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THE JOURNAL OF THE
ORTHOTIC AND PROSTHETIC PROFESSION

VOLUME 24
NUMBER 2
JUNE 1970

Contents

Editor
Audrey J. Calomino

Orthotics and Prosthetics: The Orthopedic and Prosthetic Appliance Journal is issued in March, June, September and December. Subscription price, payable in advance, is $6.50 a year in the Western Hemisphere rate elsewhere is $7.50 a year. Publication does not constitute official endorsement of opinions presented in articles. The Journal is the official organ of its publisher, The American Orthotic and Prosthetic Association. All correspondence should be addressed to: Editor: **Orthotics and Prosthetics,** 1440 N St., N.W., Washington, D.C. 20005. Telephone, Area Code 202, 234-8400.

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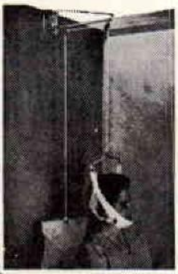

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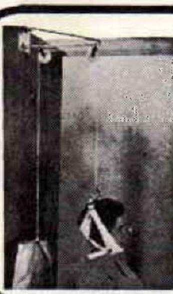

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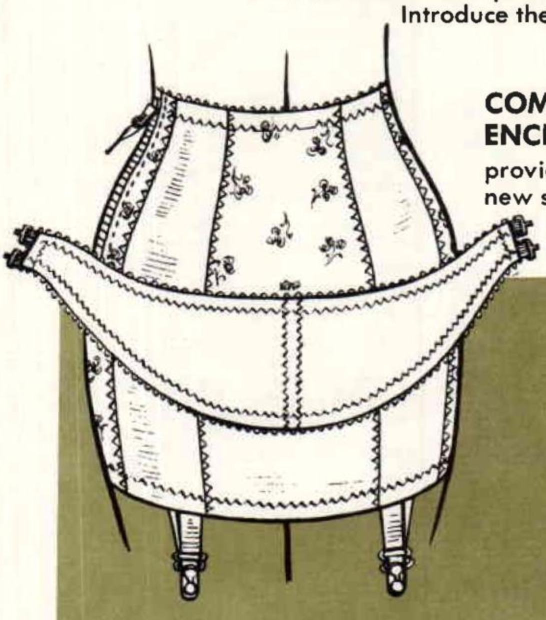

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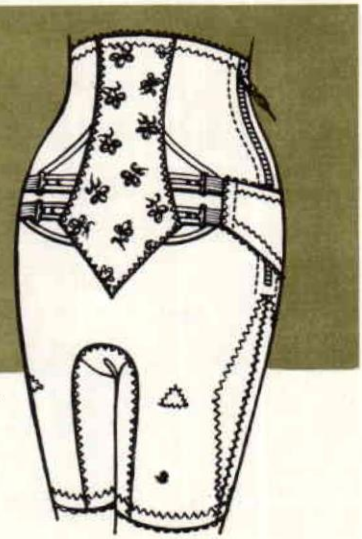

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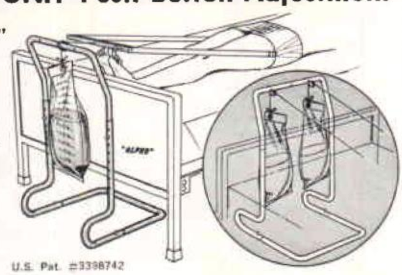

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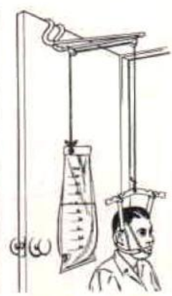

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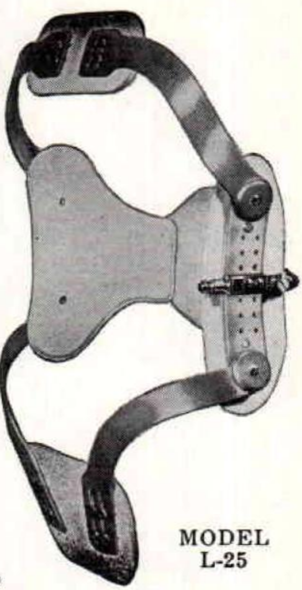

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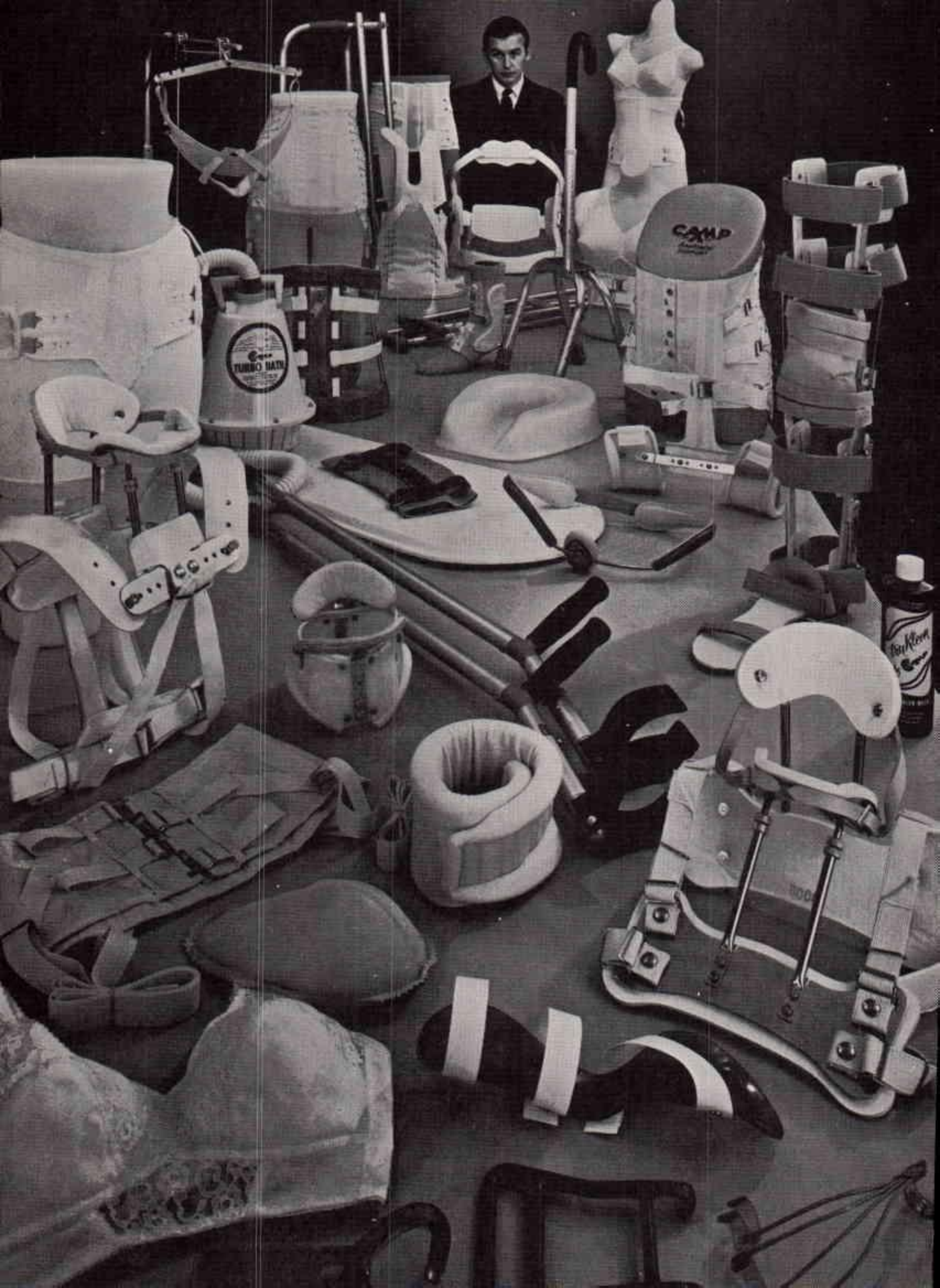
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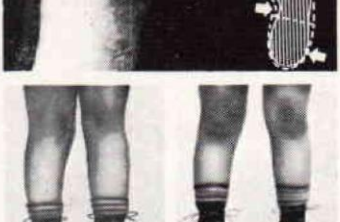

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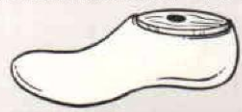

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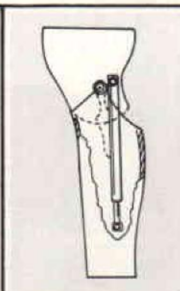

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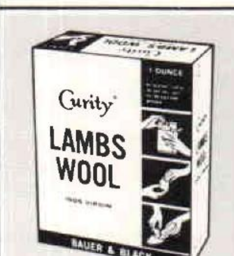

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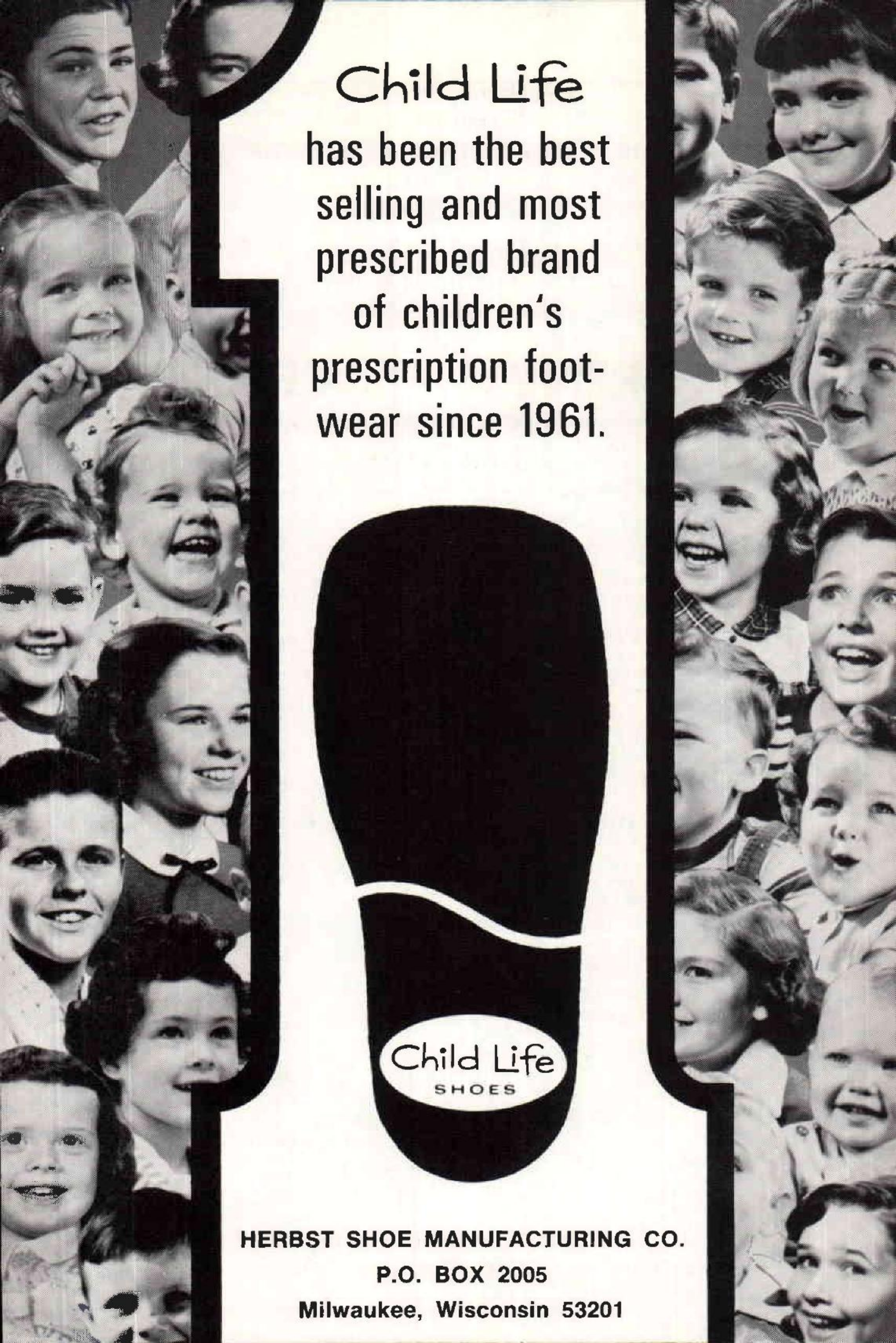
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Development of Upper Extremity Orthotics

by Thorkild J. Engen, C.O.*

PART II

PATIENT APPLICATIONS AND FUNCTIONAL GAINS

Note: Both Part I and Part II of this paper are based on excerpts from the Final Report of Social Rehabilitation Service Project RD-1564 by T. Engen, C.O., and W. A. Spencer, M.D. On behalf of the many patients who have benefited from the findings of this research project, the author wishes to express appreciation to S.R.S. for its sponsorship.

In Part I of this report which appeared in the March, 1970 issue, a description of the research and development at Texas Institute for Rehabilitation and Research of three distinct but inter-related upper extremity orthotic systems was given—the reciprocal wrist extension finger flexion orthosis, the externally powered finger prehension orthosis, and the externally powered arm orthosis.

The primary objective in any development of externally powered upper extremity orthotic systems is to restore, to a maximum degree, functions lost or reduced through disease or injury. The overall purpose of this research project has been to develop and clinically evaluate orthotic devices designed to supplement the patient's function and utilize his residuals as much as possible. Normal function has been the guide in these developments, with emphasis on the individual patient's maximum acceptance of the equipment as an integral part of himself.

Any orthotic adaptation that makes the patient feel he has become a "mechanical man," that the equipment is controlling him rather than being controlled by him, can lead to psychological distress and eradicate his motivation.

*Assistant Professor, Department of Rehabilitation, Baylor College of Medicine, Houston, Texas, and Director, Department of Orthotics, Texas Institute for Rehabilitation and Research, Houston, Texas.

The patients' primary needs in upper extremity orthotics had been identified during an earlier research project, and had resulted in the first phase of developments of the chain of components comprising an externally powered finger prehension orthosis and an arm orthosis. The project herein described has been directed toward modifications of the powered system, implementation of recent developments, additional patient applications, and clinical evaluations of the system's

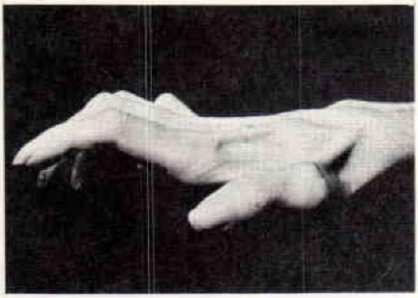

Fig. 1—Illustration of hand with severe muscle imbalance.

functional efficiency and reliability.

Since the purpose of these developments was to enable severely impaired patients to regain as great a degree of useful function as possible, it is appropriate to now discuss a number of patient applications.

Plastic Hand Orthosis

The plastic hand orthosis, which is the basic and central unit of the three aforementioned orthotic systems, is in simpler cases a practical way of meeting a patient's needs with a minimum of equipment. It can be adapted for the prevention or correction of deformities, as well as incorporated into the more complex systems.

Since muscle imbalance due to

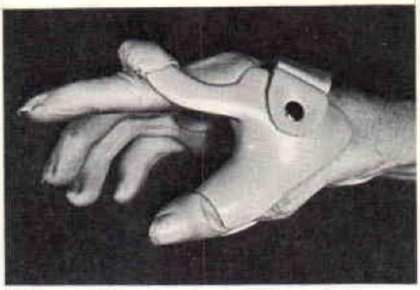

Fig. 2—A short opponens orthosis supports the metacarpal arch, the lumbrical muscles, and the opponens muscle group.

neuromuscular disorders can result in malpositioning of the thumb and hyperextension of the metacarpophalangeal joints, orthotic assistance may be required for correction. Patient R.S., for example, had a severe muscle imbalance due to Charcot-Marie-Tooth disease (Fig. 1). The plastic hand orthosis was made into a short opponens with metacarpal support to passively realign the metacarpal arch and thumb opposition, and a lumbrical support was added to prevent hyperextension of the MP joints (Fig. 2).

