in height and attitude, so they are more accommodating to a mobility impaired person than the seats of a passenger car, but the height of the entry step on a van is as much an impediment to an ambulatory SCI person as stairsteps in a building. Even if he can surmount the stepwell and get inside, he cannot stand upright either for sitting or moving about, unless the roof has been extended. On vans that have been modified for a raised roof, the side or rear cargo doorway is also modified to give more head clearance to people entering and leaving the passenger area.

To accomplish the transition from ground level to the level of the van floor, both ambulatory people and wheelchair users can be aided by a ramp or a platform lift. The ramp is the least expensive access device and offers the most trouble free service, but another person is needed both to deploy it into operating position and to assist the user while he is traversing the bridge. The lift, though more expensive, is frequently preferred over the ramp. For attendant operation, a lift carries the load, thereby reducing the labor and risk of injury. Unlike a ramp, certain types of lifts can be self-operated by a passenger in a wheelchair. There are two general designs of platform lifts: the folding lift (also called flop-out) and the swinging lift (also called rotary). A lift of the folding type consists of a platform for supporting and carrying the passenger and an electromechanical or electro-hydraulic power mechanism that provides the lifting force. Deployed for operation, it unfolds outward to a horizontal attitude ready for moving the passenger between the floor and ground levels. The folding lift is usually offered in semi or fully automatic operating modes. The semi-automatic version raises and lowers under power while an attendant provides the controlling function as well as the stowage operation (opening/closing doors and folding/unfolding the platform). The more complicated, and more costly, fully automatic version is further equipped with switches and drive mechanisms that allow the user to control the entire process independently. Typically, the installation of a fully-automatic lift is accompanied by the installation of a powered door opener and an external lift access control panel to complete the total system of components that provide the user with a capability for independent access to the vehicle.

The swinging lift is almost always provided in a fully-automatic configuration. The platform travels vertically outside the opened cargo door between ground and vehicle floor levels. At the floor level, the platform swings (rotates) about a vertical axis into the vehicle and remains there for its stowed position, thereby limiting the available floor space inside the vehicle. This type of lift is somewhat less expensive to purchase and is lighter in weight than the folding type, but typically will not accommodate a full-sized powered wheelchair or cart.

Many users of wheelchairs can transfer to the automobile or van seat without assistance. Often the transfer is aided by the sliding across a transfer board and sometimes by pulling up on an overhead handle or wriststrap. Each person must develop his own transfer technique based on the spatial geometry of the opened doorway, the location of the seat and vehicle interior appointments, and the nature of his physical ability. The transfer process will also vary with the vehicle being used and nature of the trip. Use of a taxicab, rental car, or a friend's car presents a greater challenge because of the variability of vehicle type, many of which are not suitable to the individual wheelchair user. After transferring themselves into the car, passengers (or drivers) of sedan-type vehicles must load the wheelchair into the car or park it at the debarkation point before they can close the door. If an attendant (or cab

driver) is present, the chair can be placed in the trunk, in the back seat, or on a special rack attached to the back bumper. The independent wheelchair user must either stow the wheelchair (folded or dismantled) inside the car behind the front seat or on the roof outside. Strong and agile paraplegics can usually fold the chair and pull it inside. Those who are less able sometimes use a rooftop carrier to stow the chair. A passenger who transfers to a seat inside a van (a desirable practice from the standpoint of safety) can usually tether the empty wheelchair next to him inside the van, making it readily accessible for re-transfer and exiting the vehicle.

Access to the vehicle seat does not complete the process of safely preparing for travel. The passenger should be secured. With many SCI people, safety securement is more than a crash protection mechanism, because they may have insufficient upper body strength to withstand common vehicle accelerations. A seatbelt or over-the-shoulder harness can be very important for both purposes. When an ambulatory person is seated in a vehicle, he can almost always use the conventional safety restraint belt for passenger security. So can a wheelchair user who is able to transfer from the wheelchair to the vehicle seat. When a wheelchair user cannot transfer, he should use some form of restraining device. As a general rule, both the wheelchair and its occupant should be restrained (separately) by a vehicle structural member. Many designs of restraining devices have been tried and tested by researchers and manufacturers. To date, only two relatively satisfactory approaches have been produced. In one, the wheelchair is permanently fitted with an additional structural subassembly which serves to reinforce the structural integrity of the wheelchair and engage a mating assembly that is securely anchored to the frame of the van. Though demonstrated to be an impact resistant combination,[11] this approach has the disadvantage of restricting a passenger to the use of a van that carries the mating structure and of imposing additional weight on the routine mobility of the wheelchair, demanding additional propulsive energy from either the arms of the occupant or the batteries of the power system. A second approach separately tethers the wheelchair and the wheelchair occupant to the vehicle structure, using belts. The tethering operation is virtually impossible for a wheelchair user to perform independently and is time-consuming even for an attendant. Some of the restraint devices that are provided for wheelchairs, however adequate to the task for wheelchairs of the basic design, will not engage certain forms of wheeled mobility aids at all. Passengers using such non-standard aids must often travel unrestrained.

Many SCI people can be adapted to driving.[7] Although they may lack the leg and arm function required to operate the pedals and steering wheel, they may employ specialized products called automotive adaptive controls (also called hand controls and foot controls). Such devices transfer the locus of driving control from its conventional position in the vehicle to a location and configuration that can be operated effectively by parts of the body that are functionally able to handle the task. If the feet are not able to operate the throttle or brake pedals, a mechanical linkage can be added to transfer the input to a hand-operated lever. For most products, the throttle and brake are combined into a single lever.

Since the hand-control completely occupies one hand with starting and stopping, the other hand must do all the steering. If that hand is limited in strength, common to quadriplegics, a steering wheel spinner may be needed to assure constant hand contact with the wheel throughout its rotational circuit. Spinners are available in a variety of configurations, depending on the nature of the hand disability. Other adaptive devices take the form of extensions of vehicle control levers, shafts, and pedals (such as turn signal, gear selector, steering column, throttle, brake, and emergency brake) that improve the mechanical advantage, extend the locus of activation, or transfer the operation to the opposite side. Hand controls typically do not prevent another person, who is not disabled in driving function, to drive the car since the conventional controls remain intact, having been added-to rather than replaced.

Just extending and relocating the application of forces is sometimes inadequate to enable a quadriplegic to drive. Where conventional power assisted steering and braking requires more force than the driver can exert, it is pos-

sible to further reduce the force or range of movement required to operate the controls by performing a more extensive modification of the vehicle control components. Reduced effort steering, throttle, and brake conversions diminish the force the driver must supply. Since the driver who needs force amplification is unable to operate the vehicle without the modification, the complete reduced-effort system should be supplied with backup power that will sustain hydraulic and vacuum reserves, even if the engine (the primary source) fails. With the use of a reduced-effort system, the mechanical advantage of a large diameter steering wheel and extended lever arms is no longer needed, so the range of movement of the input controls can be reduced to accommodate limitations in upper extremity movement. A small diameter steering wheel, even one that is repositioned through universal joints and angular drives (so-called "horizontal steering"), extends the possibility of driving to people with even greater limitations of limb movement.

As with all mobility aids, professional help with selection and training is very important to the ultimate successful application of automotive adaptive aids. Specialized assessment and training facilities have been established in conjunction with major rehabilitation centers worldwide. The staff of these centers typically includes a therapist, a driver trainer, and an equipment specialist who combine their expertise to provide the disabled driver candidate with comprehensive assessment, equipment selection, vehicle modification, and driver training.[6] In some areas, the vendor of vehicle adaptive equipment and modifications is responsible for the recommendation of products and services, but the more comprehensive clinical team approach seems to be more objective.

Conclusion

Helping to attain mobility for the spinal cord injured individual is a multiparameter equation. Mobility is key and essential to almost all aspects of the process of rehabilitation and return to active life postinjury. Many products and technologies are available to help extend the residual capabilities of the patient. A team approach to mobility assessment, prescription, and training will greatly encourage the development of a system approach that can lead to a well integrated plan for the user.

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Psychological Aspects of Spinal Cord Injury

by Katharine S. Westie, Ph.D.

Spinal cord injury (SCI) is a massive assault to the psyche as well as the body. Within moments, a person who had been active and independent becomes immobilized, loses control of bowel, bladder, sexual and other bodily functions, and is dependent on others to meet the most basic needs. The instantaneous effects of the injury result in total disruption of the victim's life, and the beginning of a life-long psychological adjustment process. Optimal emotional adjustment is imperative to the recovery and rehabilitation process, due to the tremendous psychological energy and motivation required for a SCI patient to learn self-care, independence, and psychosocial coping skills.

Theories of Psychological Adjustment

Psychological adjustment to SCI has been conceptualized in terms of three major models. The first is referred to as the "stages" theory, and is derived from the well known work on grieving done by Lindeman and Kubler-Ross.[7,6] This theory proposes that individuals adjusting to losses, such as SCI, experience certain psychological stages in the readjustment process. These include (1) shock and denial, (2) depression, (3) anxiety, (4) anger, (5) "bargaining," and (6) adaptation. In using this model, it is important to understand that not all patients go through all stages, that a patient may go through a stage more than once and that stages are not necessarily experienced in a given order. This model is helpful in recognizing these emotional responses as a normal, healthy, and appropriate part of adjustment to SCI.

The second model is referred to as the "developmental" theory. It is derived from Erikson's work on psychosocial stages of development, from infancy to adulthood.[4] As applied to SCI, the developmental theory assumes that the trauma results in a natural regression, followed by a reworking of some developmental tasks previously mastered in childhood, starting with (1) basic trust, (2) autonomy, and (3) initiative. Physically and emotionally, SCI patients must progress through tasks of infancy and childhood again. Like infants, they initially may be unable to verbally communicate, need to be fed and moved, have no bowel and bladder control, and are totally dependent. As they progress through rehabilitation, they relearn childhood tasks such as rolling, feeding, developing a bowel and bladder routine, mobility, and other basic activities of daily living. They experience the adolescent task of separation from parental figures as they work toward the independence of adulthood. The rehabilitation program can be seen as facilitating attainment of these developmental landmarks.

The third model, the "individual differences" theory, proposes that adjustment is primarily related to individual differences in patients' premorbid personalities.

These models provide three different approaches to understanding psychological ad-

justment to SCI. However, they need not be seen as mutually exclusive. In fact, when used together, they provide a more complete picture of SCI patients' complex adjustment process.

Psychological Responses of Staff

Rehabilitation professionals working with SCI may find that certain patients elicit grieving responses in them, similar to those of their patients. When staff members identify with or become emotionally attached to patients, they may find themselves experiencing symptoms of depression, anger, or even denial. Highly motivated staff may also find it difficult to cope with noncompliance of depressed or angry SCI patients. Occasionally, when staff members' goals for resistant patients are not met, they may blame themselves for perceived failures or subconsciously direct anger and frustration toward patients. Although these are normal emotional responses, they may interfere with staff members' well-being and effectiveness. When situations such as these occur, consultation with the rehabilitation psychologist can provide the staff member with behavioral management techniques and enhance personal coping skills and insight. Professionally facilitated groups designed to provide peer support, teach stress management skills, and prevent "burnout" are also recommended.

Head Injury in SCI

Closed head injury (CHI) frequently accompanies traumatic SCI, though it often goes unrecognized. The reported incidence of head injury in SCI ranges from 10% to 58%.[5] Recent studies indicate that neuropsychological deficits are common among SCI patients.[2,3,13] Morris, et al. state that 50% of all SCI patients may be expected to exhibit evidence of CHI and some degree of cognitive impairment.[8]

Even mild head injuries can significantly affect cognitive and emotional functioning, especially during the first months post-injury. The most prominent areas of cognitive dysfunction following CHI are in learning, memory, and speed of information processing, all important to learning of new skills in rehabilitation settings.[2] Thus, patients' ability to acquire new knowledge may be greatly diminished at the precise time that intense demands to learn are placed on them.[1] CHI-related behaviors such as poor social judgment, poor frustration tolerance, impulsivity, emotional lability, perseveration, difficulty in initiating behavior, decreased mental stamina, fatigability, and irritability are often misperceived by staff as enduring premorbid personality traits. Neuropsychological testing can enhance patient and staff insight into the effects of CHI and facilitate treatment planning.

Psychological Treatment Approaches in the Rehabilitation Setting

Though the primary responsibility for psychological care of the SCI patient is assigned the psychologist and social worker, other rehabilitation professionals on the interdisciplinary team play an important role. Sensitivity to the patients' emotional status allows for treatment planning and interaction that maximizes physical and psychological rehabilitation.

Ideally, psychological rehabilitation begins in the Intensive Care Unit (ICU) soon after injury. At this time, many SCI patients are intubated and unable to verbally communicate. They often experience disorientation, depression and anxiety, sensory and sleep deprivation, and perhaps the temporary delusional and hallucinatory state known as "ICU psychosis." This is a critical time for team members to offer emotional support, establish a communication system and determine what the patient wants to know. Some need extensive information about their injury and care in order to best cope with fears and anxiety. Others clearly want to delay knowing more about their condition. Most welcome reassurance that their emotional responses and concerns are normal and accepted.

