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.

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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 functional efficiency and reliability.

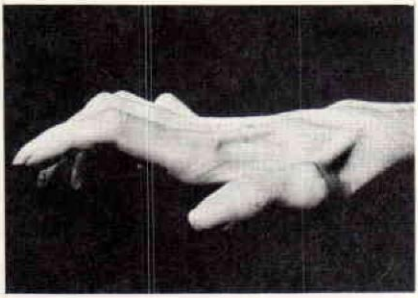

Fig. 1—Illustration of hand with severe muscle imbalance.

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 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).

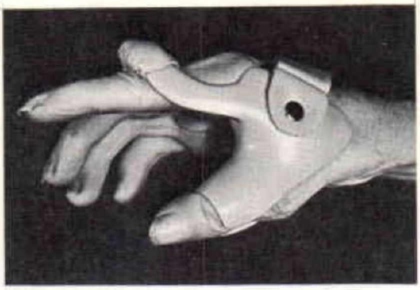

Fig. 2—A short opponens orthosis supports the metacarpal arch, the lumbrical muscles, and the opponens muscle group.

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-

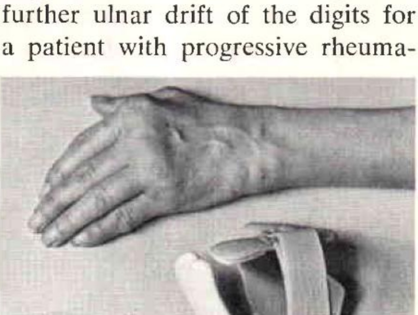

Fig. 3—Rheumatoid arthritic hand with ulnar deviation is shown without the orthosis applied.

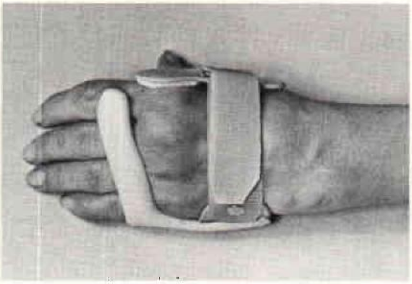

Fig. 4—Ulnar deviation is minimized with orthosis applied, and further deformities are prevented.

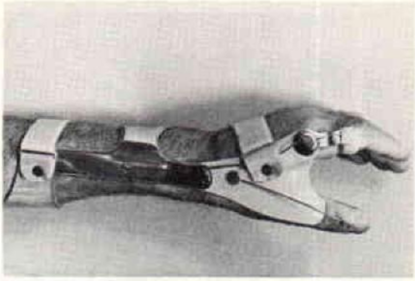

Fig. 6—Orthosis provides dynamic assistance in thumb abduction, wrist extension, and in the proximal volar phalangeal joints.

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

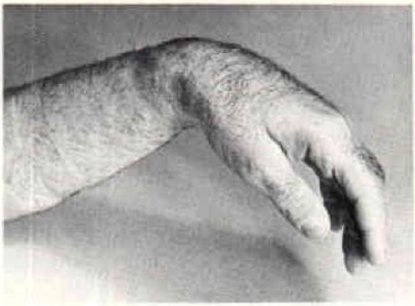

Fig. 5—Illustration of typical hand with radial palsy.

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 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

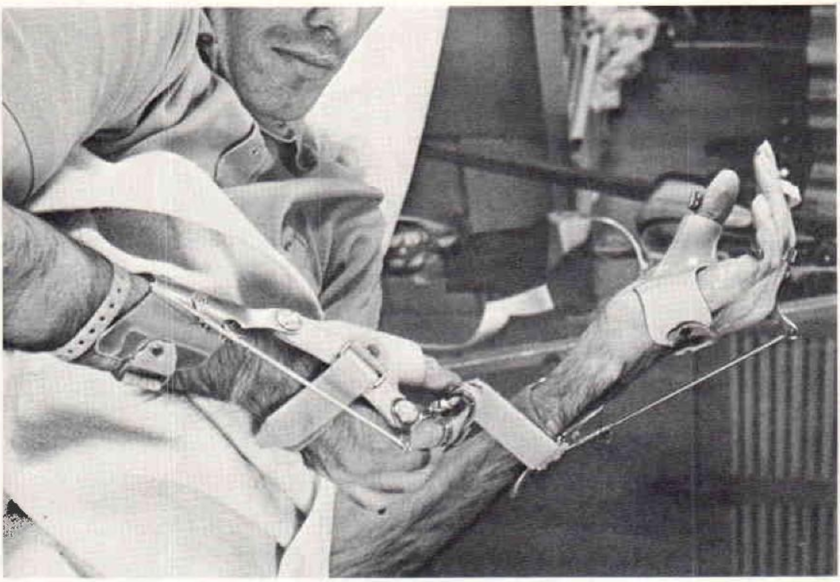

Fig. 7—Early adaptation of the reciprocal orthosis for a quadriplegic patient.

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

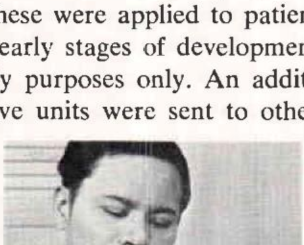

Fig. 8—Orthosis used for self-feeding.