Another adaptation of the basic hand orthosis was to add a passive volar and dorsal phalangeal support to correct and prevent further ulnar drift of the digits for a patient with progressive rheuma-

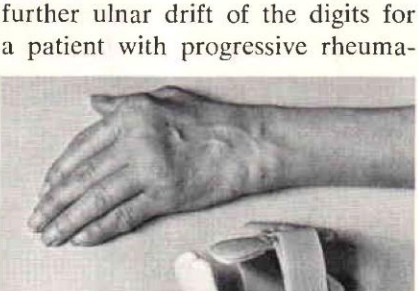

Fig. 3—Rheumatoid arthritic hand with ulnar deviation is shown without the orthosis applied.

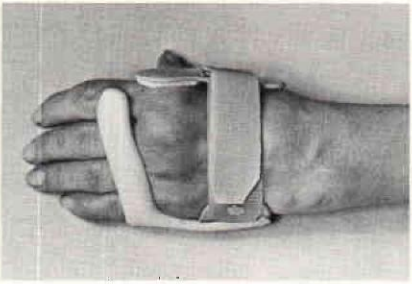

Fig. 4—Ulnar deviation is minimized with orthosis applied, and further deformities are prevented.

toid arthritis (Figs. 3 and 4). A third example of its use is seen in a patient with radial palsy (Fig. 5), who was given dynamic assistance in thumb abduction, wrist extension, and the proximal volar phalangeal joints (Fig. 6).

Reciprocal Orthosis

Nearly 500 adaptations of the reciprocal wrist extension finger

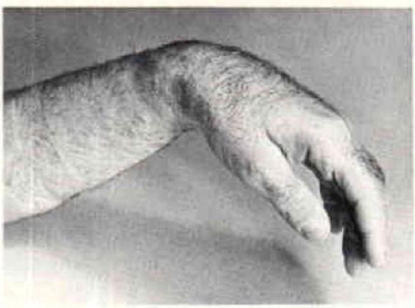

Fig. 5—Illustration of typical hand with radial palsy.

flexion orthoses have been applied and clinically evaluated at Texas Institute for Rehabilitation and Research since its development under this project, and these patients can be divided into three categories. In the first group, the orthosis is applied early in convalescent care, and the patient gradually gains enough residual movement so that eventually the device is not needed. The second category includes those

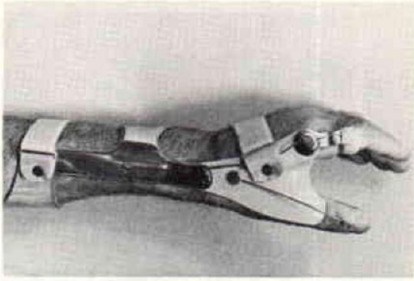

Fig. 6—Orthosis provides dynamic assistance in thumb abduction, wrist extension, and in the proximal volar phalangeal joints.

who use the orthosis for therapeutic value and who, although able to perform gross activities independently, depend upon it for manipulating small objects. The third group, which constitutes the majority, remain totally dependent upon the orthosis for all functional activities. In all cases, early adaptation is stressed (Fig. 7).

Following adaptation and training, the users of the reciprocal orthoses find their functional ability greatly enhanced. They are once again able to perform most activities of daily living (Figs. 8, 9, 10).

One particularly interesting adaptation is represented by patient G.S. This young man lost the major portion of his index finger on his dominant right hand in a traumatic amputation which occurred during January, 1965. In May, 1966, he sustained a cervical fracture at the C-7 level in a diving accident. Since he maintained active wrist extension but lacked finger prehension, bilateral reciprocal orthoses were prescribed and adapted. A prosthetic index finger was made and incorporated as a part of the adaptation, resulting in a major functional gain (Fig. 11). He is using his orthosis with excellent

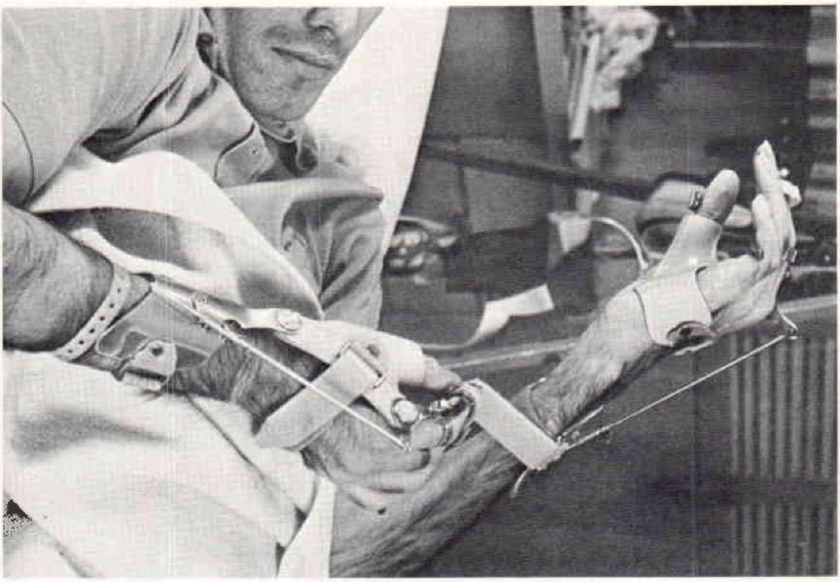

Fig. 7—Early adaptation of the reciprocal orthosis for a quadriplegic patient.

dexterity, and at this writing is continuing his high school education (Fig. 12).

Externally Powered Orthoses

Eighty externally powered units were made in the Department of Orthotics during the four-year span of the research project. Ten of these were applied to patients in the early stages of development for study purposes only. An additional twelve units were sent to other rehabilitation centers, and follow-up information is not available on these adaptations.

Of the 58 orthoses adapted in the department, 50 were applied to men and eight were made for women. This total includes 39 externally powered finger prehension orthoses with wrist friction joint, twelve arm abduction elbow flexion units, one combination feeder abduction unit, one combination finger prehension and arm orthosis, and

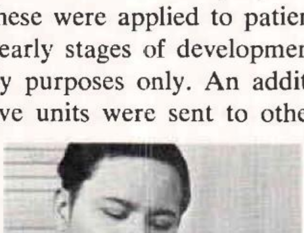

Fig. 8—Orthosis used for self-feeding.

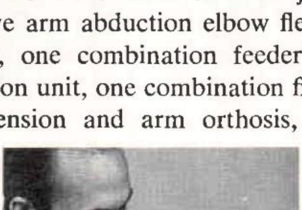

Fig. 9—Patient uses the orthosis to resume his education.

Fig. 10—The orthosis restores sufficient finger dexterity for this young lady to apply her make-up.

five powered orthoses with Dorrance hooks.

In this predominantly male patient population, the primary diagnosis was spinal cord lesion, which most frequently was located at the C-5, 6 level. The average age of these male patients was 26.4 years, while the women's age average was 35.4 years. The most common cause of these traumatic injuries to the spinal cord was automobile accidents. A complete list of the precipitating causes is given below.

Neuromuscular Diagnoses	Cases
Poliomyelitis	10
Cervical Tumor	1
Muscular Disorder	1

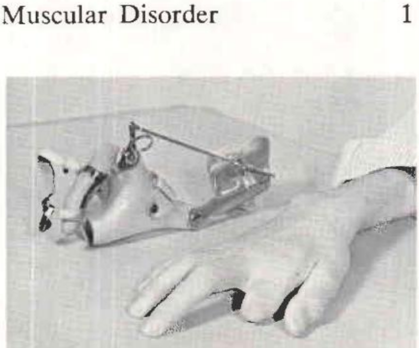

Fig. 11—A prosthetic index finger was incorporated into the reciprocal orthosis.

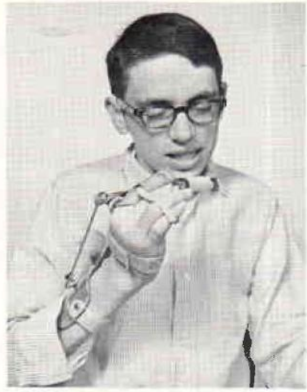

Fig. 12—The patient can now use a standard toothbrush with a swivel head, as well as write and manipulate small objects.

Diagnoses Secondary to Accidents	Cases
Automobile	20
Diving	16
Football	2
Trampoline	2
Motor Scooter	2
Gunshot wound	2
Truck	1
Fall from horse	1

A complete list of all patient applications is given in the following pages.

Prior to the application of orthotic assistance, these patients were partially or totally dependent for all functional activities. Therefore, the classification of dependence is used as the base line, rather than comparing the patient with normal individuals.

If, for instance, a totally dependent patient could feed himself various foods in a reasonably independent and coordinated fashion, he is rated Good. The rating Fair is used when a patient is able to feed himself but in a slow and somewhat uncoordinated manner. Poor means that he can feed him-

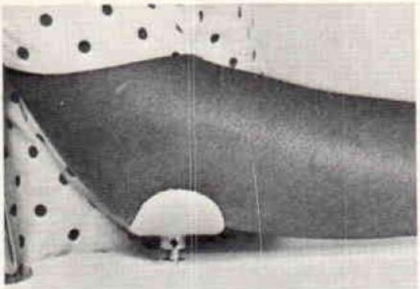

Fig. 13—Example of control site for powered arm orthosis.

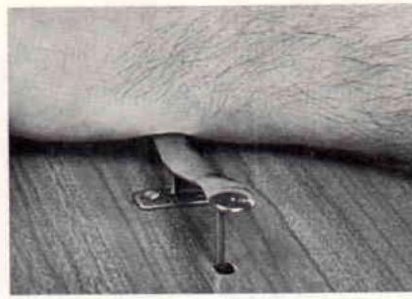

Fig. 14—Example of control site for powered finger prehension orthosis.

self to a limited degree but in a poorly coordinated way.

The ratings given in the summary of patient applications are based on the individual's performance at the time he was discharged from the Institute.

The majority of these applications can be termed successful, with a dramatic increase in the patient's functional independence. In some cases, physiological or environmental problems have contra-indicated continued use of the equipment. Examples of both successful and unsuccessful adaptations are included.

With each application, the control mechanism is located at an individually selected site which is determined by the available voluntary movements. Any slight movement initiated by the patient may be harnessed to activate the system. Care is taken to place the control valve where it will require minimum conscious effort on the patient's part, thus becoming a reflex action within a reasonably short time.

The advantage of these control arrangements is that the powered device is not activated accidently. Figs. 13 and 14 illustrate two of the more commonly used control mechanisms, and the following chart describes the location of control sites in the 58 previously outlined cases.

One of the most successful adaptations is represented by patient H.E., a 25-year-old university student (Fig. 15). In 1963, this young man had just completed his sophomore year in college where he was majoring in civil engineering. While on an outing at Lake Houston, he dove into shallow water and struck the bottom of the lake, resulting in a diagnosed incomplete lesion at the C-5, 6 level.

When first seen in the Department of Orthotics in 1964, he was dependent for all activities of daily living. Some wrist extensors re-

CONTROL SITES

Type of Application	Number
Powered Finger Prehension Orthosis:	
Unilateral (C-5, 6 lesion)—Activation of Valve control by forearm sliding movement.	29

Bilateral (C-5, 6 lesion)—Activation of valve control by forearm sliding movement. Right forearm controls left finger prehension, left forearm controls right finger prehension.	5

Powered Orthosis With Dorrance Hook:

Unilateral (C-5, 6 lesion)—Activation of valve control by forearm sliding movement.	3
Bilateral (C-5, 6 lesion)—Activation of valve control by forearm sliding movement. Right forearm controls left orthosis, left forearm controls right.	1

Feeder Abduction Unit (Combination):

Left extremity. Controlled by activation of forearm cradle.	1

Arm Units:

Unilateral (C-3, 4, 5 lesion)—Controlled by shoulder elevation with valve located on lapboard at elbow area. Left controls right powered extremity, right controls left powered extremity.	8
Unilateral (Polio)—Right extremity. Controlled by slight supination and pronation movement of left extremity.	1
Unilateral (Polio)—Controlled by voluntary dorsiflexion and plantar flexion of left foot.	1
Unilateral (Polio)—Controlled by shoulder abduction of powered left extremity.	1
Unilateral (Muscular disorder)—Controlled by push buttons operated by slight finger flexion of opposite hand.	1

Finger Prehension and Arm Unit (Combination):

Right extremity. Controlled by shoulder elevation with valve located on lapboard at elbow area.	1

Fig. 15—Patient H. E. is shown in a civil engineering class at the University of Houston where he is a full-time student.

mained on the right extremity, while all active motion of the wrist and hand was lacking on the left. In an attempt to utilize the residuals remaining on the right, a reciprocal wrist extension finger flexion orthosis was applied.

Although this adaptation improved his functional capacity considerably, the patient was formerly left-handed, and he found it extremely difficult to attempt writing with his right hand. Following numerous requests by the patient, a powered finger prehension orthosis with wrist friction joint was prescribed and adapted for the left extremity.

Following a training period in the Department of Occupational Therapy, he was able to feed himself, write with a pencil or pen, type, handle a telephone, shave with an electric razor, brush his teeth, and participate in various avocational activities.

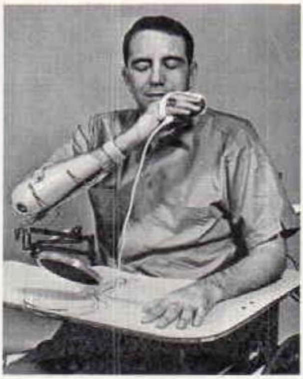

Fig. 16—Patient using powered arm orthosis.

Today he is completing his education in engineering at the University of Houston. He wears his orthosis approximately 12 hours a day and uses it in all activities. In addition to those functions he could perform originally, his capabilities have now expanded to include self-feeding, including eating soup, washing himself, drawing, painting, and such avocational activities as checkers and dominoes.

A less successful adaptation is exemplified by J.M., a 33-year-old ranch supervisor who recently discontinued using an arm abduction, elbow flexion orthosis due to irreversible physiological problems.

This highly motivated and intelligent man was a ranch foreman until his accident in 1964. While riding a horse, he was hit on the left side of the head by a tree limb, causing him to fall to the ground. He was diagnosed as having a C-4, 5 fracture accompanied by severe muscle spasticity.

At the time of his original admission, he could only shrug his shoulders and position his head. In 1965, he was fitted with a right powered arm unit as an experimental, therapeutic device to see if the spasms would subside in time (Fig. 16). The lapboard control site was located under the left elbow and was activated by elevating and relaxing the shoulder.

He used this unit for several hours daily for 18 months, but as his

Fig. 17—A special chin-activated control unit was made so the patient could operate his electric wheelchair independently.

muscle spasms increased he found it impossible to attain good function with the powered orthosis. In a medical re-evaluation in March, 1968, it was seen that the patient had not increased his voluntary control over his upper extremities due to the persisting spasms. The equipment could not offset these uncontrollable movements, and was thus rendered useless for him.

In view of the fact that no useful function could be restored to his upper extremities, his second objective was independent wheelchair mobility. He obtained a standard E & J electric wheelchair. Since only his head was free of spasms, it was decided to modify the standard control mechanism so it could be operated by his chin (Fig. 17).

The regulator control switch was encased in a new covering and mounted on a removeable stainless steel arm which was attached to the chair. A molded cup which followed the contours of J.M.'s chin was then mounted on the control mechanism. This arrangement permitted him to obtain completely independent control of his wheelchair in any direction. This degree of independence from a wheelchair level has permitted him to be more productive in carrying out his responsibilities as a ranch supervisor.

In a few instances, an externally powered orthotic adaptation has appeared successful, yet it has not met the patient's functional needs in certain areas. Patient C.L., a 36-year-old computer programmer at Baylor College of Medicine, presented such a problem.

This patient received a fracture-dislocation of C-4 on C-5 in a diving accident in 1948. Following an evaluation in the Department of Orthotics in 1963, he was fitted with a powered finger prehension orthosis with wrist friction joint. He used this orthosis for three years, primarily during his working hours. During this time, however, continuous repairs were necessitated because of his heavy work load.