As the patient progresses through acute care into the rehabilitation setting, regularly scheduled psychotherapy sessions can facilitate the adjustment process. The psychologist can help the team understand the patient's stage of adjustment, and provide consultation on behavioral management approaches.

Emotional responses dealt with by psychotherapy include a range of ego defenses, most commonly repression and denial. It is important to recognize that these defenses protect the psyche from material too traumatic to deal with

consciously, thereby preventing decompensation. In this regard, denial and repression are adaptive, and indeed may be the reason SCI patients are able to function in the stressful rehabilitation situation so soon post-injury. Typically, as denial decreases over time, depression, anxiety, and anger increase. How these emotions are expressed depends largely on the patient's premorbid personality style.

Normal emotional responses to SCI may be manifested in behaviors which impede progress in the rehabilitation setting. For instance, depression may cause psychomotor slowing, decreased motivation, and social withdrawal. Anxiety may create psychogenic somatic symptoms and poor concentration. Anger may result in noncompliant or destructive behavior. Psychotherapy can help via reinforcing adaptive coping skills and teaching new coping strategies. The psychologist may also work with the interdisciplinary team to develop behavioral modification programs, based on learning theory, to decrease these behaviors. Contingency management and behavioral "contracting" are most frequently used in rehabilitation settings. Approaches emphasizing positive reinforcement to "shape" desired behaviors are particularly effective.[10] Although such programs may be time-consuming initially, they can rapidly decrease maladaptive behavior and ultimately increase the patient's sense of control and self-esteem.

Psychological treatment of SCI often includes group psychotherapy, which is an excellent method to both maximize patient learning and efficiently use therapist time. Patient groups can provide emotional support, peer role models, teach new coping skills, and decrease social discomfort. Likewise, multiple-family group psychotherapy is a powerful and effective tool for facilitating family adjustment to SCI.[9,12] Family members experience similar emotional responses to the patient and similarly benefit from psychological intervention. If not included in the team effort, a well-meaning family member could inadvertently sabotage the independence-oriented rehabilitation approach, or be too psychologically distressed to provide the emotional or physical care the patient needs.

Other issues which need to be routinely addressed by the psychologist, in conjunction with the rehabilitation team, are sexual adjustment, vocational rehabilitation and pain management training. Prevention of medical complications, particularly those which have significant behavioral/emotional components, need to be emphasized. An example is pressure sores, which often occur when depression and/or substance abuse lead to poor self-care.

Psychological Response to Orthotic Devices

SCI patients' ability to emotionally adjust to orthotic devices (sometimes referred to as "gadget tolerance"), is related to type of orthosis, premorbid personality factors, and stage of emotional adjustment.

Orthoses used to stabilize the spine after surgery sometimes become the "target" of patients' emotional distress. For instance, it is easier for the patient who is denying the seriousness of his SCI to blame pain and decreased function on the TLSO. Anger expressed toward an inanimate object is "safe," whereas anger directed toward family or staff may have negative repercussions. Insight into these psychodynamics can help the orthotist deal with constant requests for adjustments to orthoses, or anger responses of post-surgical SCI patients.

Upper and lower limb orthoses used to increase independence elicit a variety of emotional responses. The potential for increased function often provides a major psychological "lift," enhancing patients' sense of competence and self-esteem. However, inclusion of psychological factors in the selection of candidates for orthoses is critical. Fitting a patient who is not emotionally ready for an orthosis will result in loss of time and a failure experience for all concerned.

There are numerous reasons why SCI patients may resist orthotic devices, or are unsuccessful with them, including the following:

Body image

Many SCI patients value the fact that they look "normal" except for the wheelchair. The magnitude of disability may be "invisible." When orthoses are introduced, patients sometimes report that people stare at them more. Their sense of "being different" and social discomfort increases. For this reason, sensi-

tivity to aesthetics is important in designing orthoses for this population.

Independence-Dependence Conflicts

In some patients, there are secondary gains in their dependent state, though they may not be consciously aware of this. For example, when an upper limb orthosis significantly increases independence in activities of daily living, the patient may experience withdrawal of valued reinforcers (e.g. time and attention from caregivers). This can lead to rejection of the orthosis. If significant others (family and staff) are willing to provide extra attention and reinforcement for the new independence behaviors, these issues usually resolve well.

Self-Concept

SCI patients may not integrate disability into their self-concept for some time. In one study, 130 SCI patients were interviewed about their dreams in order to examine subconscious content regarding self-perception. The authors found that 75% of these patients, injured less than one year, had never seen themselves in a wheelchair in dreams.[11] This is one illustration of the initial need of SCI patients to maintain an underlying self-image as nondisabled. Orthoses may conflict with this self-image in more recently injured SCI patients.

Denial

Orthoses may threaten patients' denial systems. Patients not yet ready to acknowledge the extent or permanence of their disabilities frequently reject orthoses. Alternatively, they may accept temporary orthoses, but reject definitive ones. Patients with self-image and denial issues benefit from psychotherapy and being given more time to adjust emotionally to their disability. They should be provided with information on obtaining recommended orthoses for the future. At the other extreme, patients sometimes build denial systems based on unrealistically high hopes for orthoses. For example, a patient using lower limb orthoses for ambulation may find they are not practical for use in valued pre-injury activities. This could lead to breaking down of denial and increased depression or anger, which may temporarily create decreased motivaton or rejection of the orthoses. Clear communication, emphasizing realistic expectations before introducing orthoses, may prevent some of these responses.

Premorbid Personality

Longstanding personality attributes (such as poor frustration tolerance, risk-taking behavior, and substance abuse) and stage of adjustment (especially depression) can lead to poor self-care resulting in pressure sores or poor follow-through in any activities requiring sustained effort. Attention to psychological factors in selecting candidates for orthoses is the most important factor in preventing these problems.

Summary

Spinal cord injury results in an overwhelming physical and emotional adjustment process. By understanding emotional responses, and applying them in treatment planning and interaction with patients, rehabilitation professionals can greatly enhance the psychological adjustment of SCI patients.

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The Relationship Between Orthotics and Gainful Employment of the Disabled

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S.T. Layton, Ph.D.
J.H. Bowker, M.D.

Statement of Problem

Physical and sensory disabilities restrict individuals from functional access to the environment.[1,2,3] Since our environment is best suited to the average person, losses such as these represent formidable barriers to fruitful interactions with the environment and society.

Of special significance in this regard is the ability to function productively in gainful employment. National statistics reveal that the unemployment rate among the disabled is tenfold that of the general population (70% versus 7%).[4] Barring all other variables, this statistic reflects that our environment is especially inaccessible to the disabled.

There are several factors which contribute to this serious unemployment problem.[1,4] Notable among these is the fact that the disabled are unable to return to work due to "access" deficiencies caused by the nature of their disability. In this sense "access" means to bridge the barriers to the environment imposed by physical or sensory disability (Figure 2). This paper deals with the probable relationships between adaptive devices and employment/economic opportunities for the disabled.

Probable Solutions to Access Deficiencies

Appropriate solutions to these "access" problems can be complex, but all necessitate the use of orthotic or adaptive devices. Typically, these devices will aid the disabled to achieve a level of performance that, at best, approaches that of the able-bodied person.

The primary device for the severely disabled remains the wheelchair which, when appropriately prescribed and adapted, provides mobility throughout the workplace and good sitting posture for proper interface with tools at the workstation. A stand-up chair allows the worker to utilize a standard file cabinet and reach objects on higher shelving. Quadriplegics can manipulate keyboard sticks either with wrist-driven flexor-hinge orthoses if C-6 function is present or with the use of a universal utensil holder for those with C-5 function.

The advent of high-technology electronic devices such as computers and robots has greatly expanded the horizons of the severely disabled in the workplace. These devices, which are cost and energy efficient, can transform minimum physical energy into tangible and im-

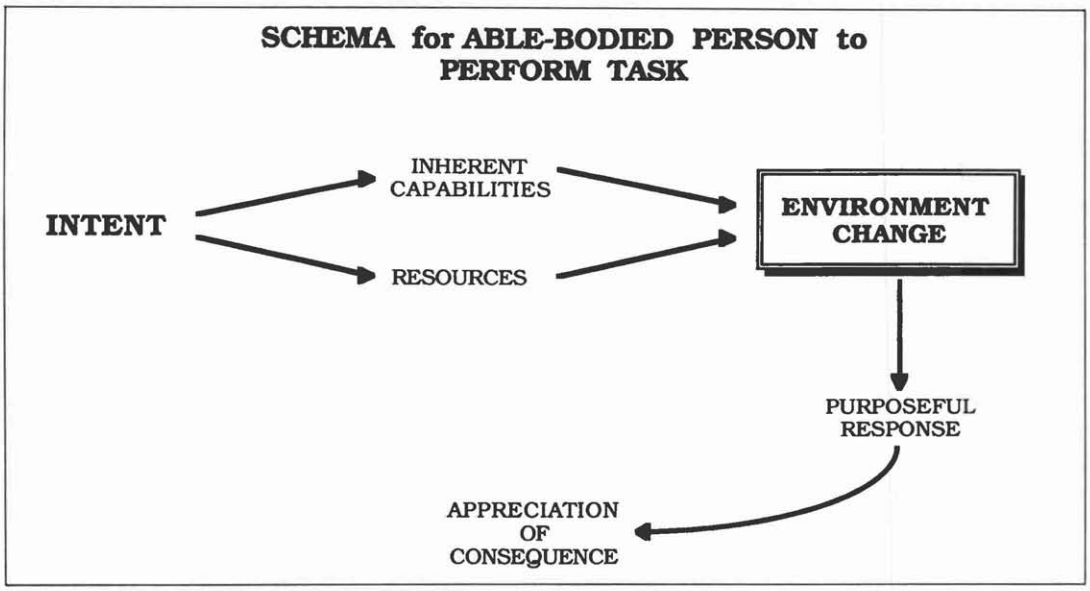

Figure 1.

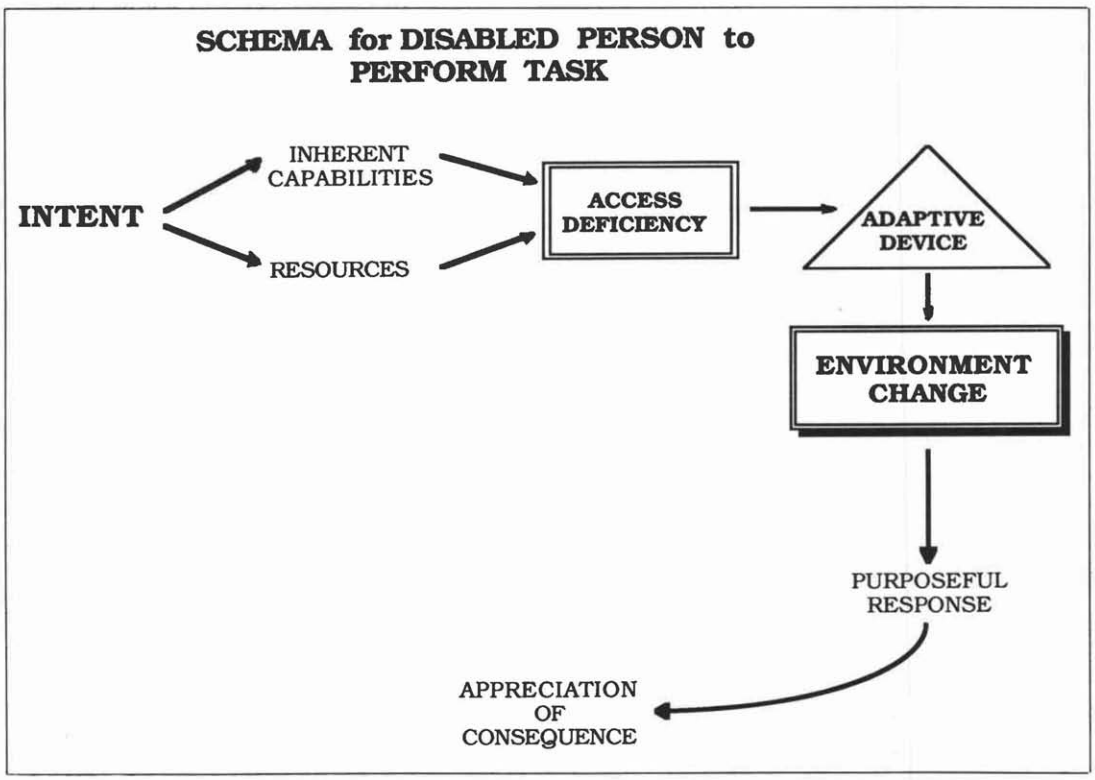

Figure 2.

pressive work events. A simple example is that of a quadriplegic operating a microcomputer by activating a switch by a "sip and puff" device or speech-recognition software and hardware.

For the purpose of this discussion, it is necessary to focus on the relevance of these devices to independent living and the achievement of gainful employment for the disabled. A behavioral model for task performance may be considered which allows the definition of the necessary device required to achieve a particular task.

Figure 1 is a schematic representation of the performance of a common task by an able-bodied individual. In this illustration, an intent or desire to perform a particular task is first identified.[5] After assessing the person's inherent capabilities and resources, the activity can then be performed. Consequently, the immediate environment is altered, a purposeful response is made, and the consequences are appreciated.