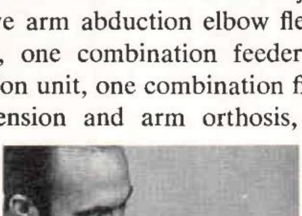

Fig. 9—Patient uses the orthosis to resume his education.

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

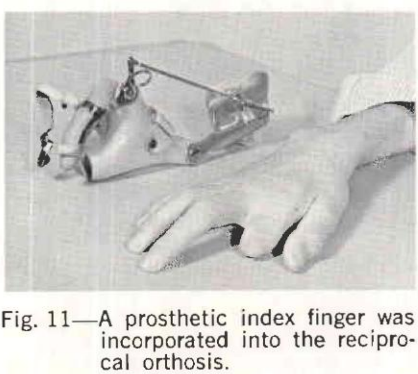

Fig. 11—A prosthetic index finger was incorporated into the reciprocal orthosis.

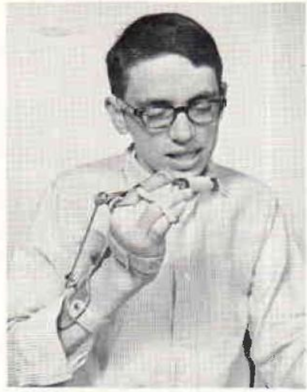

Fig. 12—The patient can now use a standard toothbrush with a swivel head, as well as write and manipulate small objects.

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-

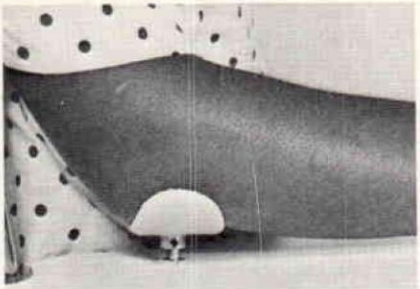

Fig. 13—Example of control site for powered arm orthosis.

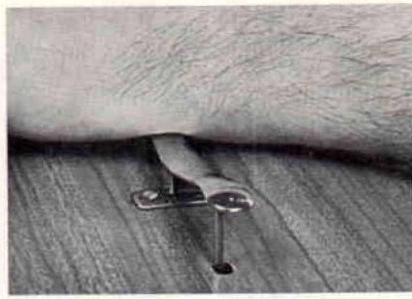

Fig. 14—Example of control site for powered finger prehension orthosis.

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.

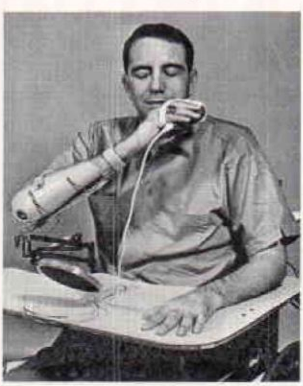

Fig. 16—Patient using powered arm orthosis.

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

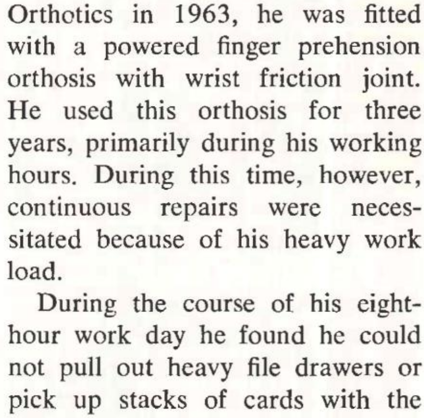

Fig. 18—The special powered hook enables C. L. to perform all facets of his work as a computer programmer.

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

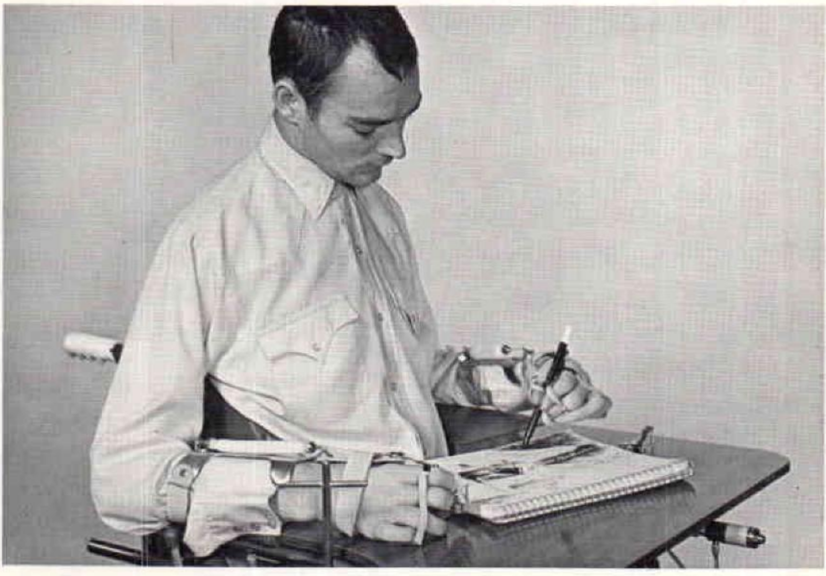

Fig. 20—Patient D. W. sketching, using bilateral finger prehension orthoses.

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.

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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

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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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