During the course of his eight-hour work day he found he could not pull out heavy file drawers or pick up stacks of cards with the prehension unit. It became quite evident that this patient needed something more durable to suit his

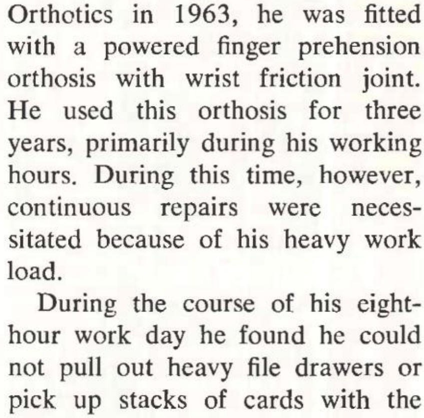

Fig. 18—The special powered hook enables C. L. to perform all facets of his work as a computer programmer.

particular requirements.

In 1966, a special externally powered hook was made for him (Fig. 18). A Dorrance aluminum hook #88X was adapted to a special finger support with a wrist friction joint. The power actuator was adapted on the radial side of the forearm to open the terminal device. Rubber bands around the hook provide a closing force of eight pounds, which can be increased if needed.

This arrangement gave the patient the additional mechanical strength needed for his special occupation while still maintaining a smooth, gradational, controlled movement of the powered terminal device. In addition to utilizing the unit at work, C.L. is able to feed himself, brush his teeth, shave, type, write with a ball point or pencil, turn pages, and handle a telephone. His avocational activities include drawing or painting. He normally wears the orthosis between 12 and 14 hours a day.

With this modification, it was possible to solve the particular requirements of his and three other patients. This was done, however, only by sacrificing the cosmetic factor. These individuals were willing to relinquish cosmesis in order to obtain the added functional versatility provided by the structural strength of the terminal device.

Any externally powered orthotic adaptation is successful *only* if

(1) the patient accepts the possibly unacceptable fact of chronic impairment;

(2) the patient accepts the assistive devices provided him; and

(3) his environment is conducive to increased functional ability.

This acceptance comes slowly, perhaps extending over a prolonged period of time.

An example is patient J.C., a 23-year-old student at the University of Houston. In 1964, he dove from a 15-foot elevation into a pool and received a fracture at the C-5, 6 level. At the time of the initial evaluation, he was found to have good range of motion in the upper extremities, and active shoulder motion, elbow flexion, and forearm supination-pronation. As he was totally dependent on others for self-care, he was fitted with an externally powered finger prehension orthosis with wrist friction joint on his dominent right extremity.

At the completion of his Occupational Therapy program, he was able to feed himself, shave, brush his teeth, write, type, and turn pages. In spite of this progress, once discharged the patient was unable to continue using his powered device because of numerous family problems such as inattention and lack of cooperation. As his frustration and depression increased, he became hostile to his environment, refused all offers of assistance, and was content to be totally dependent on others.

When the home situation was rectified after many months of counseling, the patient began to develop renewed interest in himself and his future. He enrolled in South Texas Junior College, taking six hours per semester. He recently transferred to the University of Houston, where at this writing he is majoring in education. He once again performs all the activities listed previously.

Patient Follow-Up

While the patients are in the Institute they follow a closely supervised Occupational Therapy program. Their progress is checked often to determine the usefulness of the powered orthosis for each patient. At one point in the project, however, it was determined there was no method of recording continued usage of the equipment following the patient's discharge.

In order to secure this vital information on the usefulness of the systems in the patients' home environments, a questionnaire was prepared and mailed to 38 patients. This number represents the patients with whom contact had been maintained since application of the powered device.

Completed forms were received from 84 per cent of the patients. These represent a sampling of all types of adaptations—prehension units, arm units, and powered orthoses with Dorrance hooks. The questionnaire was divided into four main sections:

1. Those activities generally accomplished with the orthosis.
2. Vocational or educational activities.
3. Problems encountered with the orthosis.
4. Suggestions for improving the orthosis in design or usefulness. A sample of this questionnaire follows.

Whenever a patient fitted with a powered orthosis is discharged from the Institute, the Department of Occupational Therapy prepares a summary evaluation of his functional gain. Based on these evaluations, all of these patients were able to perform the activities listed on the questionnaire in the immediate post-application period.

Replies to the questionnaire are given in the following charts. It should be noted, however, that the nature of some activities predisposes a high percentage of response. For instance, only three women are involved; therefore, the figures given for applying make-up are based on these responses alone. Also, the majority of the male patients have short haircuts which require little or no combing.

ORTHOTIC SYSTEM FOLLOW-UP QUESTIONNAIRE

This form should be completed and mailed to the Institute every six months. It is most important that we have this information from all individuals using the orthosis in order for us to continue with further development and improvement of the unit.

1. Among the activities listed below, put a check mark before each activity that you ordinarily or usually do.

   A. Feeding

   .... Finger foods
   .... Soup
   .... Cut own meat
   .... Put food on fork or spoon
   .... Drink from cup or glass

B. Personal Hygiene

.... Brush teeth
.... Put toothpaste on brush
.... Wash face and neck
.... Shave yourself
.... Apply make-up
.... Comb hair
.... Help in dressing

2. Do you use the unit for any of the following activities?

.... Play cards
.... Play checkers/chess
.... Play dominoes
.... Turn pages
.... Type? Electric Manual
.... Write with ball point or pencil
.... Draw or paint
.... Sew or knit
.... Handle a telephone, including dialing

3. Do you have a job? Yes .... No ....
Full time? .... Part time? ....
Give a brief description of the job ....
....

4. Are you engaged in an educational or training program?
Yes .... No ....
Type of program: ....

5. Does the orthosis perform as well for you as it did before you were discharged from the Institute? Yes .... No ....

6. Do you normally wear your orthosis at least part of every day? Yes .... No ....
About how many hours do you wear it? ....

7. What problems have you had with the equipment?

.... Pressure points
.... Discomfort
.... Redness of skin
.... Unit is too heavy
.... Carbon dioxide leaks
.... Muscle ends pull loose
.... Muscle leakage
.... Mechanical breakdowns

Other (Describe) ....
....
....

8. Do you have any suggestions to improve the orthosis, to make it more comfortable or useful for you? ....
....
....
....

9. Additional Comments: ....
....
....
....
....
....
....

Summary of Orthotic Questionnaire

29 Males Replying

1. Activities of Daily Living
   - A. Feeding
     - 19 Finger foods
     - 13 Soup
     - 0 Cut own meat
     - 20 Put food on fork or spoon
     - 10 Drink from cup or glass
   - B. Personal Hygiene
     - 15 Brush teeth
     - 3 Put toothpaste on brush
     - 5 Wash face and neck
     - 4 Comb hair
     - 2 Help in dressing
     - 11 Shave yourself
2. Avocational Activities
   - 7 Play cards
   - 11 Play checkers, chess
   - 8 Play dominoes
   - 16 Turn pages
   - 19 Write with ball point or pencil
   - 12 Handle a telephone, including dialing
   - 17 Type, electric or manual
   - 8 Draw or paint

3 Females Replying

1. Activities of Daily Living
   - A. Feeding
     - 2 Finger foods
     - 2 Soup
     - 0 Cut own meat
     - 2 Put food on fork or spoon
     - 2 Drink from cup or glass
   - B. Personal Hygiene
     - 2 Brush teeth
     - 0 Put toothpaste on brush
     - 2 Apply makeup
     - 1 Wash face and neck
2. Avocational Activities
   - 1 Play cards
   - 1 Play checkers, chess
   - 1 Play dominoes
   - 3 Turn pages
   - 3 Write with ball point or pencil
   - 1 Handle a telephone, including dialing
   - 3 Type, electric or manual
   - 2 Draw or paint

One indication of the success of these powered adaptations is the fact that twenty-three patients are using their orthoses in some form of vocation, either a job or continuing education. Five of these patients are employed full time in the following fields: Computer programmer, art teacher, hospital receptionist and co-editor of a volunteer newsletter (Fig. 19); editor of an intra-institute newspaper, and home management.

Another patient is employed part time as an assistant lawyer while completing his master's thesis,

Fig. 19—The powered arm orthosis enables N.W. to perform her duties as a hospital receptionist.

and a seventh is beginning to establish himself as a free-lance artist (Fig. 20). Each of these positions requires a variety of duties and skills which are performed quite capably by the involved individuals with the aid of their powered equipment.

In addition to those now employed, fourteen others are currently attending school. This includes all levels of education, from high school to graduate school. Two others indicated plans to return to

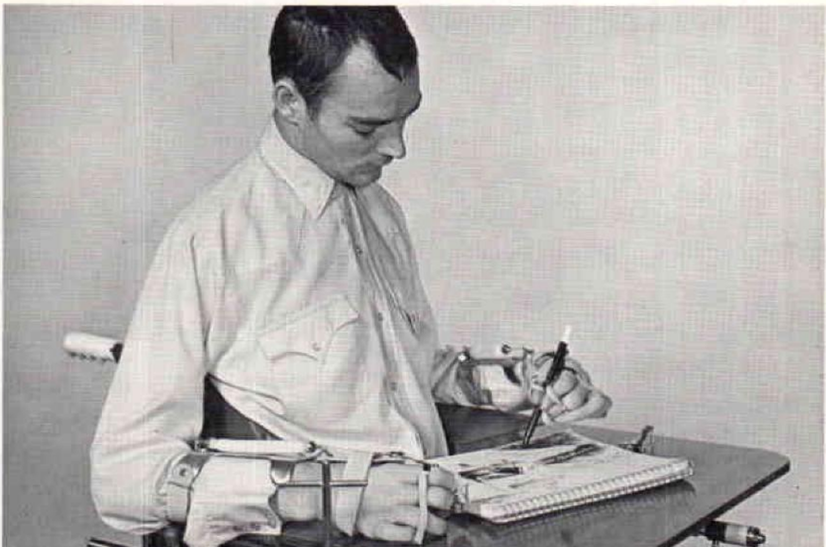

Fig. 20—Patient D. W. sketching, using bilateral finger prehension orthoses.

school in the fall.

One particular man, who uses bilateral powered finger prehension orthoses, recently graduated from the University of Houston with a degree in mechanical engineering. He has since enrolled in law school with plans to become a patent attorney.

The questionnaires which were returned indicated the average length of wearing time for the powered orthoses is seven and a half hours per day. The length of time is dependent on the individual's activities, with some wearing the orthosis as much as twelve to fourteen hours daily.

The problems pinpointed by the questionnaires mainly concerned carbon dioxide leaks and mechanical breakdowns. As the problems were identified, steps were taken by the Department of Orthotics to alleviate them.

Nearly all the patients made comments on the over-all system. Many of these suggestions were highly individualized ones, depending on how the patient used his equipment. Quite naturally, those who are employed have more requirements than do those who spend the majority of their time at home.

During the course of this project, recording forms were established for each patient as a powered orthosis was prescribed. By maintaining an individual folder from the pre-adaptation period through discharge, it was possible to keep accurate records on each patient's progress.

The forms compiled in the folders included the initial consultation request and reply, the hand measurement form, the occupational therapy evaluation summary, and the patient's completed questionnaire.

Since the completion of the research project under which the developments described in Part I of this report were evolved, the original group of patients has continued to be followed, and additional applications of a similar nature made.

Summary and Implications of Results

Just a few years ago, restoration of useful function for individuals with severe bilateral upper extremity motor impairment was mere wishful thinking. Today it is well known that, as a result of this and other research developments, needed and useful functions can be restored by powered assistance.

The orthotic systems developed under this project, both powered and non-powered, have been designed to be functionally efficient, of simplified modular design, economical, durable, and cosmetically acceptable. It has been our experience that these criteria are vitally important to the patient and to the overall-practicality of the orthotic system for large numbers of patients at this stage of the development of orthotics.

As a result of application to and evaluation of nearly 100 individuals using pneumatically powered systems, it was established that the system affords a practical method of restoring limited but useful hand and arm function for patients with spinal cord lesions at the C-5, 6 level. The finger prehension orthosis with a wrist joint that is friction loaded achieves this objective most efficiently. In the early years of our research, adaptation of this type of orthosis was found to be a complicated procedure. By using a "modular" assembly technique incorporating standardized plastic hand orthoses, however, the individual adaptation procedure was greatly simplified and was less time consuming and difficult for the patient.

This "system" has been designed to use the patient's own skeletal structure and biomechanical properties as an integral part of the orthotic mechanical system. This principle has proved to be very important, because its application avoids "mechanical man" solutions and the patient has increased motivation and acceptance of the artificially powered movements which remain under his direct proportional control.

Simplicity and reliability of response of the power control system is another very important factor. This permits the patient to perform his activities as naturally as is possible and with minimum conscious effort, also making him feel less "mechanized."

When very few functional residuals are available, such as with the higher spinal cord lesion patients (C-4, 5), the adaptation required is obviously more complex. The mechanical design of the powered arm unit provides important missing natural motions so that control of powered assisted movements need be directed primarily to shoulder abduction, elbow flexion and finger prehension actions. The mechanical design used also takes advantage of the skeletal anatomy, gravity forces, and mechanical leverage for complementary motions to the powered ones, such as shoulder abduction, elbow extension, and arm pronation and supination. With the powered arm unit, the patient is still able, therefore, to have useful function restored in a simplified manner that does not leave him "overloaded" with cumbersome equipment.

The plastic hand orthosis has been one of the most significant developments during this project. It can be mass produced and is made in standardized modular sizes. Its development has greatly simplified the fitting procedure of various orthotic systems which meet the prescribed needs of individual patients. The technique for usage of these systems can be taught relatively easily to other orthotists as demonstrated in structural training programs conducted as part of the study.

While this project was primarily aimed toward the development of powered orthotics, non-powered systems harnessing the patient's residuals into useful function were also designed and refined and found to have extensive utility. The reciprocal wrist extension finger flexion orthosis, designed for the quadriplegic patient with a C-6, 7 lesion who maintains active wrist extension but lacks finger movement, is an excellent example of how residual muscle actions can be effectively utilized. As a result of 450 clinical applications and evaluations of this device, we know this type of patient is able to gain considerable functional independence with a simple orthosis which includes a telescopic rod mechanism for hand pre-positioning. This mechanism permits the patient to voluntarily determine the hand-forearm anatomical relationship, thus giving him a choice of prehension force and degree of hand opening for grasping objects of different sizes and shapes.

Clinical experience and kinematic studies reveal that many factors must be considered besides orthotic mechanical design and application techniques for successful usage of an orthotic system. Poor range of shoulder or elbow motion, uncontrollable spasms of the upper extremities, and irreversible deformities of the upper extremities must be corrected or minimized along with preparatory patient management directed to sitting and physical activity tolerances. Some of these problems can be resolved in conjunction with usage of anticipatory physical therapy treatment in a program which will prevent the development of malpositioning and contractural deformities during the early post-acute period. Also, foresight and teamwork on the part of the physician, the nurse, the therapists, and the orthotists expedite proper orthotic adaptation, tolerance, and effective utilization of orthotic devices by the patient.

Following the application of the orthotic device, three to four weeks training time in activities of daily living usage of the system in an occupational therapy program is sufficient for most patients. The first objective of this program is to begin self-feeding. The daily living functional usefulness of these powered systems is indicated by the fact that fifty-eight adaptations have enabled all of the quadriplegics participating in the project to feed themselves, care for personal hygiene, write, type, and handle a telephone. Many of them routinely perform avocational activities such as playing cards or checkers, drawing, or painting.

At this stage of the development, seven of the quadriplegics (15%) have become gainfully employed in competitive situations and fourteen (30%) are pursuing educational development with realistic vocational expectations.

An orthotic follow-up questionnaire was prepared which provided an evaluation from the patient's viewpoint. Problems identified on follow-up were few. Some patients reported carbon dioxide leaks in the system, predominantly due to carelessness in handling a precision-made device in the home environment. Another problem identified, which is as yet unanswered, was how the patient could achieve removal and reapplication of the powered orthotic devices by himself. In every case, the patient's family had been instructed in the handling and care of the orthotic device prior to the patient's discharge. In spite of this, problems sometimes developed in the home, and in follow-up it was found that only seven (15%) of the fifty-two patients in the initial program with powered assistance had discontinued using it due to undesirable environmental conditions.

Psychological and social factors are significant determinants of practicality and usage of orthotic systems. A patient, having lost full voluntary use of his extremities, senses to a greater extent the feelings of those around him. If he senses a reluctance of others, such as his wife or parents, to assist him, he will soon stop asking to be transferred to a wheelchair or to have his orthosis applied.

Considering the combined efforts that are expended to give a patient an opportunity for functional improvement, it seems unfortunate to discover that sometimes a patient's home environment may become the crucial deciding factor in his becoming progressively independent or remaining a physical burden to his family.