Figure 2 depicts the same task presented to a disabled individual. This schematic is altered to demonstrate the physical and/or sensory barriers to completing a similar task.[5] A disabled person may have a desire to perform this task, but may not have the same inherent capabilities or the resources as the able-bodied counterpart. At this juncture, "access" deficits to the environment become obvious. An adaptive device is required to facilitate the fulfillment of this task. One might expect the appreciation factor to be much higher compared to the able-bodied person.

Improvement of Function

For many years orthoses have been successfully fitted to restore and sustain the ability to carry out common activities of daily living. These biomechanical devices have improved the ability of the disabled person to perform such physical tasks as sitting, walking reaching, and grasping.

Functionally, many of these activities are no different than those found in the current workplace. Those disabled persons previously employed in manual labor or manufacturing jobs would probably be displaced from their previous employment. This is due, in part, to the fact that conventional orthoses have definite limitations in their ability to replace the physical potential of the able-bodied.

Therefore, till now, the highly disproportionate number of unemployed disabled persons does not indicate a positive correlation between employment and the use of traditional orthoses or adaptive devices. However, the emergence of microcomputer technology during the last decade has provided new potential for more effective use of these devices. Furthermore, the microcomputer can be regarded as both a biomechanical accessibility device and an employment tool which can be utilized for physical and economic rehabilitation.

The Change in Definition of Work

Our global economy is rapidly evolving from an "industrial" to an "information" age.[6] Jobs are becoming more knowledge-based with increasing dependence on computer technology as the sole productivity tool.[7] Indeed, the management of information is being realized as a central resource or commodity for jobs. Consequently, demand for manual labor is being steadily replaced by a demand for workers who can effectively manage information. In the coming decade, more than 50 percent of all jobs in this country will be found in high technology based information management. The personal computer is the principal instrument used in these jobs.[7]

These events are quite beneficial to those who are physically disabled, because the labor market will depend in a large degree on mental rather than physical capabilities. Coincidentally, the tool used in these new jobs is the same tool that can be used to access the environment: the microcomputer.

Economic Rehabilitation

Even in view of recent economic and technological developments, the question of the high ratio of unemployment among the severely disabled remains a serious and complex problem. In most cases, the severely disabled are displaced from their previous careers and require intensive rehabilitation to re-enter the job market. This implies that rehabilitation is certainly not complete until educational/retraining and economic goals are met to achieve financial independence. Therefore, complete reha-

bilitation is defined here as the process by which a person who is disabled and unemployed, can be physically and, more importantly, functionally and economically rehabilitated. This can only be achieved through a comprehensive program which includes not only conventional strategies of physical and occupational therapy, but vocational diagnostics, vocational counselling and retraining, and lastly, job placement.

MEED (Microcomputer Education for the Employment of the Disabled)

Appropriate vocational diagnostics and job retraining are key elements in successful economic rehabilitation. In most instances, this training has been inadequate, frequently resulting in supported job placement. Such a disincentive is often compounded by the possible loss of government-subsidized unemployment benefits and health care coverages.

Therefore, at the University of Miami, we have developed an economic rehabilitation program based on high-technology called MEED, or Microcomputer Education for Employment of the Disabled. MEED was conceived from the federal Projects With Industry (PWI) model to pilot a high-technology approach to rehabilitative training. It is a microcomputer-based training and placement program for the severely disabled, teaching information management skills which are necessary for competitive employment in business. This training is comprehensive, job-targeted, and cost-effective.

Other Causes of High Unemployment

Although access barriers are keeping many disabled persons from the workplace, their high rates of unemployment certainly reflect a minimal relationship between employment and adaptive devices. These devices may promote job function, but may not significantly increase the chance of that person acquiring a job. Many other factors come into play, especially the social issues facing disabled individuals and the marketability of their job skills. Other factors also contribute, including: first, unavailability of suitable retraining programs; second, chronic health problems; and third, government-established major work disincentives, such as disability payments.

Conclusions

In our judgement, feasible vocational retraining approaches are needed. They must be designed to equip disabled individuals with marketable skills which are necessary for competitive employment. Partnerships among several sectors of the community are essential to make these efforts a success. These include academia, government, business and industry, and the rehabilitation and health-care communities.

Conventional orthoses will play a significant role in complementing the function of high technology devices. For example, various splints and universal utensils will improve computer keyboard access and function.

However, technology holds the key to the future of economic rehabilitation. We believe that the computer, particularly the microcomputer, is central to achieving this goal. The microcomputer is not only a valuable business productivity tool, but is also a vehicle through which a severely disabled individual can "access" his environment. In a sense, the microcomputer itself can be viewed as an orthotic or adaptive device. It is an extension of not only the body, but also the mind. So, in the "information age," the microcomputer is assuming a pivotal role in improving the quality of life for the able-bodied as well as, and even more importantly, for the physically disabled.

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Mechanical Comparison of Terminal Devices

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Introduction

Considerable controversy has developed over the appropriateness of fitting "functional hand" prostheses to juvenile and adolescent amputees. This controversy is further enhanced by the cosmetic advantages of functional hands over the more traditional hook terminal devices. Conversely, experience has shown the hook terminal devices to offer greater functional control. Prosthetists often feel obliged to fit the amputee with a more functional terminal device, while the amputee often wishes to relinquish some function for cosmesis. Because the functional hands available today do not approach the necessary control, and because hooks are so uncosmetic, a significant percentage of upper limb amputees tend not to wear their prosthesis. The fundamental question presented to the prosthetist in fitting an amputee is how much function can be gained with a particular device. If function is defined simply as prehension grip force and grip width, the next question is whether an amputee can fully operate the particular device completely and comfortably.

To date, very little objective data has been available on the comparison of terminal devices. Hence, prescription principles on the part of most prosthetists have been somewhat subjective. Quantitative force and excursion are not usually critical in fitting low level amputees; but the strength adolescents, juveniles, and higher level adult amputees can induce, becomes quite variable. The study presented here is an objective comparison of several terminal devices for mechanical function. The measured parameters were prehension grip force, grip width at full open, excursion range, and the excursion force required to fully open the terminal devices.

Methods

Test Protocol

All test data presented here was accomplished on a MTS-858 universal materials testing machine. With this hydraulically powered machine, a piston-like cross-head can be positioned accurately, while loads created on the test specimens are monitored. The degree of sophistication of this machine is not critical to the test protocol. Any testing apparatus can be used as long as displacement and created force can be measured accurately.

Two different tests were performed on each terminal device at each of the different tension settings available. The first test will be referred to as the excursion test. Here, the cross head and load cell of the test machine were attached to the cable actuator of the terminal device (Figure 1). The terminal device itself was mounted rigidly to the machine base. The result of this test was a plot of excursion of the cable actuator against the tensile force gener-

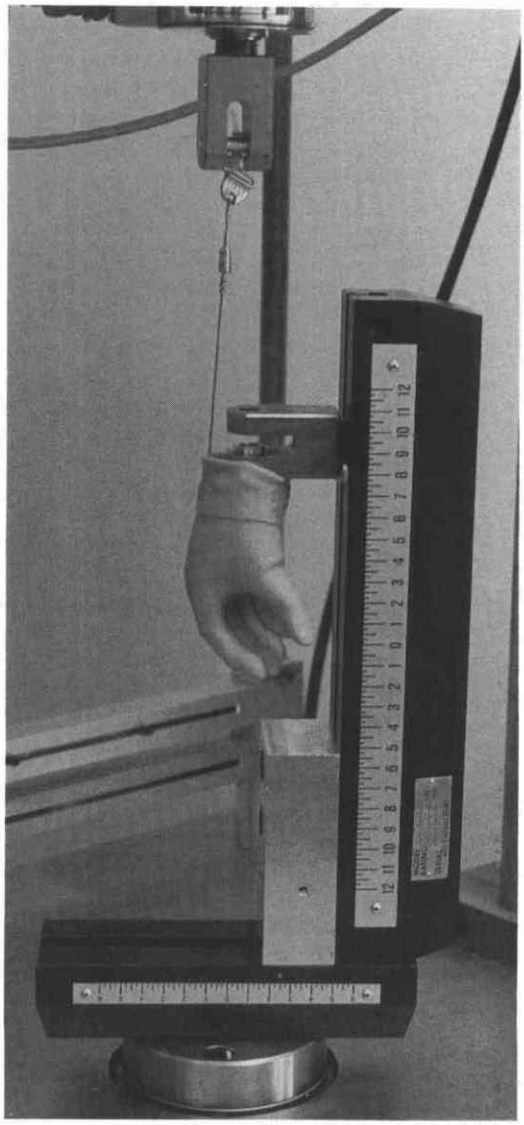

Figure 1. A 2.5″ U.N.B. STEEPER set up for excursion testing on the MTS-858 universal machine.

ated in pulling the cable (Figure 2). The rate of pull was constant at 4″ per minute and, because of this slow rate, loading was considered to be static. The plots of excursion force verses excursion of the cable actuator were all of the same general form. Figure 3 shows generalized force versus excursion plot. To present the actual loading curves for each device tested would have taken considerable space, therefore, for each device the only parameters that were tabulated are "A," "B," "C," "D," and "E." The portion of the curve up to "A," "C," represents the pre-loading of the terminal device. Excursion of the cable up to this point does not significantly move the appendages of the terminal device and is primarily due to slack in the system. The pre-load force "C," is the force necessary to overcome preloading of the spring or bands. The force constant "D," of a particular terminal device is the slope of the loading curve between the end of preloading and full open excursion of the cable. The full open excursion of the cable actuator is the distance "B," while the force required to fully open the device is labeled "E." It should be noted that with the five parameters, an estimation of the excursion-load curve of a particular device can be reconstructed. It should also be noted that the tabulated excursion parameters were measured by pulling the terminal devices open. If one was to continue to plot force versus excursion while the device was allowed to close, one would find much lower forces for a given excursion. This hysterisis in the loading curve is due primarily to friction. The loading curves are presented, rather than the unloading curves, because this is the manner in which the devices are operated.

The second test performed was to assess the prehension gripping forces that are created with each device. With the hand in a horizontal position, the base of the test machine was attached to the thumb, or one hook half, with a cable. The phalanges, or other hook half, were attached to the cross head and load cell of the test machine via a cable (Figure 4). The prosthesis was started in the full open position. A plot of grip force verses grip width was created by allowing the device to close at a constant rate of 4″ per minute (Figure 5). From these plots, the parameters "G," "H," and "I," were calculated for use with the generalized graph (Figure 6). It should be noted that the

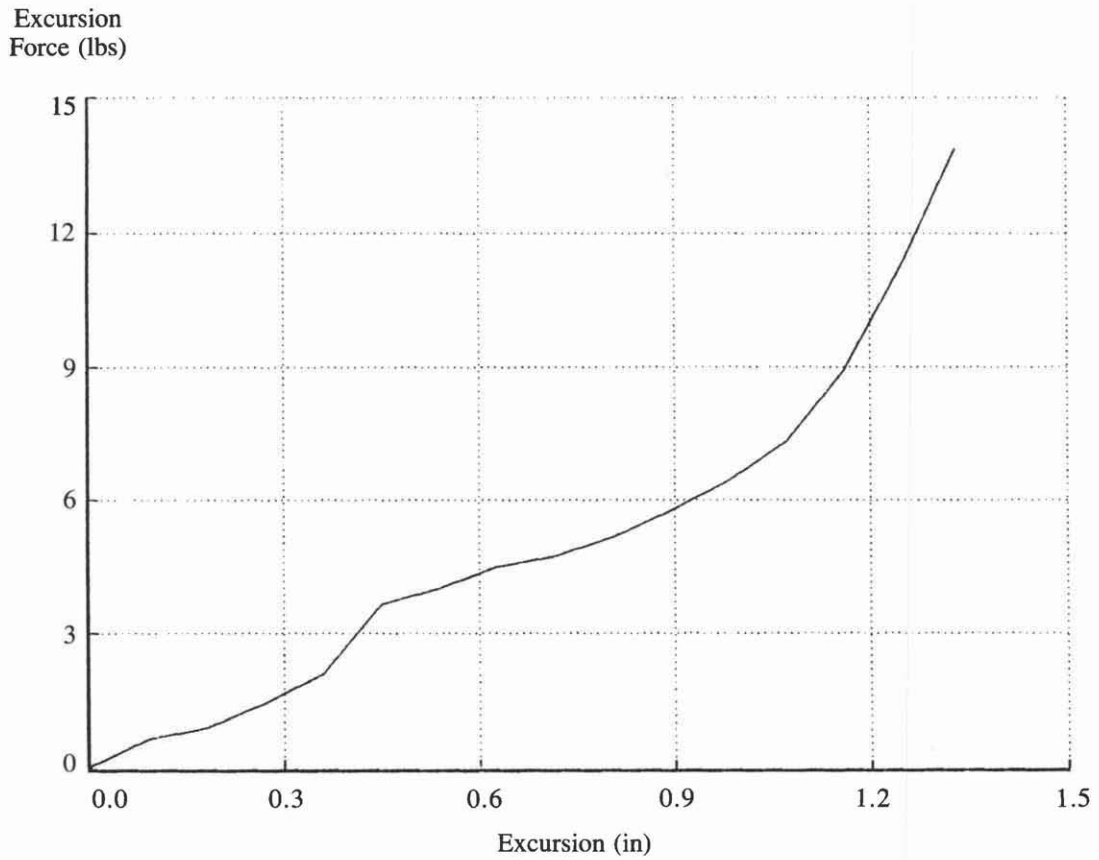

Figure 2. Experimental plot of excursion force vs. excursion travel on a 2.5″ U.N.B. STEEPER terminal device. Notice that at 0.45″ the characteristics of the curve changes. This is the point (A,C) at which the hand just begins to open.