This point was clearly illustrated by one patient who, at the time of his accident, was attending college. Following the adaptation of external power, he returned to the university for a short while, but was forced ot drop out when he was unable to obtain the necessary attendant assistance in the university setting. His family then placed him in a nursing home where he did not have the opportunity to use his equipment at all.

In view of both positive accomplishments and negative findings, it is strongly recommended that future research programs of this nature include frequent home visits before and after the patient is discharged from the hospital environment. Continued contact and counseling provided by rehabilitation personnel, including the vocational counselor, should aid in improving or restructuring the patient's physical and social environment to further his functional independence and job performance or educational opportunities.

The success of orthotic adaptations is not achieved by the mechanical application alone, but by the close cooperation of all disciplines directly or indirectly involved in the rehabilitation process. In order to obtain this full cooperation, all those concerned with patient care must know the advantages and limitations of these functional substitutes. In this way, all personnel surrounding the patient will help him view the available orthotic assistance realistically.

We believe research developments in both powered orthotics and prosthetics have now reached a point where it is imperative to establish educational programs for the proper utilization of these new techniques and methods. These programs should teach medical and other related personnel the facets of prescription, application, training, and maintenance of powered assistive devices.

Dissemination of Research and Development Results

Twenty-one publications have evolved from this research, plus the Final Report and these two articles which were condensed from that Report. In addition, an Instruction Manual was written detailing the assembly methodology of the reciprocal wrist extension finger flexion orthosis, training methods, and assembly instruction guides for other orthotic systems.

A motion picture entitled "An Application of Research in Orthotics" was made in 1965, demonstrating functional gains experienced by the severely impaired patients participating in the project using the devices described herein. An Upper Extremity Orthotic Exhibit was prepared, and was shown at national medical conventions during the project period.

Eight seminars of one week duration each have been held for various groups of orthotists, therapists, and physicians. Some of the basic developments in the project were evaluated by independent clinics under the auspices of the National Academy of Sciences—National Research Council. The results of this evaluation were published by Hector W. Kay of N.A.S. in *Artificial Limbs,* Spring, 1969, issue.

ACKNOWLEDGEMENTS

Acknowledgement is made to the many individuals participating in these research developments during the grant period, particularly to the members of the Orthotic Board and the staff of the Department of Orthotics.

Orthotic Board:

W. A. Spencer, M.D., Director, Texas Institute for Rehabilitation and Research;

P. R. Harrington, M.D., Consultant Physician; G. H. Lane, M.D., Consultant Physician; L. A. Leavitt, M.D., Consultant Physician.

Staff of the Department of Orthotics:

L. F. Ottnat, C.O., Shop Supervisor; Leo Smith, Orthotist; supporting staff members Carl Roach, Wayne Irby, Mike Northcutt, Tom Yoakum, Ernest Ogea, Steve Ottnat, John Sulak, Mrs. Amy Broussard, Mrs. Joyce Ellis, and Miss Judy Wilkinson.

Acknowledgement is also made to members of cooperating departments at Texas Institute for Rehabilitation and Research:

Mrs. Gene Keenan, Occupational Therapist; Miss Dorothy Iddings, Physical Therapist; Robert Sparks, Photographer; William Reese, Mechanical Engineer.

Furthermore, acknowledgement is made for the many reports and publications, in addition to those listed in the References, which have served as sources of information and assistance for the project. Valuable contributions have also been received from the countless people who have participated in meetings and conferences both here and abroad during the four years of the project. These exchanges of ideas have stimulated the researchers and helped to further the project.

Acknowledgement is also made to the entire professional and nonprofessional staff at the Texas Institute for Rehabilitation and Research, who contributed both ideas and service.

Finally, and most importantly, our grateful thanks are extended to the many patients who cooperated with us in the clinical evaluation of our orthotic devices.

SUMMARY OF PATIENT APPLICATIONS OF CO_2 POWERED ORTHOTICS

Patient	Age	Sex	Diagnosis	Unit Applied*	Before Application	After Application	Vocation	Avocation
1. J.G.R. (Deceased)		M	Quad—polio	1-2R	Totally dependent	Self-feeding**, typing**, page turning**, adding machine**	Owned magazine sales business	
2. B.L.N. (Deceased)		F	Quad—polio	1R	Totally dependent	Self-feeding**, typing**, page turning**, writing**, applying make-up**	Studied lab technology	
3. R.G.C.	31	M	Muscular disorder, type unknown	1R	Totally dependent	Self-feeding**, hygiene**, page turning**, writing**, shaving**, smoking**	Unknown-lost contact	
4. C.C.	28	F	Quad—polio	2R	———	———	Social Worker, Unit applied for study evaluation only	
5. N.C.H.	37	M	Quad—polio	2L	———	———	Business Manager, Unit applied for study evaluation only	
6. M.H.B., Jr.	41	M	Quad—polio	1R	———	———	College Instructor, Unit applied for study evaluation only	
7. L.B.P.	31	F	Quad—polio	1R	Page turning*, typing*, writing*	Self-feeding***, writing***, page turning***, applying make-up***, hygiene***, typing***, smoking***	Editor, TIRR newspaper	Painting, cards, drawing

8. J.E.R.	19	M	Quad—polio Multiple severe skeletal deformities	1R	Totally dependent	Self-feeding**, page turning**, writing*, typing*	High school student	Cards, checkers
9. R.V.C. (Deceased)		F	Quad—C-5, 6 automobile	2R	Turning pages*, typing*	Self-feeding***, writing***, page turning***, writing***, hygiene***, typing***, apply make-up***	Retired	
10. J.M.P.	20	M	Quad—C-5 automobile	2R	Totally dependent	Self-feeding***, hygiene***, page turning***, writing***, typing***	None	Checkers, cards, dominoes
11. E.W.Z.	36	M	Quad—C-6 automobile	2R	Totally dependent	Self-feeding***, hygiene***, page turning***, writing***, typing***, shaving***, use telephone***	Art student	Chess, checkers
12. M.W.B.	31	M	Quad—C-5, 6 trampoline	2R	Totally dependent	Self-feeding***, hygiene***, typing***, writing***, page turning***, work slide rule***, operate chair***	Law student	Chess, cards
13. A.M.N.	43	F	Quad—C-5, 6 automobile	2R	Totally dependent	Self-feeding***, writing***, typing***, apply make-up***, page turning***, telephone***, hygiene***, position utensils***	Housewife	Checkers, cards, dominoes

*Type of Application:
1. CO_2 powered arm unit (right or left) to provide synchronized elbow flexion-extension, and shoulder abduction-adduction.
2. CO_2 powered finger prehension unit (right or left) to provide finger prehension with voluntary hand-forearm positioning.
3. CO_2 powered orthosis with Dorrance hook to provide powered opening of the hook and positioning with a wrist friction joint.

Activities Rating Scale: *Poor **Fair ***Good

SUMMARY OF PATIENT APPLICATIONS OF CO_2 POWERED ORTHOTICS

	Patient	Age	Sex	Diagnosis	Unit Applied*	Before Application	After Application	Vocation	Avocation
14.	A.M.N.	43	F	Quad—C-5, 6 automobile	2L	Totally dependent	Self-feeding***, writing***, typing***, apply make-up***, page turning****, telephone***, hygiene***, position utensils***	Housewife	Checkers, cards, dominoes
15.	J.A.W.	26	M	Quad—C-5, 6 automobile	2R	Totally dependent	Self-feeding***, shaving***, page turning***, telephone***, writing***, typing***, hygiene***	None	Checkers
16.	H.M.E.	25	M	Quad—C-5, 6 diving	2L	Totally dependent	Self-feeding***, writing***, typing***, page turning***, telephone***, shaving***, hygiene***	University student	Checkers, cards, painting, drawing, dominoes
17.	J.E.M.	44	M	Quad—C-4, 5 diving, severe skeletal deformities	2R	Totally dependent	Shaving*, brushing teeth*	None	Chess, cards
18.	T.E.S.	24	M	Quad—C-4, 5 automobile	2L	Totally dependent	Self-feeding***, hygiene***, comb hair***, shaving***, writing***, type***	None	Cards, checkers, dominoes
19.	C.M.L.	36	M	Quad—C-4, 5 diving	2R	Self-feeding*, shaving*, typing*, writing*	Self-feeding***, hygiene***, comb hair***, shav-	Data programmer	Drawing, cards, painting

						ing***, typing***, writing***, page turning***		
20.	J.E.C.	25	M	Quad—C-6, 7 automobile	2R	Totally dependent	Self-feeding***, hygiene***, typing***, smoking***, shaving***, writing***	None	
21.	G.O., Jr.	18	M	Quad—C-5, 6 diving	2R	Totally dependent	Self-feeding***, writing***, typing***, hygiene***, telephone***, page turning***, comb hair***	High school student	Cards, copper tooling, wood sanding, dominoes
22.	B.B.	38	F	Quad—cervical tumor	2R	Totally dependent	Self-feeding***, apply make-up***, hygiene***, typing***, writing***	Housewife	Cards, checkers, dominoes
23.	J.S.C.	23	M	Quad—C-5, 6 diving	2R	Totally dependent	Self-feeding***, shaving***, page turning***, typing***, hygiene***, writing***, telephone***	University student	Cards, chess, dominoes
24.	L.A.N.	31	M	Quad—C-4, 5 automobile	2R	Totally dependent	Self-feeding***, shaving***, page turning***, writing***, hygiene***, typing***, telephone***, use of handkerchief***	None	Dominoes, checkers

*Type of Application:
1. CO_2 powered arm unit (right or left) to provide synchronized elbow flexion-extension, and shoulder abduction-adduction.
2. CO_2 powered finger prehension unit (right or left) to provide finger prehension with voluntary hand-forearm positioning.
3. CO_2 powered orthosis with Dorrance hook to provide powered opening of the hook and positioning with a wrist friction joint.

Activities Rating Scale:
*Poor
**Fair
***Good

SUMMARY OF PATIENT APPLICATIONS OF CO_2 POWERED ORTHOTICS

Patient	Age	Sex	Diagnosis	Unit Applied*	Before Application	After Application	Vocation	Avocation
25. J.M.	33	M	Quad—C-4 fall from horse	1R	Totally dependent	Brush teeth*, shave*	Ranch Supervisor	
26. C.P.D.	26	M	Quad—C-4, 5 automobile	2R	Totally dependent	Self-feeding***, hygiene***, page turning***, typing***, shaving***, writing***, telephone***	None	Dominoes
27. T.E.P.	35	M	Quad—C-4, 5 automobile	2R	Self-feeding*, typing*	Self-feeding***, writing***, typing***, page turning***, telephone***, hygiene***, shaving***, hair combing***	Account Executive for stock broker	Cards, chess
28. B.L.H.	25	M	Quad—C-4, 5 truck	2L	Totally dependent	Self-feeding**, smoking**, typing**, hygiene**, shaving**, telephone**	Unknown—lost contact	
29. M.W.B.	31	M	Quad—C-5, 6 trampoline	2L	Totally dependent	Self-feeding***, hygiene***, typing***, writing***, page turning***, work slide rule***, operate chair***	Law student	Chess, cards
30. R.F.S.	22	M	Quad—C-5, 6 football	2R	Totally dependent	Self-feeding***, writing***, typing***, shaving***, page turning***, hygiene***, telephone***, aid in dressing***	University student	Drawing, cards, painting

31.	S.J.Y.	48	M	Quad—polio	1R	Totally dependent	Self-feeding**, hygiene*, page turning**, typing**, shaving**, writing**, adding machine operation**	Unknown—lost contact	
32.	J.B. (Deceased)		M	Quad—C-5, 6 diving	2R	Totally dependent	Self-feeding***, writing***, typing***, telephone***	High school student	Cards
33.	E.M.	27	M	Quad—C-4, 5 automobile	1R	Totally dependent	Self-feeding**, hygiene**, page turning**, smoking**	None	
34.	G.D.B., Jr.	19	M	Quad—C-5 football	2R	Totally dependent	Self-feeding***, writing***, typing***, shaving***, hygiene***, telephone***	University student	Chess, checkers, dominoes, cards
35.	F.J.B.	25	M	Quad—C-6, 7 gunshot	2R	Totally dependent	Self-feeding***, writing***, typing***, hygiene***, telephone***, page turning***	Assistant lawyer, working on master's degree	Chess, cards
36.	F.R.B.	23	M	Quad—C-4, 5 diving	2R	Writing**, self-feeding*, page turning**, telephone*	Self-feeding***, writing***, page turning***, telephone***, hygiene***, operate chair***	University student	Cards, chess, table games

*Type of Application:
1. CO_2 powered arm unit (right or left) to provide synchronized elbow flexion-extension, and shoulder abduction-adduction.
2. CO_2 powered finger prehension unit (right or left) to provide finger prehension with voluntary hand-forearm positioning.
3. CO_2 powered orthosis with Dorrance hook to provide powered opening of the hook and positioning with a wrist friction joint.

Activities Rating Scale:
*Poor
**Fair
***Good

SUMMARY OF PATIENT APPLICATIONS OF CO_2 POWERED ORTHOTICS

Patient	Age	Sex	Diagnosis	Unit Applied*	Before Application	After Application	Vocation	Avocation
37. D.A.F.	26	M	Quad—C-5 diving	2R	Totally dependent	Self-feeding***, shaving***, page turning***, writing***, hygiene***, typing***	None	Scrabble, cards
38. N.W.	37	F	Quad—polio	1L	Fair activities with ball bearing feeders	Self-feeding***, hygiene***, page turning***, writing***, apply make-up***, typing***, telephone***	Receptiontist, hospital volunteer advisor co-editor of newsletter	Cards, checkers, dominoes, drawing, painting
39. R.E.S.	24	M	Quad—C-4, 5 automobile	1R	Totally dependent	Self-feeding***, hygiene***, page turning***, shaving***, smoking***	None	Dominoes
40. J.M.L.	20	M	Quad—C-5, 6 diving	2R	Totally dependent	Self-feeding***, writing***, typing***, hygiene***, page turning***, apply-remove glasses***	High school student	Cards, checkers, dominoes
41. J.B.	22	M	Quad—C-4 diving	1-3L	Totally dependent	Self-feeding***, shaving***, page turning***, writing***	High school student	Cards
42. J.E.R.	19	M	Quad—polio	1R	Self-feeding**, page turning**, writing*, typing*	Self-feeding***, writing**, page turning***, typing**	College student	Cards, checkers, dominoes

43. C.M.L.	36	M	Quad—C-4, 5 diving	3R	Modification of existing prehension unit	Self-feeding***, shaving***, typing***, hygiene***, writing***, page turning***, telephone***	Data programmer	Drawing, painting
44. D.W.	28	M	Quad—C-5 diving	2R	Self-feeding*, sketching*	Self-feeding***, hygiene***, shaving***, writing***, sketching***, typing***, page turning***	Art teacher	Cards, checkers, dominoes, chess
45. D.W.	28	M	Quad—C-5 diving	2L	Self-feeding*, sketching*	Self-feeding***, hygiene***, shaving***, writing***, sketching***, page turning***, telephone***, typing***	Art teacher	Cards, checkers, dominoes, chess
46. F.I.	45	M	Quad—C-4, 5 gunshot	1-2R	Totally dependent	Self-feeding***, hygiene***, typing***, writing***, shaving***, page turning***, telephone***, operate wheelchair***	Office work	Cards, dominoes
47. T.E.S.	24	M	Quad—C-4, 5 automobile	3R	Modification of existing prehension unit	Self-feeding***, smoking***, comb hair***, hygiene***, shaving***, page turning***, typing***, writing***, telephone***, use adding machine***	None	Cards, checkers, dominoes, ceramics

*Type of Application: 1. CO_2 powered arm unit (right or left) to provide synchronized elbow flexion-extension, and shoulder abduction-adduction.
2. CO_2 powered finger prehension unit (right or left) to provide finger prehension with voluntary hand-forearm positioning.
3. CO_2 powered orthosis with Dorrance hook to provide powered opening of the hook and positioning with a wrist friction joint.

Activities Rating Scale: *Poor **Fair ***Good

SUMMARY OF PATIENT APPLICATIONS OF CO_2 POWERED ORTHOTICS

Patient	Age	Sex	Diagnosis	Unit Applied*	Before Application	After Application	Vocation	Avocation
48. T.E.S.	24	M	Quad—C-4, 5 automobile	3L	Modification of existing prehension unit	Self-feeding***, smoking***, comb hair***, hygiene***, shaving***, page turning***, typing***, writing***, telephone***, use adding machine***	None	Cards, checkers, dominoes, ceramics
49. S.M.D.	15	M	Quad—C-5 automobile	2R	Totally dependent	Self-feeding***, hygiene***, typing***, shaving***, writing***, page turning***	High school student	Dominoes, cards, painting
50. S.T.W.	16	M	Quad—C-4, 5 diving	2R	Totally dependent	Self-feeding***, hygiene***, page turning***, typing***, shaving***, writing***	High school student	Checkers, cards
51. J.E.M.	44	M	Quad—C-4, 5 diving	3R	Modification of existing prehension unit	Self-feeding***, writing***, ham radio operation***, typing***	Retired	Checkers, dominoes
52. L.M.F.	19	M	Quad—C-4, 5 automobile	2R	Totally dependent	Self-feeding***, hygiene***, page turning***, typing***, shaving***, writing***	College student	Cards, checkers, painting
53. E.S.H.	24	M	Quad—C-5, 6 motor scooter	2R	Totally dependent	Self-feeding***, writing***, typing***, comb hair****, shaving***, hygiene***, telephone***,	Medical student	Cards, checkers, dominoes, painting, mosaics

						operate wheel-chair***		
54. E.S.H.	24	M	Quad—C-5, 6 motor scooter	2L	Totally dependent	Self-feeding***, writing***, typing***, comb hair***, shaving***, hygiene***, telephone***, operate wheel-chair***	Medical student	Cards, checkers, dominoes, painting, mosaics
55. R.W.	18	M	Quad—C-5 automobile	2R	Totally dependent	Self-feeding***, writing***, typing***, shaving***, hygiene***, page turning***, comb hair***	High school student	Cards
56. R.B.W.	18	M	Quad—C-5 automobile	2L	Totally dependent	Self-feeding***, writing***, typing***, shaving***, hygiene***, page turning***, comb hair***	High school student	Cards
57. R.D.M.	19	M	Quad—C-5, 6 diving	2R	Totally dependent	Self-feeding***, hygiene, typing***, shaving***, telephone***, page turning***, writing***	University student	Drawing, cards, painting, dominoes
58. E.W.Z.	36	M	Quad—C-7 automobile	3R	Modification of existing prehension unit	Self-feeding***, hygiene***, page turning***, writing***, typing***, shaving***, use telephone***, painting***, operate wheelchair***	Art student	Chess, checkers, dominoes

*Type of Application: 1. CO_2 powered arm unit (right or left) to provide synchronized elbow flexion-extension, and shoulder abduction-adduction.
2. CO_2 powered finger prehension unit (right or left) to provide finger prehension with voluntary hand-forearm positioning.
3. CO_2 powered orthosis with Dorrance hook to provide powered opening of the hook and positioning with a wrist friction joint.

Activities Rating Scale: *Poor **Fair ***Good

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A.K. Air-Cushion Sockets

by J. E. Dillard, C.P.

Distal pressure, edema and discoloration have for years been problems for a number of above-knee amputees. Many efforts have been made to solve these problems, the most successful being the application of total-contact pressure. The above-knee air-cushion socket is another method of overcoming these problems.

Shortly after this writer completed the course entitled "Advanced Below-Knee Prosthetics" at Northwestern University Medical School, several above-knee patients with badly discolored distal ends were seen. Since various methods had been tried to eliminate this problem but had not been completely successful, it was thought that if air-cushion sockets for the below-knee amputee were successful, why would they not be equally successful with the above-knee amputee?

Several volunteers with discolored distal ends were contacted and above-knee air-cushion sockets were made for them.

The first sensation indicated by the amputees was feeling in the distal end but no discomfort. Second, a gripping or tightening effect was felt in the lower third of the stump; this feeling dissipated after use of about one week. Color changes became apparent almost immediately and after approximately three weeks of use, normal skir color returned with the exception of some permanent pigment change.

One amputee who had a problem of discomfort from muscle bunching and spasms stated that

Figure 1

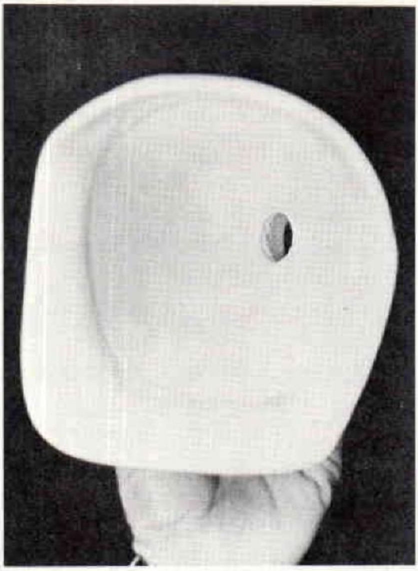

Figure 2

the air-cushion socket completely eliminated his problem.

A veteran patient, under the direction of *H. J. Buegel, M.D. was fitted on an experimental basis and discoloration was almost completely eliminated. (Fig. 1) In a letter to Dr. Buegel the patient stated that he was using the leg approximately 15 to 16 hours per day, being on his feet most of this time as a machinist. He had been unable to wear a prosthesis for about three months prior to this fitting.

The above-mentioned veteran and two other patients were fitted with suction air-cushion sockets. No lamination problems were experienced. There was some concern, however, as to whether or not a seal at the valve could be maintained without loss of air or separation (Fig. 2). To date this has not been a problem; they are functioning properly.

This method has two apparent advantages: first, the socket can be fitted somewhat looser proximally eliminating possible constriction; secondly, foam impregnated stockinette acts as a seal with a gripping action developed as a result of weight bearing.

Methods of casting and cast modifications are basically the same as for the conventional total-contact suction socket with the exception of the proximal tension analysis which should be reduced approximately one-half inch. Care should be used here in evaluating the stump as a loose proximal fit will cause undesirable noise. The proximal third of the socket is of rigid plastic with the distal two-thirds made of three layers of nylon stockinette impregnated with #384 Silastic Elastomer. A distal air chamber is formed with about three-eights to one-half inch space (Fig. 3).

Stump length measurement is critical; reducing the stump length about three-eights inch is suggested. Any additional shorting results in

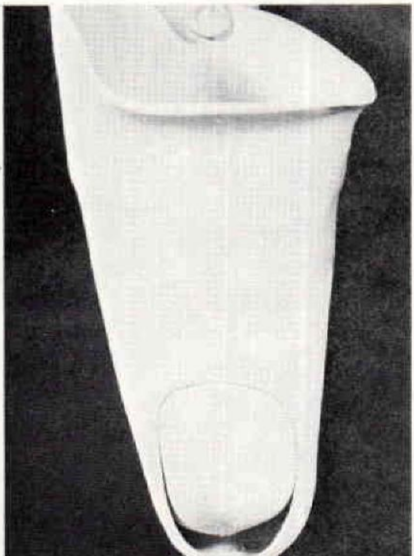

Figure 3

burning and skin irritation at the ischial seat.

Modification of the socket in the proximal third is possible and can be built up in the event of shrinkage. If extensive shrinkage occurs in the distal two-thirds, a new socket must be made. In the case of recent amputations this could mean a new socket in a very short time.

In conclusion, it is believed that this method of fitting has merit particularly for patients with hard to control edema, discoloration, and pain. It is also useful for stumps with bone spurs and little tissue, as well as an aid to stimulate circulation. Air-cushion sockets with hip-control suspension offered no problems. Atrophy can be accommodated by addition of stump socks. No problem of excessive perspiration has occured. Suction sockets can be used with close attention to the proximal fitting, but may need early replacement.

This is not a cure-all method, but one way to solve a major problem for the comfort of the amputee patient.

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Follow-Up Study On Usage of Externally-Powered Orthoses

by Joan E. Beard, O.T.R.* and Charles Long II, M.D.**

This investigation was supported, in part, by a research grant (RD-2377-M) from the Vocational Rehabilitation Administration, Department of Health, Education, and Welfare, Washington, D.C.

Over the past decade, externally-powered orthotic devices, some of which have been developed here and in conjunction with the Engineering Design Center of Case Western Reserve University, have been provided for severely paralyzed patients at Highland View, a chronic disease hospital of 340 beds.

Control systems for the flexor hinge hand splint, enabling prehension, have included those utilizing the McKibben carbon dioxide muscle (1), electrical muscle stimulation (4), and electric motor drives with three-level myoelectric control (6, 9) and with electric switch actuators (mechanical) operated by the shoulder (2), forearm, and chin (5) (Fig. 1). External powering for the Balanced Forearm Orthosis (B.F.O.), consisting of a mercury switch-activated elbow cable-drive system (8) for hand-to-mouth positioning (Fig. 2), and a special touch-plate control (7) for an electric

Figure 1

Flexor hinge hand splint, activated either by myoelectric control or by a manually-operated switch, on C5 quadriplegic patient.

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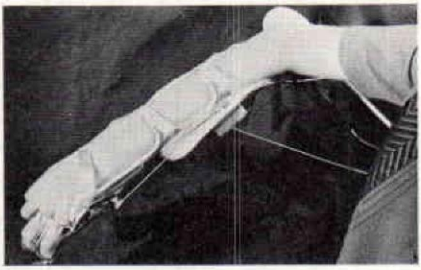

Figure 2

B.F.O. with mercury switch-controlled elbow cable and externally-powered hand splint on C4 quadripligic patient.

wheelchair, have additionally provided increased function potential for patients with C4 level quadriplegia.

Functional levels of quadriplegia used indicate the lowest level of residual motor function present (3). C4 quadriplegics, most of whom have a medical diagnosis of C4-5, have functional shoulder elevation and essentially complete paralysis of the arms. C5 quadriplegics, whose medical diagnosis is often C5-6, have shoulder and elbow muscles of fair to good strength but no wrist motion. Some C5 quadriplegics rely on B.F.O.'s but need no external powering other than for prehension.

A follow-up study was conducted primarily to determine to what extent our externally-powered orthotic devices are used by patients with C4 and C5 level quadriplegia following discharge from the hospital. The patients included in the study were all quadriplegics *without functional wrist extension* to whom orthotic devices of any type had been issued and who were first discharged from Highland View between June 1957 and November 1969, a period covering 12½ years. Information was obtained from medical records and questionnaires were completed by interview whenever possible.

Only results on usage of externally-powered devices, and educational pursuit, vocation, and living situation of those who have them, will be presented here. Other information collected, which will be correlated and reported later, includes that pertaining to usage of all orthoses and adapted equipment issued, orthotic system problems and suggestions for improvement, incidence of medical complications, special interests, evaluation of capabilities and actual level of independence in daily activities, and enumeration of causes of injury.

Number of quadriplegic patients in the study:		41
Subtract:	Expired:	8
	Could not be located:	2
	Failed to respond:	1
Number for whom questionaires have been completed:		30
Subtract:	Had some return of wrist extension:	4
	Were not issued externally-powered devices:	5
Number of C4 and C5 quadriplegics with externally-powered devices:		21

Figure 3

The number of patients participating in the study is shown in Fig. 3. The 21 patients with externally-powered orthoses, ranging in age from 17 to 57, included seven with C4 functional level quadriplegia and 14 with C5. All had traumatic spinal cord injuries. In this group, 19 questionnaires were completed by telephone or in person and two, by mail. The reliability of the findings would be expected to be greater than had more been completed by mail.

It was found that nine of these people, or 43%, are being formally educated. Two are in high school, three attend college, and four take correspondence courses. All except one person's tuition is paid by the Bureau of Vocational Rehabilitation. Eight of the nine are living at home as opposed to nursing home or extended care facilities while 76% of all 21 patients live at home. None of the 21 are working.

Usage of Orthoses

The chart (Fig. 4) shows the percentage of patients who, of those that have the special devices given, are actually using them. Thirty-one percent of the 29 devices listed are being used. A third of the patients who have any externally-powered orthotic devices are actually using them. Half of the few who have touch-plate wheelchair drive controls use them. All patients with electric-switch controlled hand splints use them; the McKibben muscle is the next popular; and no one is using his myoelectric control, electrical stimulation control, or externally-powered B.F.O. In some cases, the sample size is particularly small. It is really too soon to tell the frequency of usage of the electric switch control due to the small number issued to date and the short time-lapse since issuance (eight months for last of series). However, for many reasons, it appears to be the most functional prehension system of those used here. Most of the 21 people felt that the functional performance of the externally-powered hand splints themselves was adequate and any limitations in system design, with the exception of slow speed of application, were rarely severe enough to warrant disuse.

Three times as great a percentage of C5 quadriplegics are using their externally powered devices as are the C5's. The externally-powered B.F.O. does not possess adequate functional potential for the most severely involved patients. Both the poor quality of performance and the small number of activities which can be accomplished, due to limited range of motion and lack of forceful movement, lead to disuse. Without good proximal

Special device:	No. of C4 quadriplegics:			No. of C5 quadriplegics:			No. of C4 and C5 quads:		
	Use device:	Have device:	Percentage:	Use device:	Have device:	Percentage:	Use device:	Have device:	Percentage:
Externally-powered hand splints:									
McKibben muscle:	1	2	50%	2	9	22%	3	11	27%
Electrical stimulation:	0	1	0%	-	-	-	0	1	0%
Myoelectric:	0	4	0%	0	1	0%	0	5	0%
Electric switch:	-	-	-	4	4	100%	4	4	100%
Totals and percentages:	1	7	14%	6	14	43%	7	21	33%
External-powering for B.F.O.:	0	4	0%	-	-	-	0	4	0%
Touch-plate wheelchair drive:	2	4	50%	-	-	-	2	4	50%

Figure 4

Reasons for Disuse:	No. of times mentioned by different patients:
Slow speed of application	8
Poor quality of performance of activities	7
Slow speed of performance of activities	5
Hindrance in other activities	5
No interest or desire to do activities	3
Time limitation due to school	1
Architectural barriers	1
	30

Figure 5

arm function, the externally-powered hand splint is apparently of little value to these patients. The additional time required for application of the entire system is not justified. Poor quality of performance of activities was the reason most frequently cited by patients with C4 level quadriplegia for disuse of externally-powered orthoses.

Reasons for Disuse

Reasons given by the 14 people who do not use their externally-powered orthotic devices are shown in Fig. 5. All but two of those presently not using them had used them for a short period of time following discharge from the hospital. Although the desire to accomplish activities independently usually seems to be present, it is often more efficient and more practical for someone else to do daily activities for the patient, particularly in the home environment where many other factors are involved. Both time required for application of the device and for independent performance become too lengthy. Because the patient already depends heavily upon his family for essential daily care, he, in some instances, wants to avoid increasing demands upon them out of consideration for them and to avoid increased feelings of dependency within himself. His own time may be limited due to school. The relatively few activities which can be done independently are often interspersed in the daily routine with those in which he is not independent. It is often not worth putting on the orthosis to permit independent accomplishment of tasks requiring prehension, many of which are short-term in nature. Some things which require a longer period of time for completion and are related to interests, such as typing and page-turning, do not require prehension and can be done with simpler devices, applied with greater ease and sometimes independently. These most common activities, often required in pursuing educational goals, are frequently accomplished with B.F.O.'s without external powering, simple hand splints, or mouthsticks. Occasionally special interests are pursued which require prehension and increased usage of externally-powered hand splints.

The standard flexor hinge hand splint used here interferes with pro-

Live away	Live home	Multiplicative factor*
1/5	8/16	2.5

Not use	Use	Multiplicative factor
5/14	4/7	1.6

Proportion of patients pursuing educational goals and multiplicative factor

Live home	Live away	Multiplicative factor
4/16	3/5	2.4

Not being educated	Being educated	Multiplicative factor
3/12	4/9	1.8

Proportion of patients using externally-powered orthoses and multiplicative factor

*Quotient of two ratios.

Figure 6

pelling a regular wheelchair and can rarely be put on independently by these people. It is often not worth having it periodically applied to do an activity. Elimination of the need for removal of the splint practically necessitates the purchase of an electric wheelchair. Redesigning the splint so that it could be put on independently with ease by less severely involved C5 quadriplegics would probably be a worthwhile endeavor.