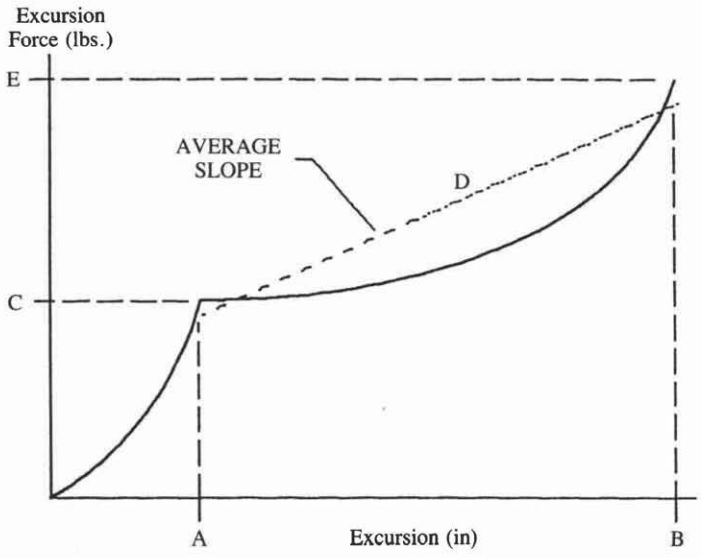

Figure 3. Generalized version of excursion force vs. excursion with parameters indicated.
A—Pre-load excursion (inches)
B—Full opening excursion (inches)
C—Pre-loading force (lb.)
D—Force constant in loading (lb./in.)
E—Total excursion force at full open (lb.)

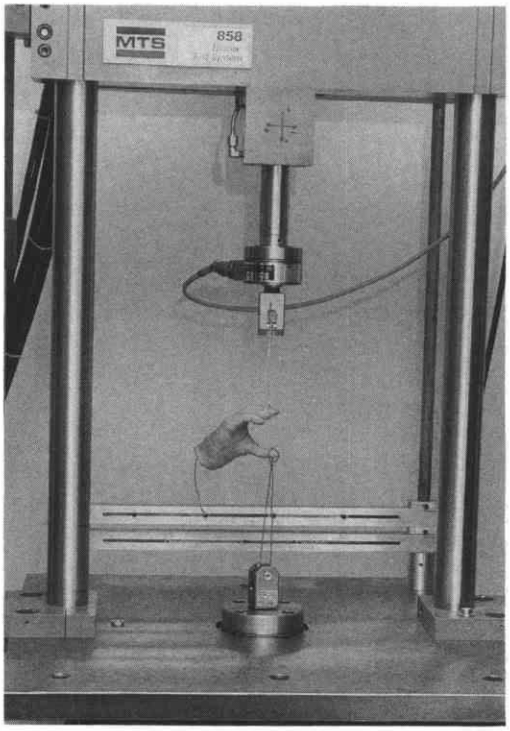

Figure 4. A 2.5″ U.N.B. STEEPER set up for prehension grip testing on the MTS-858 universal machine.

plotting direction of these curves was opposite to those discussed in Figures 2 and 3. Since the hand was started full open, maximum prehension grip force "I" and the full open grip width "F" are plotted first. The force plotted here represents the force created by the device upon its own closing. The force necessary to pull the appendages open would be greater than this force, due to friction. In Figure 6, "G" is referred to as the initial prehension force. This is the force created just prior to the grip closing completely. Also, the prehension grip force constant, "H" is the slope of the unloading curve between fully open and closed positions of the terminal device. With the parameters "F," "G," "H," and "I," an approximate reproduction of prehension grip force verses grip width can be created.

Results

Table I lists the measured parameters derived from the two tests of 33 terminal devices. Of the 12 parameters listed, the first nine were described previously in the test protocol section. The J-th parameter is the number of different devices tested of each type. When more than one device was tested of a particular type, results were averaged. The criteria for testing most of the devices was based on local availability. The ratio of maximum prehension grip force to excursion force is often called the efficiency of a terminal device. The K-th parameter is the measured efficiency. The last parameter, listed as "L," is that of the work required to open the terminal device by pulling the actuator cable. Work is defined as the excursion force times excursion length and is measured by calculating the area under the force-excursion curve. This parameter can be estimated to reasonable accuracy by considering the area under the generalized force-excursion curve (Figure 3). The work, or area under this curve can be calculated as:

$$\text{work} = \tfrac{1}{2}(A \cdot C) + (B - A)C + \tfrac{1}{2}(E - C)(B - A)$$

Discussion

General trends in the measured parameters become evident on closer examination of Table I. Organization of these tables is such that devices with numbers less than 20 were hook type terminal devices, while those with numbers 20 and over were functional hands. Preload excursion, parameter "A," can be thought of as the excursion necessary to take up slack in the system. Some functional hand units require as much as ½″ of excursion before any opening occurs. Full opening excursion, parameter "B," and the total excursion force necessary to open the terminal device, parameter "E," are self explanatory. If an amputee cannot generate either the excursion or the necessary force, a different terminal device should be considered. It should be noted that children usually have trouble operating a device with an excursion force greater than ten pounds.

The pre-loading force "C" and the force constant "D" are useful parameters in as-

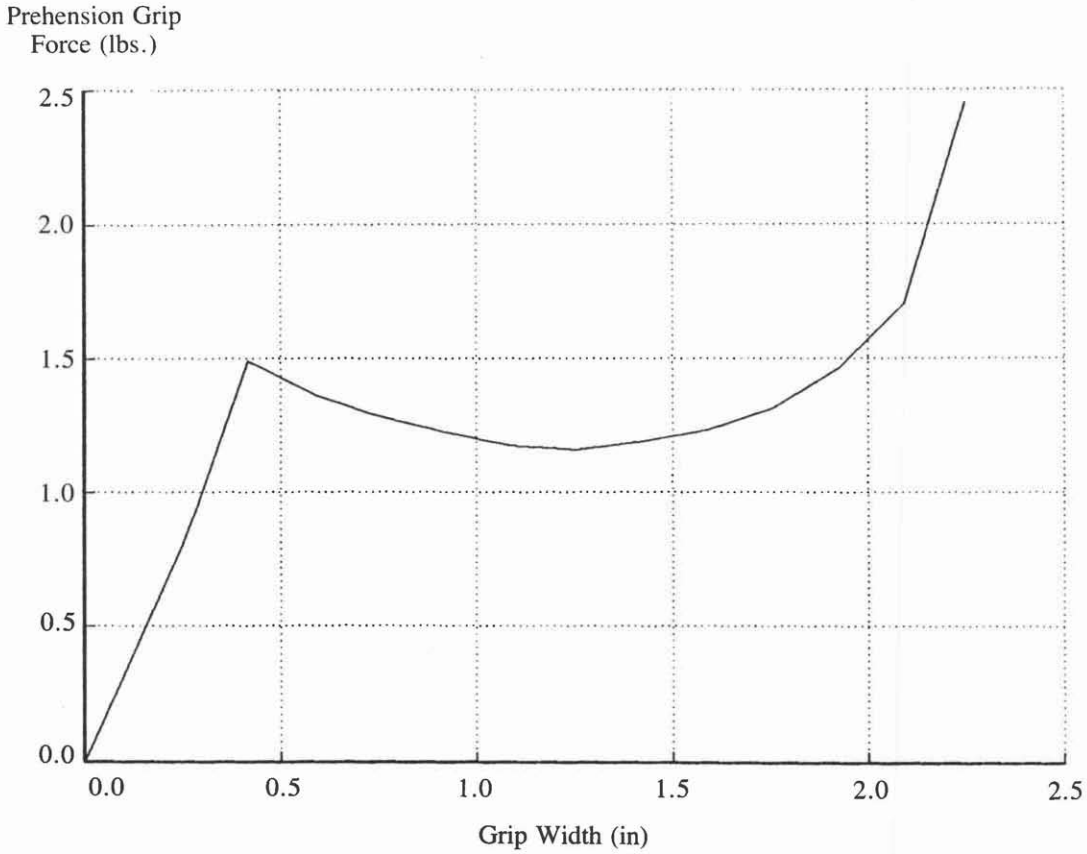

Figure 5. Experimental plot of prehension grip force vs. grip width for a 2.5″ U.N.B. STEEPER. This plot was started with the hand full open, a 2.25″ grip width, and 2.5 lb. grip force. The steep slope at approximately 0.4″ is where the inner locking mechanism activates. The hand is essentially closed at this time.

sessing the function of a terminal device when the amputee can marginally create the forces and excursion necessary for full opening. In marginal cases, large pre-loading forces will limit the function of a device. For example, although the UCLA CAPP, device number one, only takes eight pounds to open fully, a patient must be able to create at least 4.5 pounds to start the device in motion. Without regard for the pre-load, one might incorrectly think that four pounds of excursion force would open the device halfway. A terminal device with a high pre-opening excursion (more prominent in hands) could be used on an amputee with good strength initially, but might have weakness toward the end of the excursion range. This is particularly true for higher levels of amputation which rely more on scapular abduction and less humeral flexion. Another important factor to note is the grip performance of the terminal devices. Here the full open grip width "F" and maximum prehension grip force "I" are the important notable values.

The parameter that includes both grip and excursion is "K," the ratio of maximum grip force to excursion force. This term was measured to be greater than 0.40 for all of the hook type devices examined, and less than 0.40 for the functional hands. Some hooks revealed efficiencies as high as 0.70. It should be noted that the ratio of maximum grip force to excursion force can be calculated from the geometry

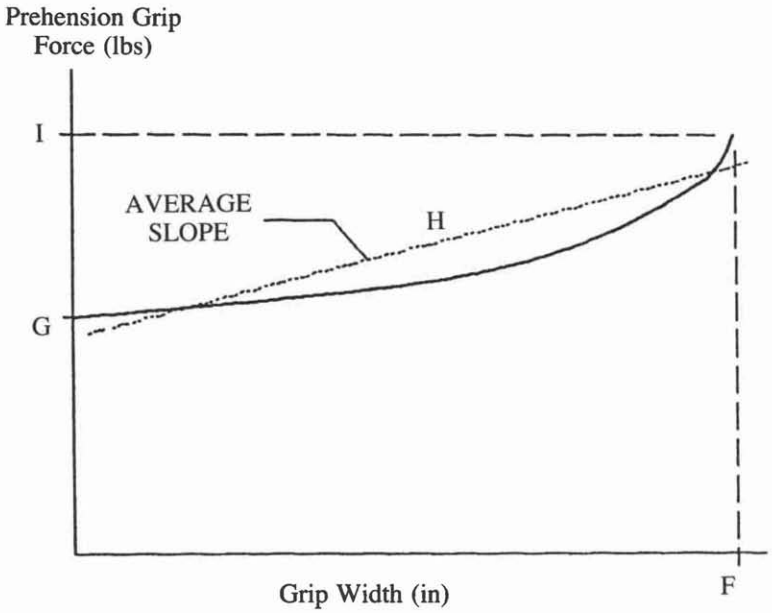

Figure 6. Generalized version of prehension grip force vs. grip width, with parameters listed.
F—Full opening grip width (inches)
G—Initial prehension grip force (lb.)
H—Prehension grip force constant (lb./in.)
I—Total prehension grip force (lb.)