Ensuring high quality and speed of performance of an increased number of activities may not be sufficient in many cases to justify the longer application time, the most frequently cited reason for disuse. Perhaps, additionally, decreasing application time, and enabling independent application by some, would eliminate competition from simpler devices and increase usage among those presently not using externally-powered orthoses. If, in addition, performance of activities were extremely efficient, approaching the normal speed, any continued avoidance of independent accomplishment with orthoses would probably be due to the basic nature of daily activities, to the degree of acceptance of the severe disability on the part of the family and the patient himself, to association of the equipment itself with disability, to level of support and encouragement from the family, to desire for attention, communication, or dependence, and to the level of desire to pursue interests. Assistance, even when it is not necessary, is usually easy to obtain in the home environment when it is desired.

Factors contributing to disuse, as expressed by the participants in this study, are interrelated and, of

	Live away	Live home	Multiplicative factor
Not use	0/2	5/12	undefined
Use	1/3	3/4	2.3
Multiplicative factor	undefined	1.8	1.3

Proportion of patients pursuing educational goals and multiplicative factor

	Live home	Live away	Multiplicative factor
Not being educated	1/8	2/4	4.0
Being educated	3/8	1/1	2.7
Multiplicative factor	3.0	2.0	1.3

Proportion of patients using externally-powered orthoses and multiplicative factor

Figure 7

course, vary among individuals. This discussion may help to formulate a more realistic picture, although further evaluation remains highly subjective.

Correlation with Living Situation and Education

Relationships appear to be present between living situation and pursuance of educational goals, as well as between each of these and usage of externally-powered orthoses. The sample sizes are too small to make a statistical evaluation, or even the expression of percentage increase between groups, meaningful. Nevertheless, some interesting, and reasonable, trends are revealed.

The numbers of people pursuing educational goals and using externally-powered orthoses, of those groups specified, are shown in Figs. 6 and 7. In the second chart of Fig. 7, the lower number in the first box, for example, signifies the number of people who live at home and are not pursuing educational goals. The upper figure, or numerator, is the number, of this group, who are using their orthoses. In Fig. 7, in comparing groups, the alternate variable is controlled.

The numerical comparison of groups is employed for convenience. However, it must be kept in mind that the multiplicative factors (quotients of two fractions) are very approximate due to the small sample size. The figures in the lower right-hand box of each chart of Fig. 7 are also approximate and relate the magnitude of increase, in education and in usage, resulting from a change in each of the two variables affecting them.

The greatest proportion of patients doing educational work involved the group living at home and using their orthoses. Those using their devices tended to be living away from home and pursuing educational goals.

Two and a half times as great a percentage of those living at home (eight out of 16) as of those living away (one out of five) are pursuing educational goals. In the first chart of Fig. 7, eliminating the effect of using upon education by including only those who are not using their orthoses, we see that no one living away from home is pursuing educational goals while five of the twelve at home are. This trend may be partly to the increased physical help and psychological support often available at home for this type of pursuit.

While living at home strongly increased the likelihood of pursuing educational goals, living away increased usage of orthoses with similar intensity. Three out of five people living away from home and only four of the 16 at home use their externally-powered orthoses. Those who can and desire to do routine tasks independently are often encouraged to do them in living situations away from home where time is available and fewer intimate relationships exist. As stated previously, it is often more efficient simply to be assisted in the home situation.

Usage of orthoses also increased, but to a lesser extent, with ongoing education. Almost twice as great a percentage of those pursuing educational goals (four out of nine) as of those not pursuing them (three out of 12) use their devices, Eliminating the living situation influence resulted in three times as great a percentage. A math course, for example, ocasionally creates a need to use the externally-powered hand splint even though the activities most related to education do not require its use. It is possible that those living at home who are able to do some routine activities quite efficiently are more likely to be enthused about doing so if they are also enthused about their educational or leisure-time pursuits. Support from the family is then available for both desired endeavors. Yet, schooling imposes increased limitations on time upon the family and patient, making performance of routine tasks by the family more expedient in other cases.

In this study, the relative influences appear to differ little in intensity. Fig. 7 shows that a change in living situation results in only 1.3 times as great a proportion of patients, either pursuing educational goals or using orthoses, as does a change in the alternate variable. The effect of living at home, as compared with usage, upon education is about the same as, or slightly less than, the relative effects of living away and pursuing educational goals upon usage of orthoses.

The factors contributing to disuse, discussed in the previous section, tie in nicely and, along with additional knowledge of the patient and his situation and types of activities for which the orthoses are used, provided some explanation for the trends exhibited here.

Conclusion

In spite of the fact that most reasons for disuse are not exclusively related to the system's functional capabilities, design and provision of useful orthoses, especially for C4 quadriplegics, remains an important challenge in the field of rehabilitation. Only one of the seven C4 quadriplegics in this study uses his externally-powered hand splint. No one uses the external powering for the B.F.O., which does not possess adequate functional potential for the most severely involved patients of this group. The 43% of the C5 quadriplegics, who do use their externally-powered hand splints, find the added functional potential useful to them. A majority of these people have good proximal musculature, wish to be as independent as possible, have electric wheelchairs, use the orthosis regularly for a variety of common activities, and do not feel application of the device takes too long. Half of them live away from home and half are pursuing educational goals, both of which appear, in this study, coincident with increase in usage of externally-powered orthoses.

As many of us realize, the presently available systems, which have been tested here and elsewhere in the past, are of very limited value to the most severely involved C4 quadriplegics. Their design, both from the structural and the control aspects, challenges the ingenuity of the engineers. Systems in the research and theoretical stages include those utilizing logic circuitry for pattern recognition and preprogrammed motion and those incorporating a more natural positional-proportional control actuator. In proceeding with these multi-axes-control devices, the importance of the basic requirements of volitional control, ease and automatism of operation, natural output motion, efficient response to error and change of intention, and short training period must never be overlooked or minimized in the design of functional orthoses.

We wish to express our sincere appreciation for the generosity exhibited by the participants in this study and for the support of the Ampersand staff.

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Vitrathene, A Multipurpose Plastic

by Siegfried W. Paul, C.P.O.*

Introduction

Vitrathene, a thermoplastic polythene plastic imported from England, has become one of the most useful additions to the nonorganic materials used at Newington Children's Hospital. This material was first introduced to us by our Canadian neighbors two years ago. The Rehabilitation Institute of Montreal, in particular, had made extensive use of this material for over five years.

Our findings in working with Vitrathene have been most gratifying and we can only confirm the excellent features of Vitrathene claimed by the manufacturer. We would like to tell of our experiences with Vitrathene, discuss its range of application, and share our technique.

The earliest use of this plastic at Newington goes back to the time when a constant pressure lumbar pad (Fig. 1) was developed for the Milwaukee brace. A nontoxic, smooth, non-adhering material was needed and Vitrathene proved to be highly suitable. No skin reactions were reported in over 250 cases. This fact is to be credited to

Figure 1

Spring-Loaded Functional Lumbar Pad Applied to Milwaukee Scoliosis Brace.

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its satiny, soaplike surface. We were also able to create the desired material thickness by welding layers of plastic with a heat gun.

The low cost of this material and its easy, time-saving application brought us to the present extensive use of Vitrathene.

Suggested Application Procedure

A cast positive which has been modified in the conventional method should be used. This cast does not have to have the smooth surface required for laminations.

Apply one layer of cotton stockinette over the cast, avoiding loose fit or wrinkles. Prepare a paper pattern and cut out plastic, using a band saw. This pattern can be exact, since the heated plastic will stretch at the time of molding. For large objects, ¼″ material thickness is recommended; $^{3}/_{16}$″ is suitable for small items.

Molding Procedure: An oven of sufficient size should be heated to 350°F. The plastic must be placed in a flat position since it will become most flexible and adhering once hot. To assure even and flat heating of the plastic, place a sheet of aluminum on the oven rack. Heavy canvas placed on top of the aluminum sheet will permit transfer of the hot pliable material. A sheet of stockinette on top of the canvas will permit molding without distortion. The cold plastic placed on the stockinette should not extend over the edges of the aluminum sheet.

Heat the Vitrathene until the entire surface is transparent. Using absestos gloves, remove the plastic from the oven by lifting the canvas from the aluminum sheet. Large objects will require two persons for transfer of the plastic to the mold.

Attempt correct positioning of the plastic on the cast on the first attempt. The hot plastic will stick to the stockinette and it is not possible to remove the material till it has hardened sufficiently.

Remove the canvas after placing the hot plastic on the cast and mold the Vitrathene to the contours of the cast, using slight manual pressure. Wrap Ace bandages over the stockinette. This should be done with a fair amount of pull. Use wide bandages for larger items; narrow ones for small splints and deep undercuts. Check on even contact of the plastic with the mold and apply pressure as long as the plaster is hot.

Avoid excessive tightness of the bandages or too much manual pressure; either would result in an undesirably rough inner surface. Remove bandages and outer stockinette as soon as the plastic has cooled off to the point where its pink color has returned. Early removal eliminates the possibility of difficulties in removing the baked-on stockinette later on. Reapply the Ace bandages till the plastic is cold. Dip the mold in water to expedite the cooling process.

After the plastic has cooled sufficiently, remove the entire lap-up from the cast, then remove the inner stockinette, and trim the appliance to the desired shape. Round the edges with a sand cone.

Fit the appliance on the patient. Local adjustments can be made by heating the surface with a heat gun tipped with a funnel.

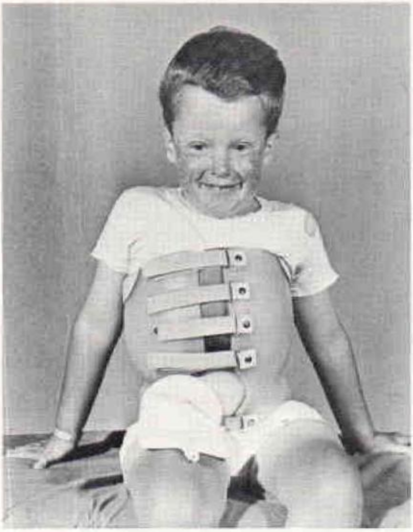


Figure 2

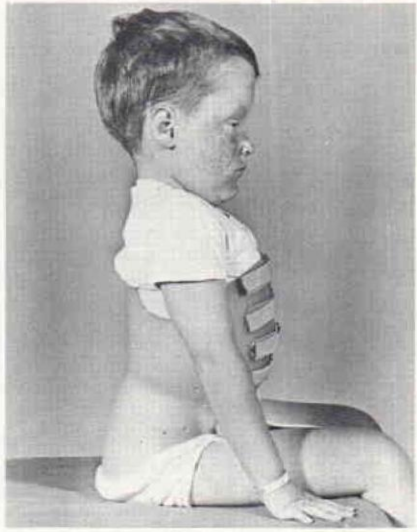


Figure 2A

Body Jacket with Ileal Conduit Worn by a Myelomeningocele Patient.

Finishing will consist of no more than buffing of the edges with a felt or rubber cone, perforation of the entire surface, and application of fasteners.

Vitrathene can be riveted or stitched, glue will not bond to its surface. Slight markings from the stockinette will not irritate the skin, however, excessive imprints should be buffed with a felt or rubber cone.

Tongues can be fabricated of 1/8" Vitrathene, or other suitable materials. Uses of Vitrathene applications for which Vitrathene has been used are as follows:

Body Jacket (Fig. 2)

Indication: Polio, muscular dystrophy myelomeningocele, advanced paralytic scoliosis, primarily for mentally retarded patients not suitable for Milwaukee brace application or surgery.

Anterior or Posterior Body Shell

Indication: Infantile scoliosis, secondary to myelomeningocele. Such shells can be designed as corrective, preventive and supportive appliances.

Recumbency Splint (Fig. 3)

Indication: Congenital hip dislocation and Legg Calve Perthes disease.

The Wu abduction splint used for the recumbent type of treatment of Legg Calve Perthes disease for over twenty years has been replaced at Newington with a plastic splint, eliminating side effects like varus and valgus deformities of knee and ankle.

The new approach also cuts the fabrication time to 1/3 of that of the former design.

Pretibial Shells

Vitrathene has proven of sufficient strength for incorporation in long leg orthoses.

Lower-Extremity Splint (Fig. 4)

Indication: Post-operative application and preventive or protective type of splinting. Application

Figure 3

Legg Calve Perthes Recumbency Splint.

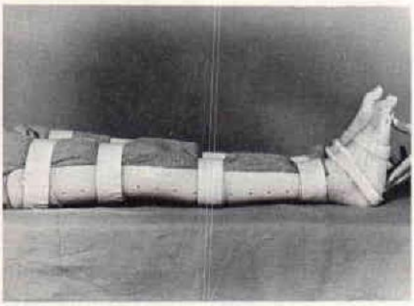


Figure 4

Lower Extremity Splint.

can range from the muscular dystrophy patient to the adult hemiplegic patient for use as a night splint.

Medial Stabilizing Shell (Fig. 5)

Indication: Legg Calve Perthes disease.

The Newington Ambulatory Legg Calve Perthes Orthosis is shown here.

Hand Splint (Fig. 6)

Indication: Volar or Dorsal splints for post-operative application, paralytic and support or protection requiring conditions.

Prosthetic Sockets

With the use of Vitrathene, the fabrication time for a prosthetic socket is reduced considerably. Therefore the cost is also reduced. In addition, Vitrathene does not soften as a result of increased body temperature and can be adjusted

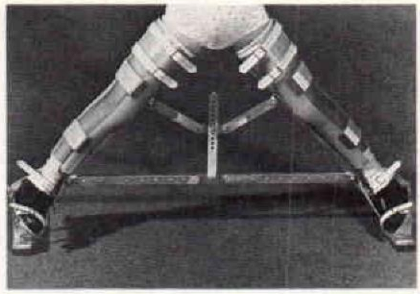


Figure 5

Newington Ambulatory Legg Calve Perthes Orthoses with Medial Plastic Stabilizing Shells.

by using a heat gun.

Dental Retainer

The Dental Department at Newington made use of Vitrathene for dental retainers for a period of over three years. The ⅛″ Vitrathene application resulted in a far less frequent need of replacement of retainers worn by our Milwaukee brace patients. Low cost, nontoxicity, greater durability, much improved prophylacticity and better cosmetic color are among its other advantages.

These are just a few of the possible applications of Vitrathene which required no more than the standard equipment of an Orthotic and/or Prosthetic facility.

New developments have been achieved due to the oustanding features of this material. No nega-

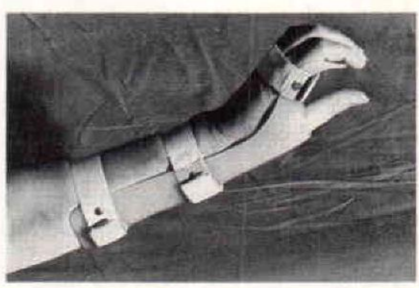


Figure 6

Hand Splint.

tive reports have come to our attention. Our physicians, patients and parents have been the true benefactors of this multipurpose plastic.

TECHNICAL INFORMATION

General

Vitrathene is the trade name for compression moulded polythene sheet manufactured by Stanley Smith & Company.

Vitrathene sheet has outstanding resistance to attack by alkalis, e.g. concentrated caustic soda at 60°C. (140°F.) and acids, e.g. concentrated hydrofluric acid at 20°C. (68°F.). It is odorless, non-toxic and therefore eminently suitable for use in contact with all types of foodstuffs. Further, Vitrathene sheet is dimensionally stable, possesses outstanding electrical properties, maintains its excellent physical properties over the range of −25°C. (−13°F.) to +90°C. (194°F.), exhibits very low water vapour permeability and is easily fabricated by existing and familiar methods for thermoplastic sheet. The recommended maximum service temperature is 60°C. (140°F.) if maximum benefit is to be achieved with these properties due to diminishing resistance to chemical attack with rising temperature and the melting point being 115°C.-120°C. (239°F.-248°F.).

Range

Sheet:

Color & Grade Pink, Grade 2 SSAO Sheet for Orthopaedic Splints. Only the one grade and color is supplied for this application.

Surface Finish Satin Finish.

Thickness ⅛″, 3/16″, ¼″.

Sheet Size 36″ x 36″. ⅛″ sheet yields approximately 0.60 lbs./sq. ft. or 1.67 sq. ft./lb.—other thicknesses are pro rata.

Specials Other thicknesses and sheet sizes available in carton lots. Write for details and prices. Allow 6 to 8 weeks for delivery.

Composition Backed Sheet The above sheet can be supplied, on special order basis, with a firmly adhering composition backing which successfully overcomes the problems normally associated with sticking polythene to various substrates, i.e., that no glues give really satisfactory adhesion and the expansion and contraction of the sheet under fluctuating temperatures tends to break down what little bond there is.

By applying the composition at the time of manufacture of the sheet, these two components act as one and the composition itself is easily able to be stuck to a variety of subtrates, e.g., steel, aluminum, wood, block-board, plywood, etc., thus enabling polythene to be used as a facing onto other materials. For advice on specific adhesives it is recommended that the adhesive manufacturers themselves be consulted.

Knit-Rite offers composition backed sheets. These are available on a special order basis. Please advise of your interest, supplying details of application and type of backing desired.

Vitrathene Welding Rod Welding rod of ⅛″ nominal diameter is available in ½ lb. packs of 18″ lengths.

Chemical Vitrathene at temperatures above 60-70°C. is soluble in organic solvents such as aromatic hydrocarbons, benzene, toluene, xylene; aliphatic hydrocarbons like hexanone, petroleum ether and in chlorinated hydrocarbons such as carbon tetrachloride, trichlorethylene and chlorbenzene.

Environmental Stress Cracking

When polythene is stressed by either external deformation or internal frozen-in strain and is in contact with certain materials, environmental stress cracking may occur. Such cracking may be caused by liquids or vapors (especially the vapors of volatile polar liquids): active compounds are such as alcohols, esters, soaps, liquid hydrocarbons and silicone fluids; inactive are such as water, polyhydric alcohols, sugars, hydrolysed protein, rosin, acid, and neutral inorganic salts.

Painting

Paints will not adhere readily to Vitrathene without special preparation, due to its chemical inertness.

Fabrication

The following general fabrication methods, already well established in the handling of thermoplastic sheet, are equally applicable to Vitrathene polythene sheet.

Cutting Sheet up to ⅛″ can be cut by metal shears or by guillotine (preferably with a clamp to avoid the material pulling into the blade): greater thicknesses can be cut by mechanically clamped power guillotine. All thicknesses can be cut with a circular saw but this is only suitable for straight cuts: bandsaws, on the other hand, can be used to cut all types of shaped blanks.

Drilling Holes up to 1″ in diameter can be drilled with standard drills, using slow speed; and greater than 1″ by means of trepanning tools. Drills should be lifted frequently to allow them to cool and overcome sticking due to overheating.

Punching & Blanking Normal methods, using forge-steel cutters and a fly-press, are suitable.

Bending Localized heating along the line of the desired bend by hot wire allows easy bending of the sheet. Where composition-backed sheet is being used, heating should be from the polythene side only and any bend should have the polythene surface on the outside.

Planing The use of all-metal woodworking planes is satisfactory to finish cut edges, etc.

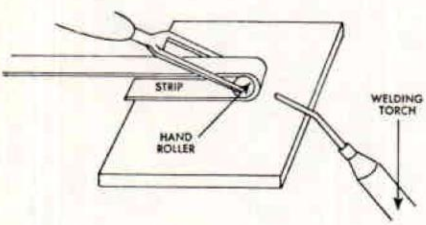
Routing Standard high speed routers, fitted with compressed air cooling and swarf removal, are suitable.

Grinding & Buffing Neither of those processes are recommended.

Adhesive bonding Due to the excellent chemical resistance of "Vitrathene" sheet, it is very difficult to produce an adhesive bond using those systems at present known. Where it is required to bond polythene to other substrates, Vitrathene composition backed sheet must be used.

Butt welding The edges of two sheets to be joined are heated either by radiant heat or a heated tool until nearly molten. The source of heat is then quickly removed and the sheets brought together with a slight sliding movement and under pressure (preferably in a jig) and allowed to cool. It is not considered that this method is as effective as hot gas welding (see below), but can sometimes be used in conjunction with it for flat sheet and also for joining tube to itself or a suitable fitting.

For flat thin sheet, a strip weld is sometimes applied over the butt weld, which is first ground flat. This is best illustrated as follows:



Hot Gas Welding The edges of the sheet to be joined are chamfered to give an included angle of 60-70°. (Where possible a sheet should have a sealing run of rod on the reverse and so a chamfer is necessary to accommodate this too). The sheets should be positioned so that there is a gap of approximately 1/32″ between them. Both the area to be welded and the welding rod must be clean and free from oil, grease, moisture, etc.

A welding torch heated either electrically or by gas, feeding air or nitrogen can be used but it must produce a temperature of approximately 300°C. at a position ¼″ from the nozzle using a gas pressure of approximately 2 lbs./sq. in. (some form of metering device to monitor this is strongly advised).

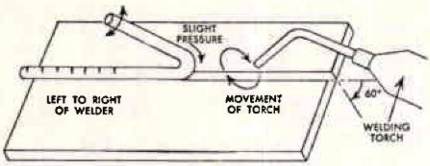
The end of the welding rod is trimmed to an angle of 45° and the rod itself ideally should be sufficiently long for the weld to be made in one piece.

There are three methods of welding Vitrathene sheet: experience will decide which is the most suitable under any given circumstances. They are:

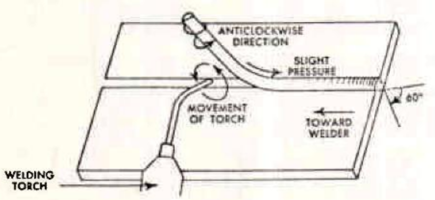
1) Ripple Welding The welder holds the torch in the right hand and the welding rod in the left. The end of the rod is heated with the torch and pressed into the V-groove, then welding commences working from left to right with the rod held in the plane of the V-groove and at right angles to it, but tilted slightly to the left so that it forms a radius as it feeds into the groove: the welding torch is aimed along the groove so that it softens both the sheet and the welding rod and moved in a circular manner at approximately 2 cycles per second to heat both the rod and the sheet—experience will dictate the relative dwell on sheet and rod to give optimum even softening, since this varies with thickness of sheet and diameter of rod: the greater this is, the longer dwell, proportionately, it must receive for softening. As the polythene melts, and fuses, the rod is moved from side to side (approximately 2 cycles/sec.), so that efficient mixing and fusion of the components is achieved. The speed of welding is ⅝″ per minute.

2) Sraight Fillet Welding The method for this is identical with (1) with the exception that the rod is not moved from side to side. This results in a slightly weaker but neater weld and is best suited to multi-runs and fillets: it means further that high speed welding nozzles can be used with Vitrathene sheet.

Both methods (1) and (2) can be illustrated by:



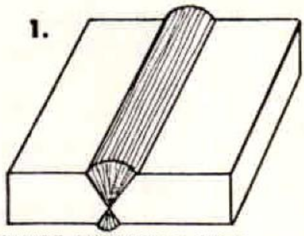
3) Twist Welding In this method, welds are made towards the welder. The rod is held at right angles to the V-groove and at an angle of about 60° to the sheet. The nozzle is pointed along the groove (see para. (1) concerning ratio of heating and movement of the torch) and the rod is slowly but continuously rotated in an anti-clockwise direction: the welding proceeds toward the welder. It is considered that this method ensures better mixing of the molten polythene but options differ on this: speed of welding is about the same as for ripple welding. This may be illustrated by:



If required, welds may be dressed level with the sheet by means of a sharp knife to improve appearance but, of course, the strength is decreased.

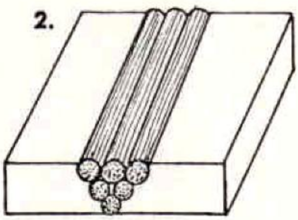
The various types of weld suitable for Vitrathene sheet are:

1.



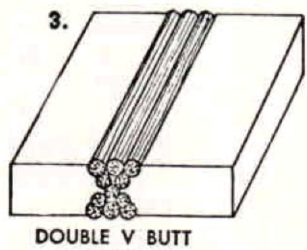
SQUARE BUTT WELD WITH SEALING RUN ON UNDERSIDE

2.



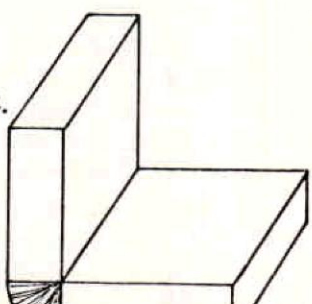
SINGLE V BUTT WELD (MULTIPLE RUN)

3.



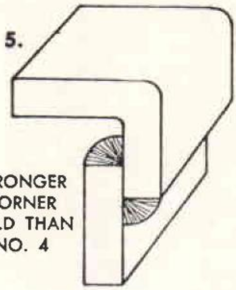
DOUBLE V BUTT WELD

4.



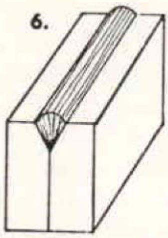
CORNER WELD

5.



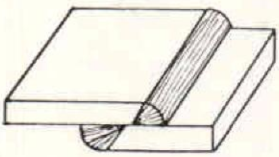
STRONGER CORNER WELD THAN NO. 4

6.



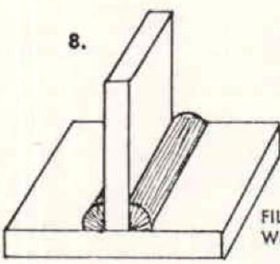
EDGE WELD

7.



LAP WELD

8.



FILLET WELD

Forming Thin gauges of Vitrathene sheet are amenable to vacuum forming although the sharp melting point of the material makes this a rather tricky process. Only experience and trial of any intended forming can decide whether vacuum forming is a viable process at any particular time.

All other types of established forming can be used with the sheet heated prior to forming in a suitable oven.

POLYTHENE SPLINTS

Polythene

Sheet polythene ⅛ inch, $^3/_{16}$ inch, and ¼ inch thick is a most useful material for the manufacture of lightweight semi-rigid orthopaedic appliances. It is a thermosplastic material and has a moulding temperature of 140°C. (284°F.). The sheet material used for surgical appliances (+) is tinted pink by the addition of 0.01 percent of a mixture of cadmium sulphide or cadmium sulphoselenide or both types of pigments; it also contains 0.101 percent of an antioxidant: diorthoisocresyl propane. Polythene is unaffected by fluids commonly used in industry; it is a tough, resilient material which is particularly suitable for use on patients who are able to remain at work during their treatment. Temperatures below 100°C. (212°F.) do not affect the appliances. Splints should not be placed in front of an electric fire or on top of a gas cooker, as temperatures in excess of 100°C. (212°F.) are easily reached and distortion of the appliance will result. While polythene can be ignited with difficulty—it burns with a yellowish smoky flame—the flame can be readily extinguished and its inflammability is in no way a hazard, since a flame has to be held in contact with the splint for up to a minute before ignition will occur. This material has been used for splints for 8 years (see page 5) and no case of allergy or dermatitis is known. Occasionally patients who sweat excessively may complain of irritation, but this is due to lack of ventilation holes in the splint or to inadequate washing of themselves or the splint. Excessive local pressure may cause reddening of the skin. Carefully controlled local heating of the appliance may sometimes relieve this pressure, but, unless extreme care is exercised, distortion of the appliance will result.

Equipment for the Manufacture of Appliances

The equipment required for making splints is minimal, but it is advantageous for speed and ease of manufacture of appliances in quantity to have the following equipment:

1. An infra-red process heating oven, size 4 feet 6 inches by 4 feet 6 inches. 64 x 250 watt internal reflector infra-red process heating bulbs will be required to cover 16 square feet. They should be held in suitable holders to give adequate ventilation of the stems of the bulbs and to give a clearance between the bulbs and the abestos covered floor of the oven of 12-14 inches. Since polythene is a poor heat conductor and the lamps give a high surface temperature, it is advisable to switch the current on and off intermittently by means of a time cycling device. Suitable ovens are now commercially available. Various other types of gas or electric ovens can be improvised, but it is essential that even heating of the polythene is obtained and that the temperature of the material does not rise above 150°C. (302°F.). Experimental work with porous plastic suggests that a hot-air circulating oven may be a more suitable way of heating these materials.

2. A foot-operated punching and riveting machine with a throat of not less than 12 inches. ⅛ inch, $^3/_{16}$ inch, and ¼ inch punches are required. This machine can be used for the insertion of tubular rivets, eyelets, press studs, and for punching ventilation holes; the latter operation should be done from the foam surface of the appliance.

3. A bandsaw for cutting the polythene. This machine should have a throat of not less than 18 inches.

4. A 6 inch soft wire mop and sanding discs attached to a standard double-ended polishing head.

5. A leather worker's knife and whetstone.

6. Ribbed surgical stockinet, width 12 inches, as used for plaster work.

7. A medium to coarse metal file and various grades of sandpaper.

Polyurethane Foam

Polyurethane foams are thermoset materials. Various densities of foam are available, the most satisfactory one for orthopaedic purposes having a specific gravity of between 0.055 to 0.065. It is fully porous to water vapor, readily compressed and almost non-inflammable. Temperatures up to 170°C. do not affect its properties and when it is used in combination with polythene, only distortion of its cellular structure occurs during moulding. Because of its extremely low thermal conductivity, polythene-polyurethane laminates can be applied directly to the patient, providing the temperature of the polythene does not exceed 140°C. The laminate is applied with the polyurethane in contact with the skin. If excessive pressure which would collapse the foam is used to form the splint, burns may result; hence only splints having simple curves, for example, cock up splints or leg gutters, can be moulded with safety on the patient. For larger splints, such as spinal jackets, long leg splints, cervical collars and hip spicas, a positive plaster cast is essential.

Forming the Splints

A piece of polythene of the appropriate size is cut with the bandsaw, or less easily with a sharp leather knife. If a knife is used, care should be taken that cuts are not made in the polythene by the knife, as these can cause subsequent cracking in the material. Such cracking is more liable to occur following knife trimming of the splint after moulding. The direction of pull of the knife should always be away from that part of the sheet which is to form the splint. The polythene should be washed with warm water and soap so as to remove any dust or grease which may contaminate the surface and prevent adhesion of either the reinforcing strip or the polyurethane. A sheet of the foam, the overall dimensions of which are about ¼ inch to ½ inch greater than those of the polythene sheet, is placed in the oven and covered with the polythene. Reinforcing strips of polythene which are obtained from offcuts are placed in the appropriate positions on top of the polythene.

To establish the working conditions for a particular oven, the time-temperature relationship should be recorded by inserting in the sheet of polythene a thermo-couple connected to a pyrometer. The temperature of the polythene cannot be recorded by placing mercury thermometers on the surface of the sheet if infra-red heating is employed. When the polythene is ready for moulding, both the reinforcing strip, if present, and the main sheet of polythene should be transparent. If any bubbles occur between the reinforcing strip and the main polythene sheet, they should be pricked with a pin to let out the air. A piece of stockinet is applied, using light pressure, to the surface of the polythene. The stockinet should not be unduly stretched and care should be taken to see that creases are not produced. The stockinet-polythene-polyurethane laminate is lifted from the oven and is applied to the plaster cast. It is then gently stretched into position and a few nails are driven into the cast through the moulding at convenient points to hold it in position. When the moulding has cooled, the stockinet is stripped from the surface of the polythene and the splint removed from the cast. The edges are trimmed, ventilation holes are punched in appropriate places and buckles and straps riveted in position. Ventilation holes, ⅛ inch in diameter, should be drilled or punched in areas which are carrying a load, in other parts of the splint larger holes may be made. Leather or plastic tongues, where the splint edges comes together in encircling splints, should be attached to prevent nipping of the skin.

When moulding small splints direct on the patient, the operator should always check that the laminate is not excessively hot by resting the foam side of the laminate on the back of his own hand for a few seconds prior to moulding it on the patient. For patients who may be apprehensive on this procedure, a sheet of $^{1}/_{16}$ inch polyurethane may be applied to the patient and held in position by adhesive tape prior to forming the hot laminate. The laminate is then moulded by applying even, wet 2-inch cotton bandages.

Addendum

Polythene splints have been in use for fifteen years. It has been found that for hot countries it is preferable not to line the splint with a foam material. Unlined splints should be well ventilated with ⅛ inch drill holes and **washed frequently.**

The most secure buckles are those with prongs piercing the strap. However, both splints and clothes are damaged, while the plain buckles without prongs are liable to slip. A most effective fastening which overcomes most buckle problems is the "touch and close" fastener, known as Velcro. The two parts of this nylon fastening material are stuck or sewn on to strips of plastic or leather, or used by itself. Providing it is kept clean, this fastening material will perform satisfactorily for a considerable time.