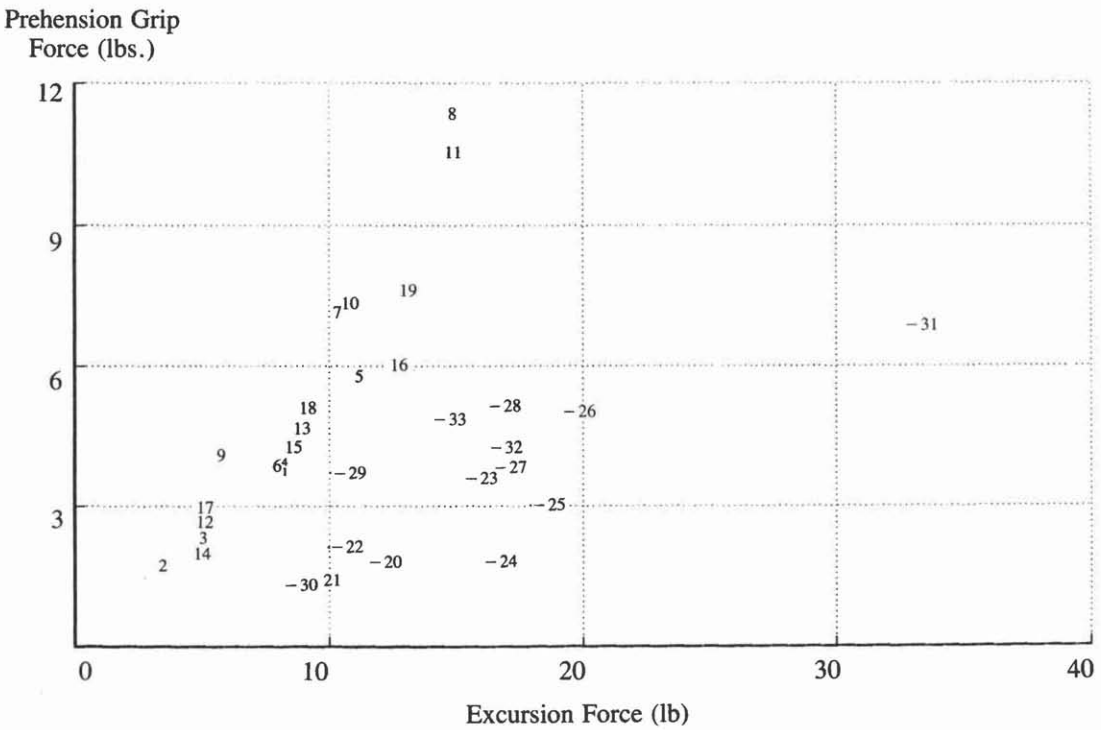

Figure 7. Graph of prehension grip force vs. excursion force for all terminal devices. Note that all hand terminal devices have a preceding dash.

Device Number	1	2	3	4	5	6	7	8	9	10	11
A. Pre-load Excursion (in)	0.25	0.06	0.12	0.12	0.12	0.03	0.06	0.06	0.06	0.12	0.12
B. Full Opening Excursion (in)	1.75	1.68	2.06	2.06	2.06	1.87	1.87	1.87	1.87	1.87	1.87
C. Pre-loading Force (lbs)	4.50	1.80	3.80	7.25	10.50	5.40	6.00	9.60	2.50	6.00	8.50
D. Force Constant In Loading (lbs/in)	2.30	0.90	0.50	0.36	0.25	1.30	2.30	2.80	1.60	2.50	3.40
E. Total Excursion Force Needed to Open Terminal Device (lbs)	7.95	3.26	4.77	7.95	11.00	7.80	10.16	14.67	5.40	10.37	14.45
F. Full Opening Grip width (in)	3.00	3.00	4.00	4.00	4.00	2.37	2.37	2.37	2.25	2.25	2.25
G. Initial Prehension Grip Force (lbs)	0.75	0.36	0.92	2.08	3.46	1.55	3.49	5.77	1.48	3.42	5.26
H. Prehension Grip Force Constant (lbs/in)	1.00	0.42	0.30	0.47	0.55	0.97	1.50	2.30	1.10	1.70	2.30
I. Maximum Prehension Grip Force (lbs)	3.75	1.62	2.12	3.96	5.66	3.85	7.05	11.22	3.96	7.25	10.44
J. Number of Hands Tested	2.00	3.00	1.00	1.00	1.00	3.00	3.00	3.00	2.00	2.00	2.00
K. Efficiency: Ratio of Maximum Prehension Grip Force to Excursion Force	0.47	0.50	0.44	0.50	0.51	0.49	0.69	0.76	0.73	0.70	0.72
L. Excursion Work (lb-in)	9.90	4.15	8.54	15.18	21.49	12.23	14.80	22.25	7.22	14.68	20.59

Table I. Values measured from hook and hand type terminal devices.

Description of Terminal Devices Tested

The following list of terminal devices corresponds to the device number of Table I.

1. CAPP regular spring, center pull, nylon cabled
2. CAPP soft spring, center pull, nylon cabled
3. HOSMER SSS-555, 1 band, steel cabled
4. HOSMER SSS-555, 2 bands, steel cabled
5. HOSMER SSS-555, 3 bands, steel cabled
6. HOSMER 10P, 1 band, steel cabled
7. HOSMER 10P, 2 bands, steel cabled
8. HOSMER 10P, 3 bands, steel cabled
9. HOSMER 10X, 1 band, steel cabled
10. HOSMER 10X, 2 bands, steel cabled
11. HOSMER 10X, 3 bands, steel cabled

12. HOSMER 12P, 1 band, steel cabled
13. HOSMER 12P, 2 bands, steel cabled
14. HOSMER 88X, 1 band, steel cabled
15. HOSMER 88X, 2 bands, steel cabled
16. HOSMER 88X, 3 bands, steel cabled
17. HOSMER 99X, 1 band, steel cabled
18. HOSMER 99X, 2 bands, steel cabled
19. HOSMER 99X, 3 bands, steel cabled
20. U.N.B. STEEPER, 2.0″ w/glove, nylon pull
21. U.N.B. STEEPER, 2.25″ w/glove, tension #1 (softest), nylon pull
22. U.N.B. STEEPER, 2.25″ w/glove, tension #2, nylon pull
23. U.N.B. STEEPER, 2.25″ w/glove, tension #3, nylon pull
24. U.N.B. STEEPER, 2.50″ w/glove, steel cabled
25. U.N.B. STEEPER, 2.75″ w/glove, steel cabled
26. HOSMER SIERRA, gloved, steel cabled
27. HOSMER ROBINS-AIDS, soft-mechanical, gloved, steel cabled
28. HOSMER BECKER-IMPERIAL, gloved, steel cabled
29. HOSMER, #201 gloved, steel cabled
30. HOSMER, #301 gloved, steel cabled
31. HOSMER, #401 gloved, steel cabled
32. OTTO-BOCK, 6.75″, gloved, steel cabled
33. OTTO-BOCK, 7.75″ gloved, steel cabled

Device Number	12	13	14	15	16	17	18	19	20	21	22
A. Pre-load Excursion (in)	0.06	0.06	0.12	0.12	0.12	0.06	0.12	0.12	0.05	0.25	0.25
B. Full Opening Excursion (in)	1.31	1.31	1.75	1.75	1.75	1.87	1.87	1.87	0.87	0.87	0.87
C. Pre-loading Force (lbs)	1.20	2.80	3.10	6.20	10.10	3.50	7.70	12.00	3.00	4.00	4.50
D. Force Constant In Loading (lbs/in)	2.70	4.50	0.88	1.20	1.33	0.59	0.57	0.37	10.30	8.00	8.64
E. Total Excursion Force Needed to Open Terminal Device (lbs)	4.57	8.42	4.53	8.15	12.27	4.56	8.70	12.65	11.40	8.96	9.86
F. Full Opening Grip width (in)	1.50	1.50	3.37	3.37	3.37	3.00	3.00	3.00	1.75	2.00	2.00
G. Initial Prehension Grip Force (lbs)	0.96	1.79	0.95	2.15	3.38	1.20	2.48	4.33	0.00	0.00	2.00
H. Prehension Grip Force Constant (lbs/in)	1.20	1.80	0.31	0.60	0.75	0.54	0.84	1.06	0.98	0.65	0.00
I. Maximum Prehension Grip Force (lbs)	2.76	4.49	2.00	4.17	5.91	2.82	5.00	7.51	1.70	1.30	2.00
J. Number of Hands Tested	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00
K. Efficiency: Ratio of Maximum Prehension Grip Force to Excursion Force	0.60	0.53	0.44	0.51	0.48	0.62	0.57	0.59	0.15	0.14	0.20
L. Excursion Work (lb-in)	3.64	7.10	6.40	12.07	18.84	7.40	14.81	22.29	5.98	4.52	5.01

Table I (continued).

Device Number	23	24	25	26	27	28	29	30	31	32	33
A. Pre-load Excursion (in)	0.10	0.42	0.42	0.44	0.12	0.44	0.06	0.06	0.69	0.09	0.06
B. Full Opening Excursion (in)	0.87	1.35	1.50	1.44	1.31	2.06	1.37	1.31	1.62	1.75	2.75
C. Pre-loading Force (lbs)	7.50	4.20	5.50	7.50	8.50	13.25	2.75	2.50	15.25	3.75	3.75
D. Force Constant In Loading (lbs/in)	10.00	12.70	11.43	11.50	6.60	1.80	5.50	4.50	18.60	7.40	3.80
E. Total Excursion Force Needed to Open Terminal Device (lbs)	15.20	16.00	17.84	19.00	16.35	16.17	9.95	8.12	32.55	16.03	13.97
F. Full Opening Grip width (in)	2.00	2.25	2.50	1.50	2.00	3.25	2.50	2.50	2.50	1.87	2.50
G. Initial Prehension Grip Force (lbs)	1.10	1.47	2.65	0.64	0.30	1.44	2.85	1.20	6.75	1.83	3.24
H. Prehension Grip Force Constant (lbs/in)	1.20	0.10	0.10	2.70	1.70	1.10	0.30	0.00	0.00	1.20	0.60
I. Maximum Prehension Grip Force (lbs)	3.50	1.70	2.90	4.95	3.70	5.02	3.60	1.20	6.75	4.07	4.74
J. Number of Hands Tested	1.00	2.00	1.00	1.00	1.00	1.00	3.00	1.00	1.00	3.00	3.00
K. Efficiency: Ratio of Maximum Prehension Grip Force to Excursion Force	0.23	0.11	0.16	0.39	0.22	0.31	0.36	0.15	0.21	0.25	0.34
L. Excursion Work (lb-in)	9.11	10.28	13.76	14.90	15.30	26.75	8.40	6.71	27.49	16.59	23.95

Table I (continued).

of a particular device and is independent of the spring or rubber band tension. The measured results show this to be the case, in that parameter "K" did not significantly vary when spring tensions or the number of rubber bands were changed. Measured efficiencies for the functional hands were, in general, less than hook terminal devices. This consistent discrepancy is due largely to friction in the mechanics of the internal hinges within the hands in addition to glove attachments.

The final parameter "L" which is the total amount of work required to operate the terminal device is also of extreme importance. Hands compare more favorably to hooks because on a general basis hands require less excursion than hooks for full opening. This is an important factor for children as well as higher levels of amputation, because of less available excursion.

Plotting maximum prehension grip force against total excursion force, the relative performance between hooks and hands can be compared (Figure 7). For clarity, the hand device numbers were plotted with a preceding dash. For any particular excursion force, it can be easily seen that grip force is greater for the hook devices. The devices 7, 8, 10, 11, and 19, were particularly good performers, which required excursion forces less than 15 pounds, and created prehension grip forces greater than seven pounds. In light of this comparison, it

should be challenging for terminal device designers to come up with functional hand devices that approach the efficiencies of hooks.

Conclusions

This comparison of terminal devices is only preliminary in that many more terminal devices have yet to be analyzed. Furthermore, the number of devices tested was very small. In spite of these limitations, the best protocol allowing comparisons between the different terminal devices was felt to be objective and reflect the relative performance of different devices.

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The University College London's Plastic Below-the-Knee Socket and Shank System

by Virgil Faulkner, C.P.O.
Norman G. Gall, M.D.

The use of thermoplastic materials in the fabrication of prosthetic sockets has been a goal of the prosthetic profession for many years. In the 1960s, the Veterans Administration Prosthetic Research Laboratory developed a procedure using a thermoplastic material called "polysar" that allows the prosthetist to mold the plastic socket directly onto the residual limb.

In 1975, Tucker and Sullivan[7] used polysar in the forming of prosthetic sockets. In 1978, Compton and Edelstein[1] developed a new thermoplastic material which, reportedly, could be molded directly to the amputee's residual limb.

In 1981, Lawrence and Davies,[6] used polypropylene to form a lightweight prosthetic socket over a modified model. They developed a system of preformed modules which are heated in an oven. A programmed computer assures that the preforms are uniformly heated and are not subject to high stress during the fabrication procedure. This results in a socket capable of withstanding high sheer and extreme rotational forces created when the amputee puts full weight on the prosthesis.

Polypropylene, when combined with other polymers, makes an ideal material for use in prosthetic fabrication. The resulting prosthesis is inexpensive, lightweight, and very durable (Figure 1).

Davies, et al.[4] have developed a Rapidform process for automated manufacture of prosthetic shanks and sockets. This group has conducted an in-depth study of fatigue strength-to-weight ratio of metals, composites, thermoplastic, and thermoset materials. Their study demonstrates that a copolymer of polypropylene and nylon is an excellent material in socket manufacture. Because polypropylene is a semi-crystalline material, some shrinkage does occur during heating and cooling processes. During their investigation, Davies, et al. developed a system for minimizing this shrinkage and have labeled it a "Technique of Double Deformation." The polypropylene is first injected molded into a bell shaped preform (Figure 2). The preform is then heated and vacuum-formed over a positive model of the residual limb.