For neck supports, P.V.C. strapping carrying a ¾ inch adjustable press stud is most useful.

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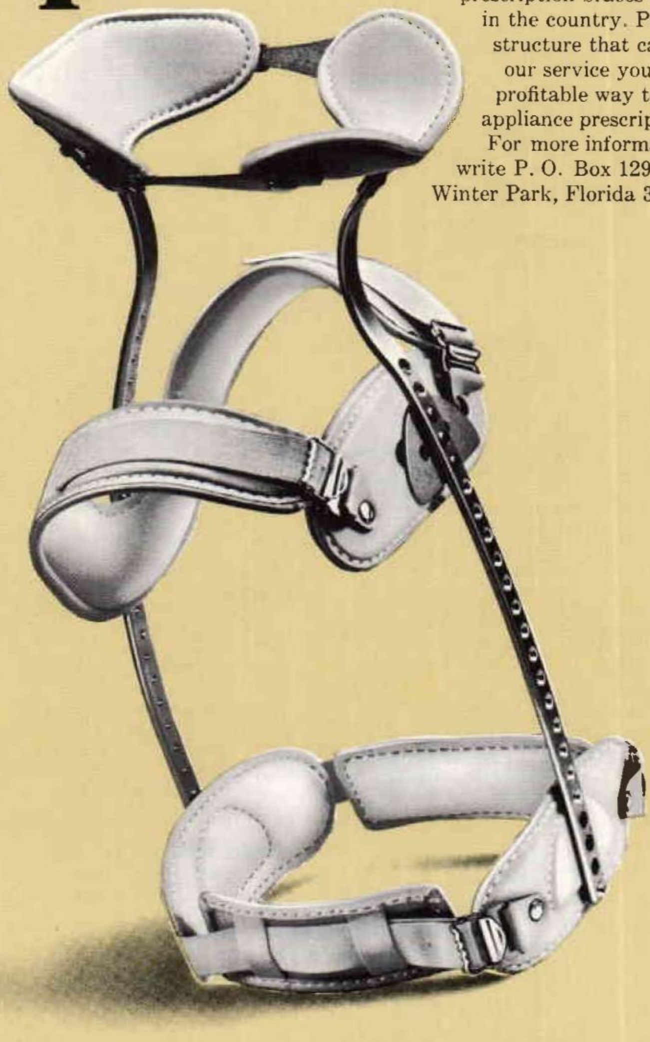

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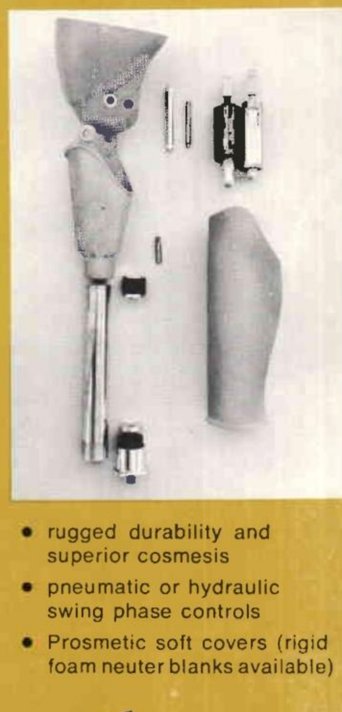

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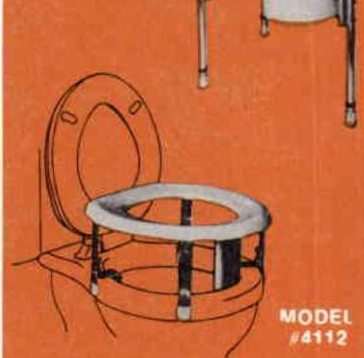

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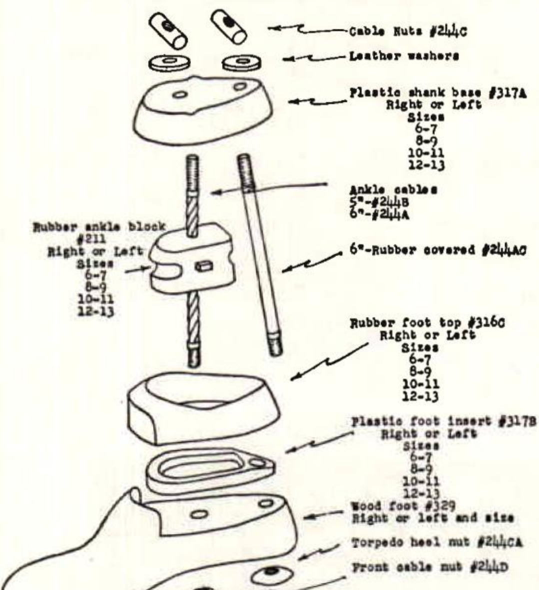

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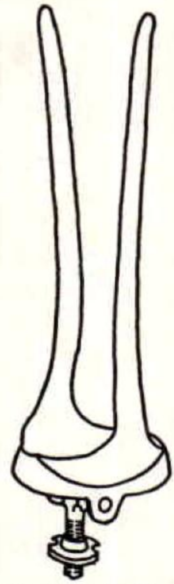

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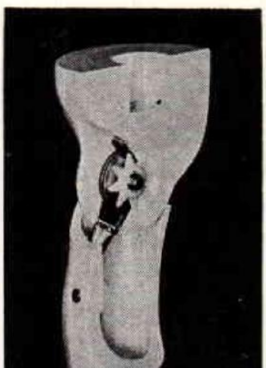

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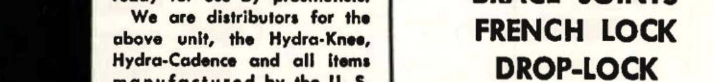

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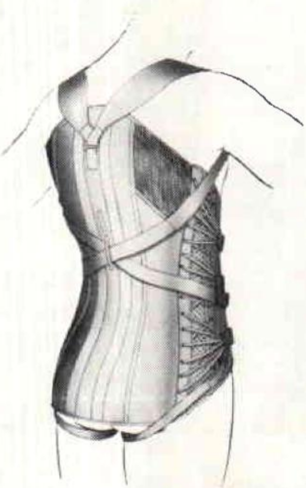

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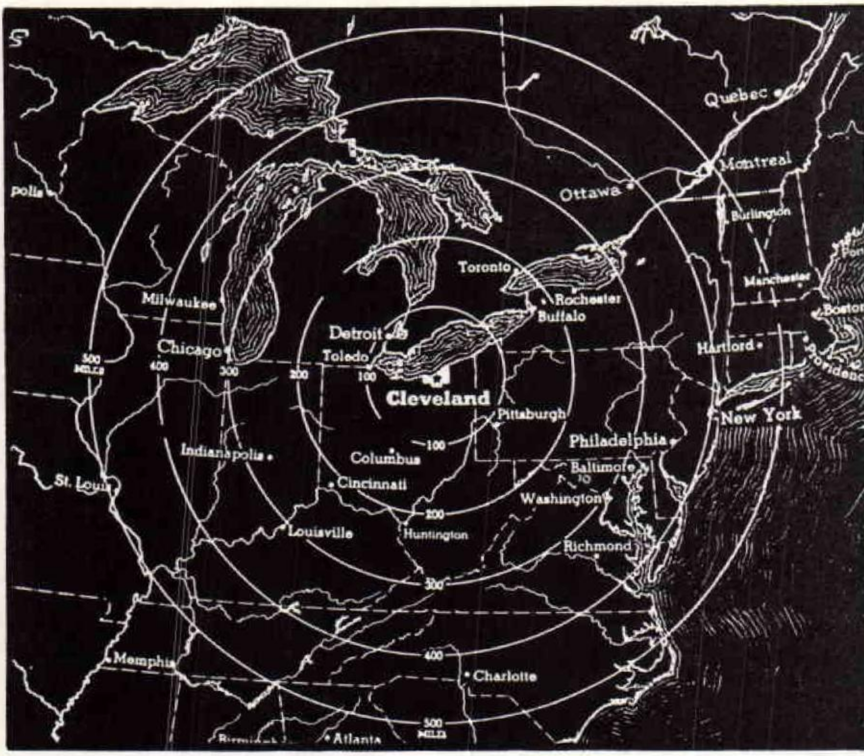

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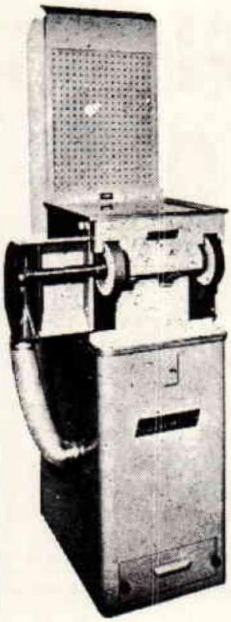

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The Editor

The 1970 NATIONAL ASSEMBLY of the

AMERICAN ORTHOTIC AND PROSTHETIC ASSOCIATION

will be held

SEPTEMBER 30 to OCTOBER 3, 1970

at the

PORTLAND HILTON HOTEL

PORTLAND, OREGON

For Program Details and Registration Information
write to

The American Orthotic and Prosthetic Association

1440 N Street, N.W.

Washington, D. C. 20005

The Assembly is open to all who are interested in the
rehabilitation of the orthopedically disabled

Prosthetics and Orthotics

New York University Post-Graduate Medical School

Course Schedule

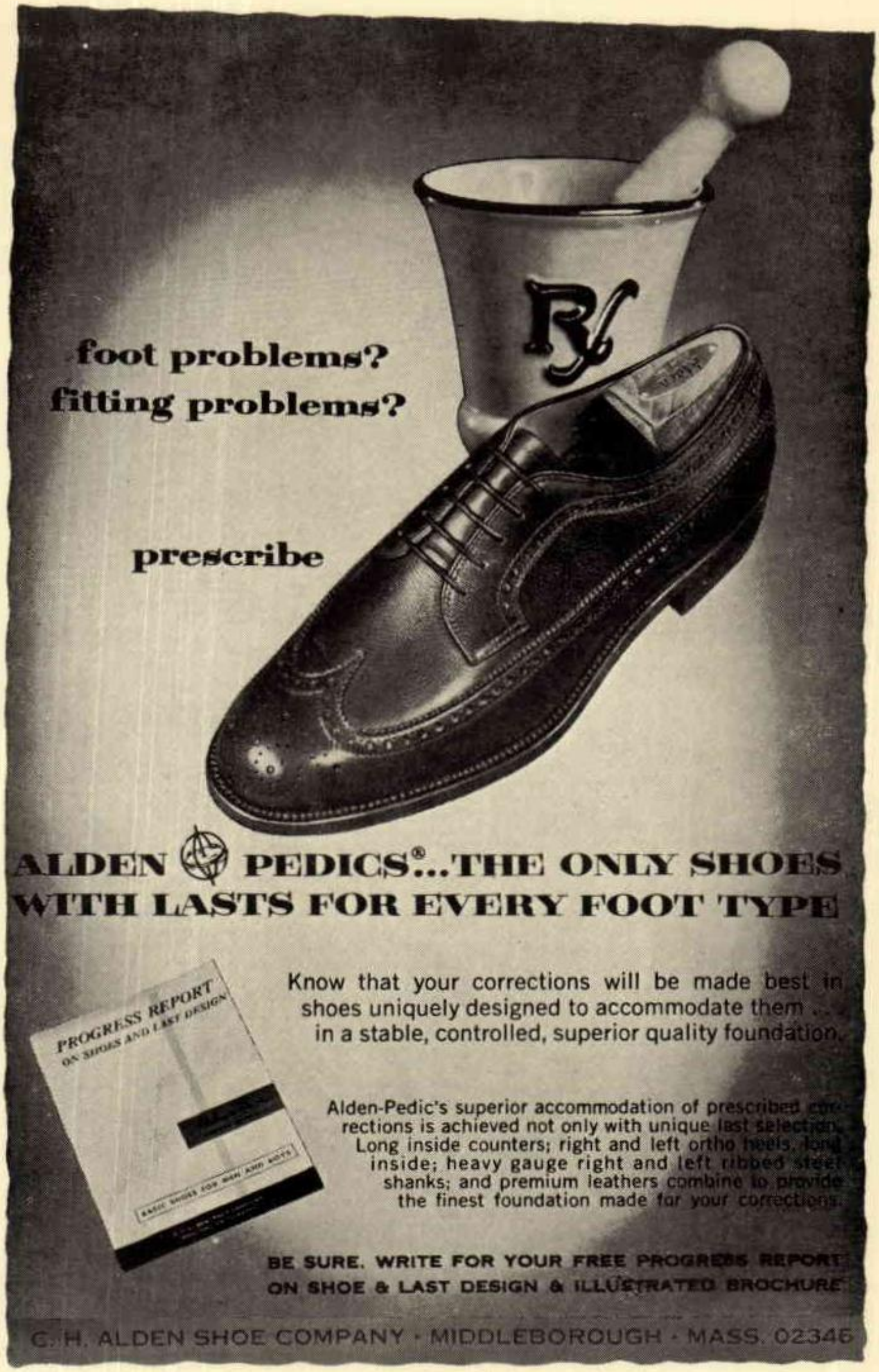
1970

Aug. 24-Sept. 11	740A	Below-Knee Prosthetics (for Prosthetists)
Sept. 14-18	7402A	Advanced Below-Knee Prosthetics (for Prosthetists)
Sept. 14-25	742A	Lower Extremity Prosthetics (for Therapists)
Oct. 5-9	751A	Lower Extremity Orthotics (for Physicians and Surgeons)
Oct. 5-9	752A	Lower Extremity Orthotics (for Therapists)
Oct. 19-24	741A	Lower Extremity Prosthetics (for Physicians and Surgeons)
Nov. 2-6	750B	Prosthetics & Orthotics (for Rehabilitation Counselors)
Nov. 2-13	742B	Lower Extremity Prosthetics (for Therapists)
Nov 16-21	741B	Lower Extremity Prosthetics (for Physicians and Surgeons)
Dec. 2-4	755A	Spinal Orthotics (for Physicians and Surgeons)
Nov. 30-Dec. 11	745A	Upper Extremity Prosthetics & Orthotics (for Therapists)
Dec. 7-11	744A	Upper Extremity Prosthetics & Orthotics (for Physicians and Surgeons)

1971

Jan. 4-8	7531A	Advanced Lower Extremity Orthotics (for Orthotists)
Jan. 11-22	756A	Spinal Orthotics (for Orthotists)
Jan. 25-29	7402B	Advanced Below-Knee Prosthetics (for Prosthetists)
Feb. 1-12	742C	Lower Extremity Prosthetics (for Therapists)
Feb. 22-27	741C	Lower Extremity Prosthetics (for Physicians and Surgeons)

Mar. 22-26	751B	Lower Extremity Orthotics (for Physicians and Surgeons)
Mar. 22-26	752B	Lower Extremity Orthotics (for Therapists)
Mar. 22-24	7411B	Immediate & Early Postsurgical Prosthetics (for Physicians and Surgeons)
Mar. 22-27	7401B	Immediate & Early Postsurgical Prosthetics (for Prosthetists)
Mar. 31-Apr. 2	755B	Spinal Orthotics (for Physicians and Surgeons)
Mar. 29-Apr. 9	745B	Upper Extremity Prosthetics & Orthotics (for Therapists)
Apr. 5-9	744B	Upper Extremity Prosthetics & Orthotics (for Physicians and Surgeons)
Apr. 19-23	751C	Lower Extremity Orthotics (for Physicians and Surgeons)
Apr. 19-23	752C	Lower Extremity Orthotics (for Therapists)
Apr. 28-30	755C	Spinal Orthotics (for Physicians & Surgeons)
May 3-7	750D	Prosthetics & Orthotics (for Rehabilitation Counselors)
May 3-14	742D	Lower Extremity Prosthetics (for Therapists)
May 17-22	741D	Lower Extremity Prosthetics (for Physicians and Surgeons)
May 17-28	753B	Lower Extremity Orthotics (for Orthotists)
June 1-5	7531B	Advanced Lower Extremity Orthotics (for Orthotists)
June 7-25	743A	Above-Knee Prosthetics (for Prosthetists)
June 28-July 2	7402C	Advanced Below-Knee Prosthetics (for Prosthetists)
July 12-23	746A	Upper Extremity Prosthetics (for Prosthetists)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