This group has also developed a computer controlled carving machine designed for making positive residual limb models. This project did not use the carving machine, instead the positive model was designed and modified

Figure 1. Polypropylene:

Density (lb/in)	**0.033**
Tensile Strength Density (in × 10^5)	**1.55**
Tensile Modulus Density (in × 10^8)	**0.15**
Tensile Strength (lb/in)	**5.1**
Comp. Yield Strength (lb/in)	**5.0**
Tensile Modulus (lb/in 2 × 10^3)	**0.16**

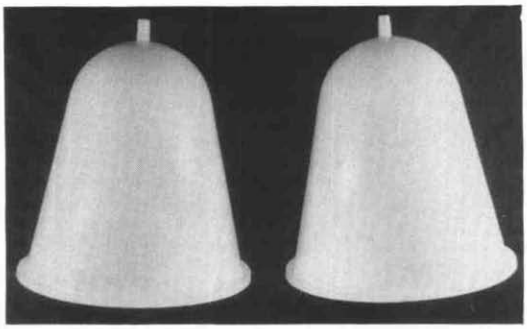

Figure 2. The polypropylene is first injected molded into a bell-shaped preform.

by the REL, then shipped as a negative to University College London for socket fabrication.

The Rapidform, a vacuum forming prosthetic socket manufacturing machine (Figure 3) consists of three sections: a loading bay, an oven with bottom access, and a driving section containing the vacuum system and associated power drives. The procedure consists of the preform being placed in the oven along with the positive model. When heat conditions, which are controlled by a microprocessor, are correct, the positive model is envaginated into the softened preform. Vacuum is applied, forming the plastic around the model, followed by an anneling process. After the process is completed, the model and socket are removed. The rapidform socket machine is almost totally automatic; it requires only that the operator load and unload the preform and positive model.

As part of the system, Coombs, et al. used a rotational molding machine (Figure 4) to make hollow tapered columns, rotational molded, from nylon that can be used for prosthetic shanks (Figure 5).

Shanks produced by rotational molding are inexpensive, lightweight, and very strong. Rotational molding is routinely used by the plastic industry, but this is the first instance of its use in the prosthetic field.

Rotationally molded shank sections are custom made for each prosthesis. Each shank is assembled from two pieces; Metallic inserts are molded in at both ends of the shank for attachment of the foot and alignment unit, and the socket.

Coombs, et al.[3] have also developed the

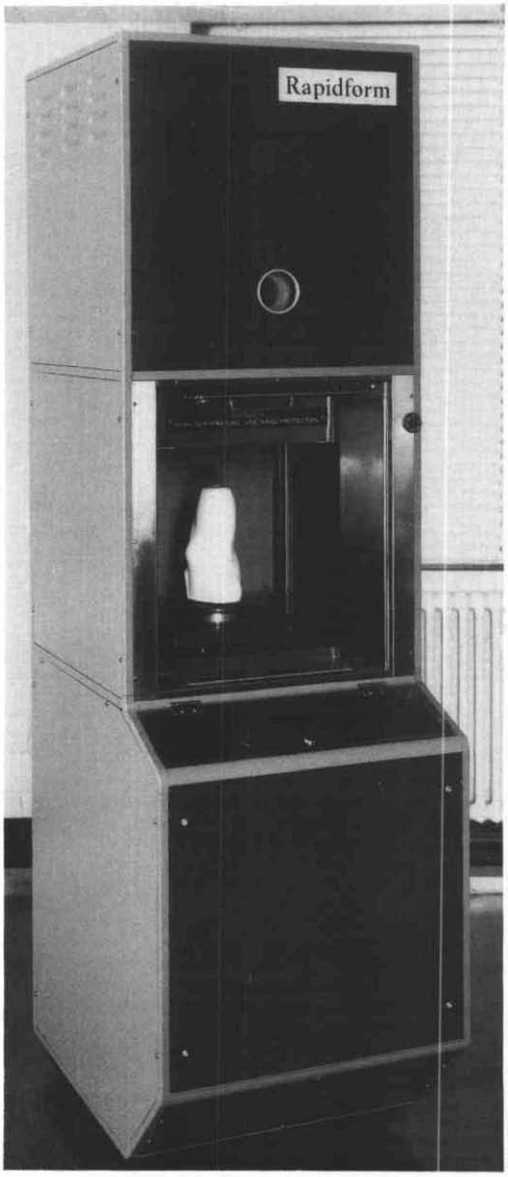

Figure 3. The Rapidform prosthetic socket manufacturing machine.

"jacked-alignment device" (Figure 6) as a companion prosthetic component to the rapidform socket and the rotational molded shank.

The jacked-alignment device is designed primarily to be used with the rotational molded

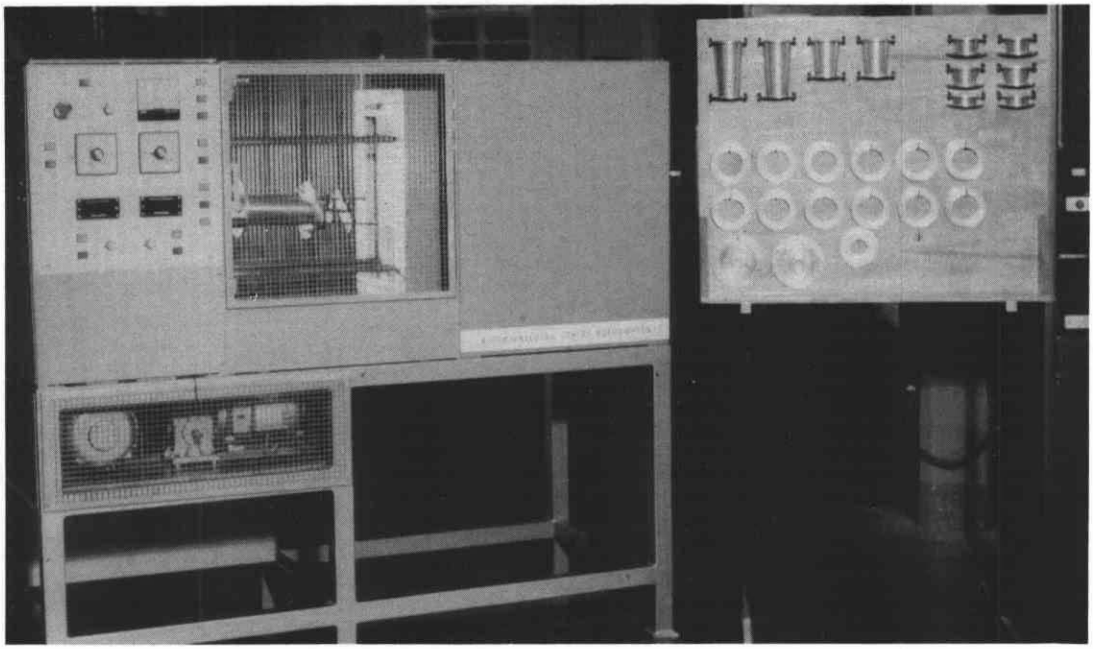

Figure 4. The Rotational Molding Machine.

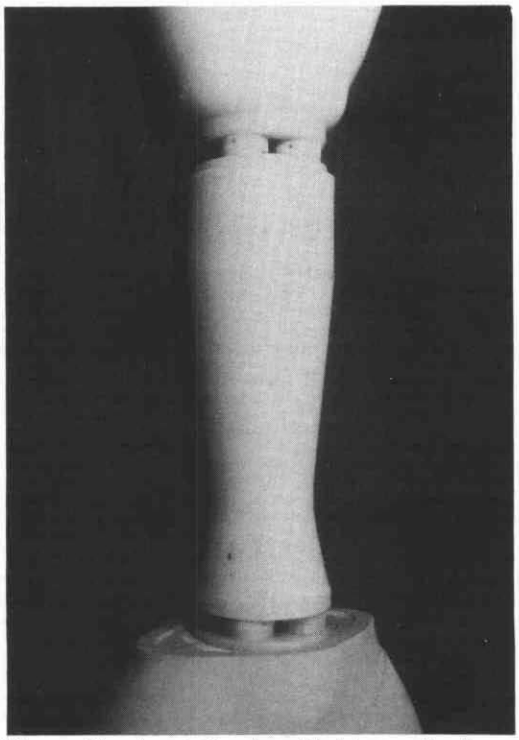

Figure 5A. A rotational molded tapered column made from nylon.

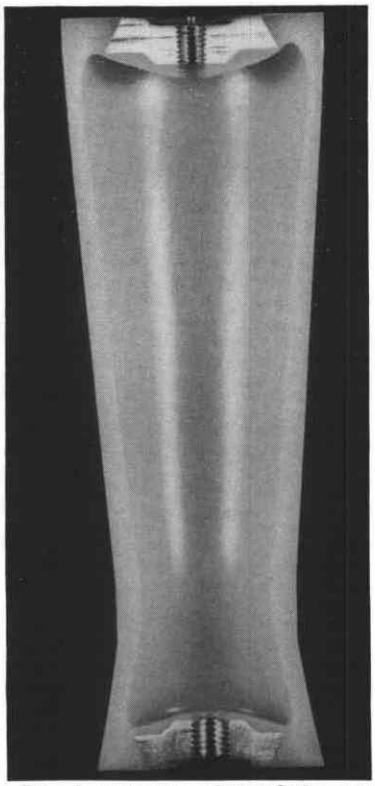

Figure 5B. A cutaway view of the rotational molded tapered column.

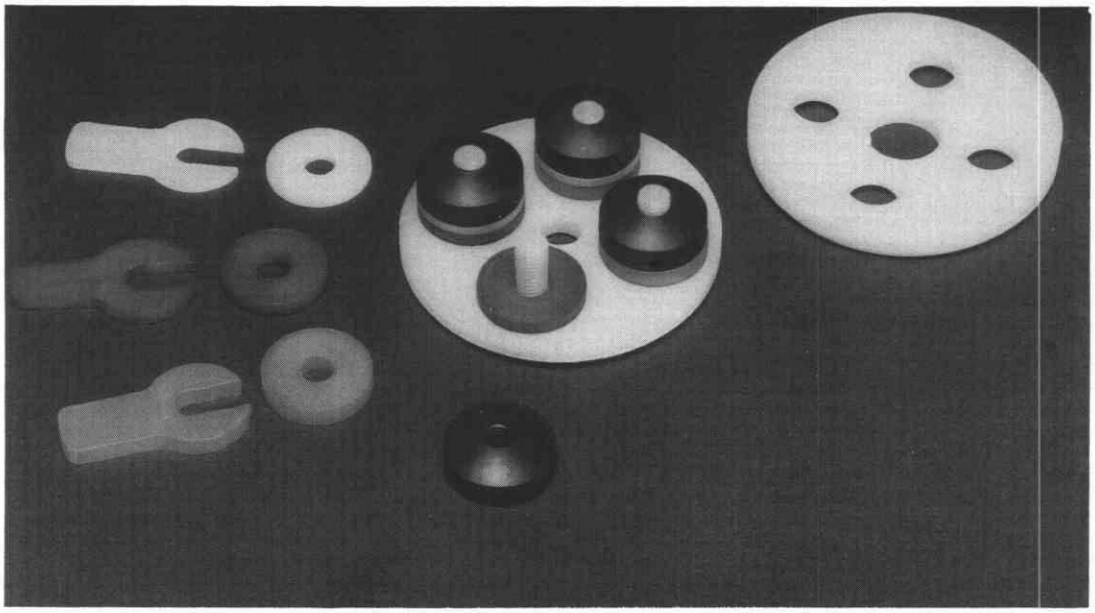

Figure 6A. The UCL's jacked alignment device.

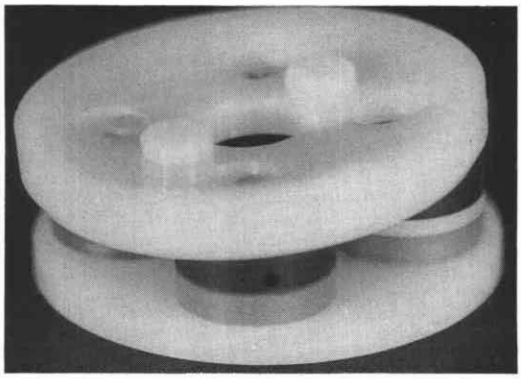

Figure 6B. The UCL's jacked alignment device.

shank, but may be used with other shank systems when appropriately designed. The device allows rotation of both the foot and the socket and allows tilting action in the anterior-posterior and the medial lateral planes. Tilting is accomplished by a series of four jacked nuts spaced 90° apart. The tilting action is accomplished using the same method as in the "Staros Gardner Alignment Coupling."[8]

The jacked-alignment device is made from thermoplastic material and weighs approximately 50 grams.

The Rehabilitation Engineering Laboratory (REL) at the University of Texas Health Science Center San Antonio and The Bioengineering Center at University College London (UCL) designed a cooperative research project to answer the following questions.

1. Can an amputee, cast and measured in the United States, be successfuly fitted with a prosthesis made in the United Kingdom?
2. What fabrication techniques are necessary to design and fabricate the prosthesis?
3. Will the rapidform socket and rotational molded shank with the jacked-alignment device be suitable as components for below-the-knee protheses for veteran amputees?

The REL selected five below-knee veteran amputees that were users of a patellar tendon bearing (PTB) prosthesis and had worn the prosthesis for at least six months prior to being selected for fitting with the new light-weight prosthesis.

Each amputee was cast in the usual manner for producing a negative mold of the residual limb. Each negative mold was used to produce a positive of the residual limb. The positive residual limb model was modified using normal biomechanical considerations for prosthetic socket manufacture. The modified positive model was sent to UCL where a below-the-knee prosthetic socket was made by the Rapidform machine, using a copolymer polypro-

pylene. Each socket produced had a soft thermoplastic liner.

According to preset measurements, a rotationally molded shank was made and attached to the socket with the jacked-alignment unit by UCL. The socket and shank were returned to REL where a Solid Ankle Cushion Heel (SACH) foot was attached to the prosthesis. Each prosthesis was dynamically aligned and properly adjusted for the individual amputee. The aligned prosthesis was secured by placing one roll of fiberglass casting tape around the distal one-fourth of the socket, around the alignment device, down the shank, and around the distal alignment device and the proximal portion of the SACH foot (Figure 7).

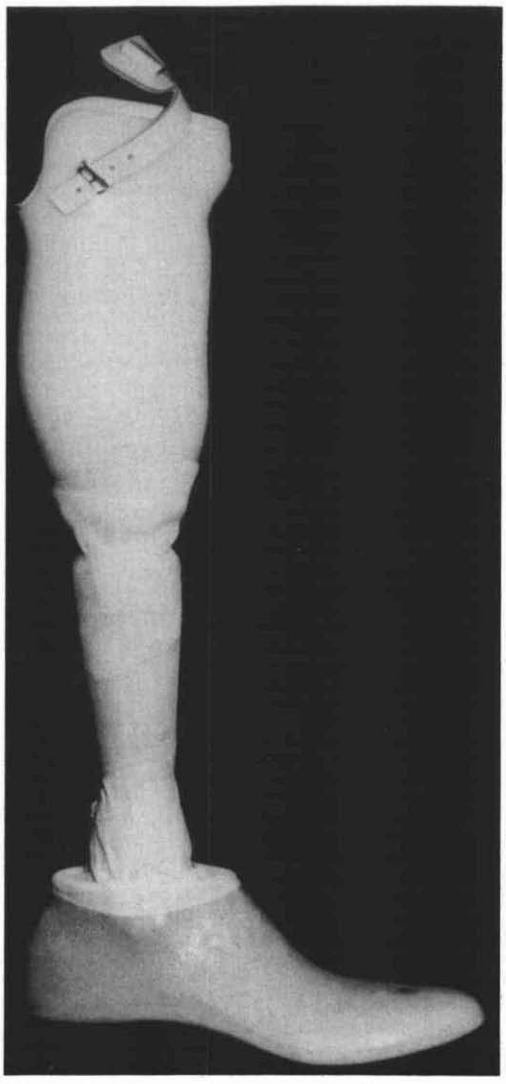

Figure 7. The completed prosthesis.

The prosthesis was delivered to the amputee to be worn for a period of six months. Each amputee wore the lightweight prosthesis for six months. During this time, they returned to the prosthetic lab once each month for visual observation of the prosthesis and their gait while ambulating.

Each amputee wore the lightweight prosthesis for the full term required with no failures of the components.

Four amputees continue to use the new prosthesis. One amputee (a bilateral) discontinued use of the prosthesis, because the research team required him to ambulate with the experimental prosthesis only while using crutches. One amputee experienced fitting difficulties around the fibula head, which was heavily scarred. He has required several adjustments to his socket; however, he prefers the experimental over his regular prosthesis and continues to use it full-time.

This project has proven the feasibility of using a central fabrication facility and the desirability of producing prosthetic sockets by a controlled procedure. The rotational molded prosthetic shanks have proven to be reliable components in this project. The jacked-alignment device does not seem to be strong enough, therefore, it should be reinforced with some material, such as fiberglass casting tape.

It is recommended that the Rapidform process for automated manufacture of prostheses, discribed by Davies, et al., be given a clinical trial over a three year period in the United States. This would require purchase or lease of the entire system as described by Klasson.[5]

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Clinical Prosthetics and Orthotics, Vol. 11, No. 4, pp. 251–253

An Above-Elbow Electrically Controlled Prosthesis Complicated by the Presence of a Cardiac Pacemaker

by Gustav Rubin, M.D., FACS
Fred Harris, B.E., C.O.

It is the purpose of this paper to present problems attendant upon the selection of an appropriate upper extremity prosthesis for the amputee who has an implanted cardiac pacemaker. In view of the increasing use of pacemakers, the case to be reported may not be an isolated instance. The solution and the reasons for deciding on the prosthesis described will be outlined.

M.C. was initially referred to this center's Clinic Team on November 2, 1978, at which time he was 36 years of age. The patient sustained multiple shell fragment wounds in 1967, as a result of which he was amputated above the elbow on the left. He had wounds of the right elbow as well, with resulting limitation of motion on that side.

On examination, there was a 10-″ left above-elbow residual limb in good condition, except for a distal, tender bone prominence. The residual limb was powerful with a good range of shoulder motion. On the right side, the elbow was thickened; there was crepitus on motion and motion was limited to a range of 45° to 100° when full extension is considered to be 0°. Elbow motion produced discomfort, but the patient was able to reach his mouth with his right hand.

He reported that he had been able to use a conventional body-powered prosthesis until he developed a cardiac problem, which required the implantation of a pacemaker in the right pectoral area eight months before evaluation at our center (i.e., in early 1978). The distal tender bone prominence had not been a problem when fitted without pressure on that area. Since that time, he has been unable to wear a prosthesis. He works in a supervisory capacity and indicated a preference for a hand rather than a hook. He was informed elsewhere that he could not wear a prosthesis because of the pacemaker.

There were two basic considerations that required resolution in the opinion of the Clinic Team.

1. Excessive body movements for the control of the prosthesis should be avoided to prevent breakage of the fine cardiac wire components of the pacemaker. Such body movements would be required by conventional figure-of-eight body powered harnessing.
2. A harness must be fabricated to avoid pressure on the pacemaker.

To avoid excessive body movements, the clinic team decided to provide the patient with a switch controlled, electrically operated prosthesis which would require ⅛″ excursion of the switch components. This could be accomplished with such limited motion as to preclude the likelihood of breaking the cardiac wire.

Having made this proposal, the Clinic Team had to determine the compatibility of the pace-

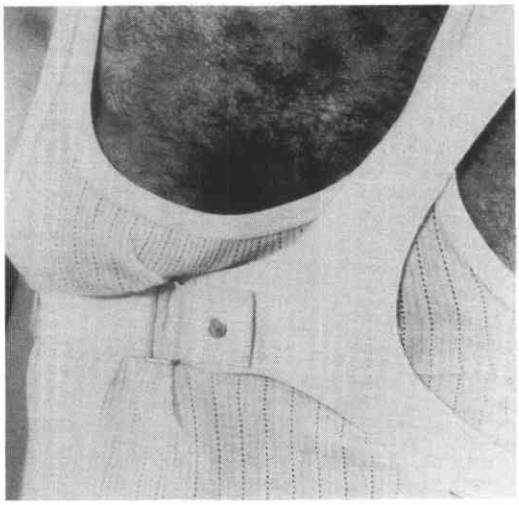


Figure 1. Note that the frame harness frees the right pectoral area with its underlying implanted pacemaker.

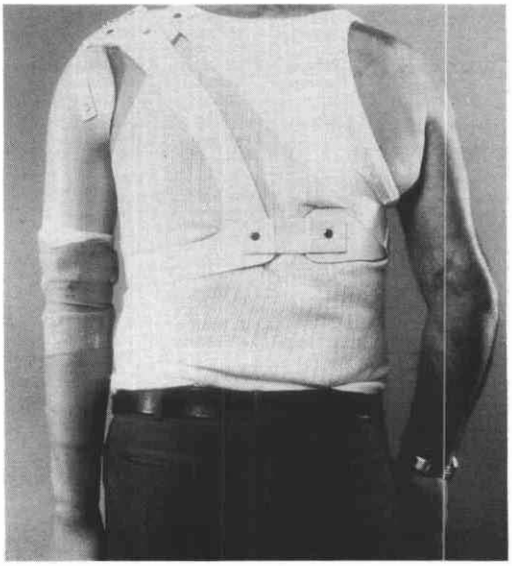


Figure 2. Posterior view of frame harness.

maker with the switch controlled electrical prosthesis. Carl Mason, Chief Engineer at the Center and the Electrical Engineer in charge of upper extremity unit development, was asked to join the Clinic Team. A chest x-ray was taken to view the pacemaker. Mason's opinion was that the pacemaker was a lithium powered unit recently developed and was properly shielded, and that it would not interfere with the prosthesis. He confirmed this by telephone communication with the hospital at which the pacemaker was implanted.

The Clinic Team decided to fabricate a harness frame of thermoplastic material which would be windowed over the pacemaker and would not shift significantly with body movements (Figures 1 and 2).

When this proposal was outlined to the patient, he indicated that he would prefer an electrically operated hand as well as an electric elbow. The final decision was to fit the patient with a VAPC switch controlled elbow and an Otto Bock myoelectric hand, employing biceps and triceps control. The prosthesis was delivered in 1979 (Figure 3). The amputee learned to use this prosthesis well and required replacement in July, 1981. In the interim, he had surgical intervention to correct the limitation of right elbow motion and, as a result, that situation was greatly improved.

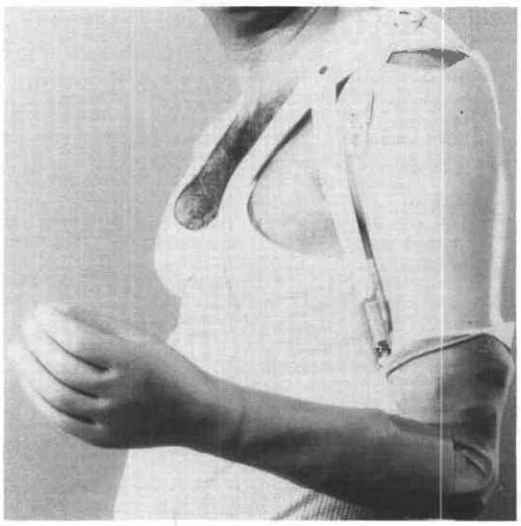


Figure 3. Note switch control element for elbow. The Bock myoelectric components have been utilized for the hand.

In 1984, because of the unavailability of VAPC elbow components, the elbow components were changed to the Boston elbow unit. The Otto Bock hand system was continued. Carl Mason had indicated that there would be no electrical incompatibility problems with the Boston elbow, and there were none.

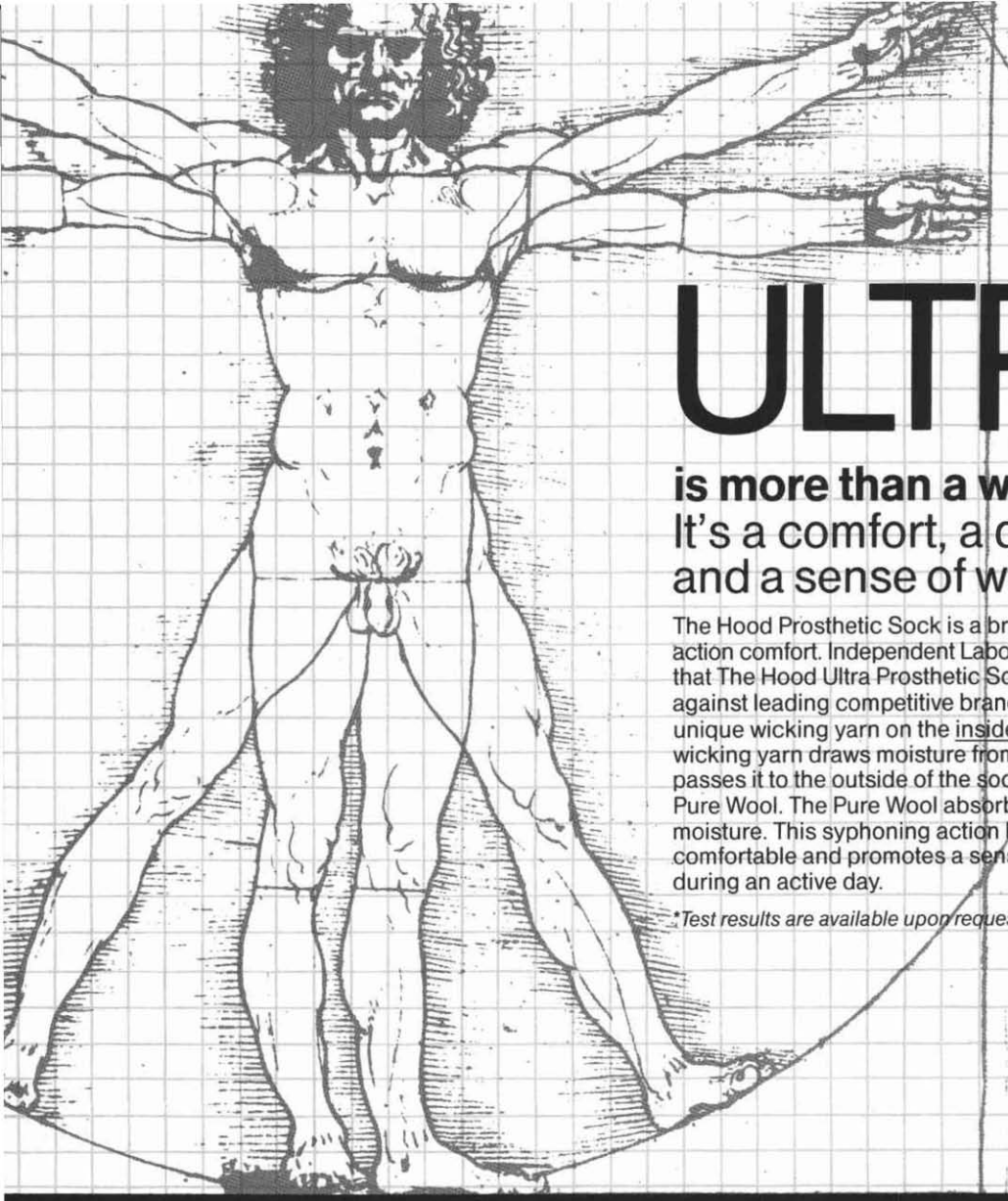
Summary

A switch controlled electric elbow and a myoelectric hand were provided for an above-elbow upper extremity amputee after these components were found to be compatible with the electrical system of an implanted cardiac pacemaker. Over a five year period of use, there have been no problems. The amputee had been denied a body powered prosthesis elsewhere because of the possibility that cardiac wire breakage might be caused by the more extensive body movements required to control the elbow and terminal device of a conventional artificial limb.

Authors

Gustav Rubin, M.D., FACS, is Director of STAMP (Special Team for Amputations, Mobility, Prosthetics/Orthotics), at the Veterans Administration Medical Center, 1st Avenue and 24th Street, New York, New York 10010.

Fred Harris, B.E., C.O., is also with STAMP.



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Calendar

1987

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 13, "Current Concepts in Seating," course sponsored by Pin Dot Products, Hotel Sofitel, Chicago, Illinois. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

October 15, "Current Concepts in Seating," course sponsored by Pin Dot Products, Hyatt Regency, Detroit, Michigan. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

October 16, "Current Concepts in Seating," course sponsored by Pin Dot Products, Radisson South, Minneapolis, Minnesota. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

October 17, Academy Continuing Education Seminar, MD, DC, and VA Chapter. Contact: Douglas Bourgoyne, P.O. Box 1857, Waldorf, Maryland 20601; tel (301) 645-6518 or 843-0783.

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.

November 10, "Current Concepts in Seating," course sponsored by Pin Dot Products, Marriott LaGuardia, New York, New York. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

November 11, "Current Concepts in Seating," course sponsored by Pin Dot Products, Holiday Inn—City Line, Philadelphia, Pennsylvania. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

November 11–13, 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.

November 13–14, Academy Northwest Chapter Seminar, Hilton, Seattle-Tacoma Airport.

November 14, Academy Midwest Chapter Fall Scientific Seminar, RIC, 17th Floor, 345 East Superior Street, Chicago, Illinois 60611. Contact: Mark Edwards, CP, (312) 908-8006.

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 18, "Current Concepts in Seating," course sponsored by Pin Dot Products, Hyatt Regency Peachtree Center, Atlanta, Georgia. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

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.

December 10, "Current Concepts in Seating," course sponsored by Pin Dot Products, Sheraton Park Central, Dallas, Texas. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

December 11, "Current Concepts in Seating," course sponsored by Pin Dot Products, Sheraton Tech Center, Denver, Colorado. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

1988

January 25, "Current Concepts in Seating," course sponsored by Pin Dot Products, Holiday Inn—Crowne Plaza, San Francisco, California. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

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.

January 26, "Current Concepts in Seating," course sponsored by Pin Dot Products, Hyatt Anaheim, Orange County, California. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

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

February 9–10, "Application of the Rochester Parapodium and the LSU-RGO in Pediatric Paraplegia," course sponsored by the American Physical Therapy Association at University Hospital School, the University of Iowa, Iowa City, Iowa. Contact: Loretta K. Lough, L.P.T., M.A., Room 212, University Hospital School, The University of Iowa, Iowa City, Iowa 52242.

February 16, "Current Concepts in Seating," course sponsored by Pin Dot Products, Hyatt Regency, Washington, DC. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

February 17, "Current Concepts in Seating," course sponsored by Pin Dot Products, Lafayette Hotel, Boston, Massachussetts. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

March 5, Academy Midwest Chapter Spring Scientific Seminar/Social Event. Contact: Mark Edwards, CP, (312) 908-8006.

March 10, "Current Concepts in Seating," course sponsored by Pin Dot Products, Hotel Sofitel, Miami, Florida. Contact: Pin Dot Products, 2215 West Belmont, Chicago, Illinois 60618; 800-451-3553.

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

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April 11–15, 10th Congress of the International Federation of Physical Medicine and Rehabilitation, Sheraton Hotel, Toronto, Ontario. Contact: Secretary, 545 Jarvis Street, Toronto, Ontario M4Y 2H8, Canada.

May 13–15, AOPA Region IX, COPA, and the California Chapters of the Academy Combined Annual Meeting.

July 16–18, AFI-ENDOLITE Prosthetic Certificate Course, "Endolite High Technology Prosthesis," Miami Lakes Inn & Country Club, Miami, Florida. Contact: Karen Hewitts, Registrar, AFI-ENDOLITE, 2400 West 82 Street, Hialeah, Florida 33016; (305) 823-8300.

August 13–15, AFI-ENDOLITE Prosthetic Certificate Course, "Endolite High Technology Prosthesis," Miami Lakes Inn & Country Club, Miami, Florida. Contact: Karen Hewitts, Registrar, AFI-ENDOLITE, 2400 West 82 Street, Hialeah, Florida 33016; (305) 823-8300.

September 3–5, AFI-ENDOLITE Prosthetic Certificate Course, "Endolite High Technology Prosthesis," Miami Lakes Inn & Country Club, Miami, Florida. Contact: Karen Hewitts, Registrar, AFI-ENDOLITE, 2400 West 82 Street, Hialeah, Florida 33016; (305) 823-8300.

September 24, Academy Northern California Chapter Seminar, San Francisco, California. Contact: Robert A. Bangham, CO, % Hittenbergers, 1117 Market Street, San Francisco, California 94103.

October 15–17, AFI-ENDOLITE Prosthetic Certificate Course, "Endolite High Technology Prosthesis," Miami Lakes Inn & Country Club, Miami, Florida. Contact: Karen Hewitts, Registrar, AFI-ENDOLITE, 2400 West 82 Street, Hialeah, Florida 33016; (305) 823-8300.

October 25–30, AOPA Annual National Assembly, Sheraton Washington Hotel, Washington, D.C. Contact: AOPA National Headquarters, (703) 836-7116.

November 12–14, AFI-ENDOLITE Prosthetic Certificate Course, "Endolite High Technology Prosthesis," Miami Lakes Inn & Country Club, Miami, Florida. Contact: Karen Hewitts, Registrar, AFI-ENDOLITE, 2400 West 82 Street, Hialeah, Florida 33016; (305) 823-8300.

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

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

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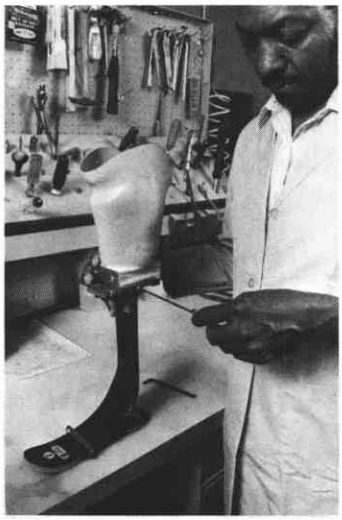

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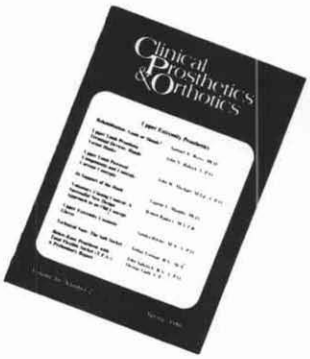

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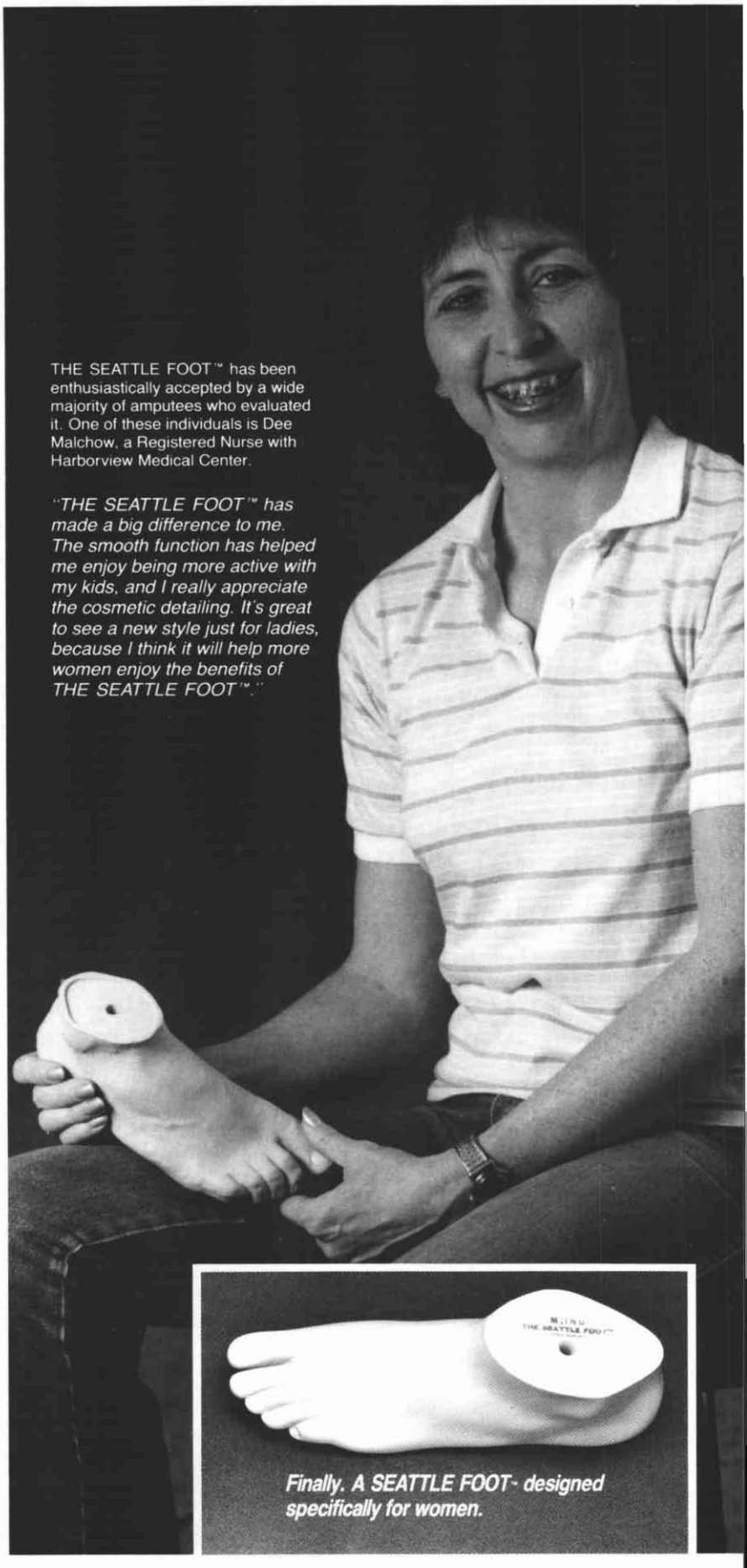

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ACADEMY CALLS ON ALL MEMBERS TO RENEW MEMBERSHIP FOR 1988

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It is important for you to recognize why renewal of your Academy membership is so vital.

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You'll remember, of course, that two years ago ABC was involved in litigation which was entered into in an effort to preserve the credentials of all ABC certified orthotists and prosthetists. As a demonstration of support of ABC's action, your Academy contributed $50,000 for use in paying some of the many legal fees. These were funds that otherwise could have provided a significant source of reserve for the Academy.

Last year there was a complete restructuring of the Orthotic and Prosthetic National Office. This office has been incorporated and is now a separate entity governed and managed by a Board of Directors composed of five representatives from each of the three associations. The Academy now shares equally the costs of salaries for the Executive Director, Director of Public Relations, and has appropriated a significant amount to fund a Government Relations Program.

The Government Relations Program, which now enters it second year for the Academy, acts in two areas which are very important to every practitioner. First, certification is the theme of every contact made with government or third party groups. Recognition of certification is one, if not the main, thrust of this program. The second area is education and the pursuit of monies to allow the schools to produce qualified professional practitioners.

A Public Relations Program, national in scope, is presently in operation. This program will achieve national recognition for the practitioner. The certified practitioner will become a recognized member of the rehabilitation team. This will take time—but we have started.

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We hope the above information will help you appreciate and understand the necessity for the modest increase in dues. All of these programs which seek to promote your credibility as a practitioner in the field of orthotics and prosthetics require your financial support. The need for your continued support is more important now than ever before.

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