prosthetist, and physical therapist, as to what is to be accomplished is of essence, but should provide final, gratifying results inherent in this method.

In closing, a word of caution: While the technic in its present stage as outlined above, is mature and sufficiently standardized to be used successfully by others, no attempt is made here to teach it or encourage its use. This is a report only on the current technic of immediate post-surgical prosthetic fitting and should be considered as such.

For clarification, the technic described here represents the current practices of the research team of the Prosthetics Research Study in Seattle, Washington, Ernest M. Burgess, M.D., Principal Investigator.

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Upper Extremity Orthotics: A Project Report †

by THORKILD J. ENGEN, C.O.*, LOUIS F. OTTNAT, C.O.**

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The Department of Orthotics of the Texas Institute for Rehabilitation and Research (TIRR), in affiliation with the Baylor University College of Medicine, has conducted a clinical research program over the past four years to develop upper extremity orthotic systems that meet the complex requirements of simplicity, functional efficiency, and cosmetic acceptability. Existing components have been modified or redesigned and new components have been created in the process of developing individualized systems to meet a variety of patient needs. This paper will summarize improvements and innovations that have come about during the project period.

Engen Plastic Hand Orthosis

A promising achievement has been the development of a systematic method of hand splinting. A plastic hand orthosis, first described in 1959,[1] has been further developed and clinically evaluated during the project. It is

† Based upon a paper presented at the National Orthotic and Prosthetic Assembly, October 16-20, 1966, Palm Springs, California. The project was supported in part by Vocational Rehabilitation Administration Grant RD-1564. The facilities of the General Clinical Research Center for Chronic Illness were used in part for this project. The Center is supported by PHS Grant FROO-129 and Grant RT4 from V.R.A.

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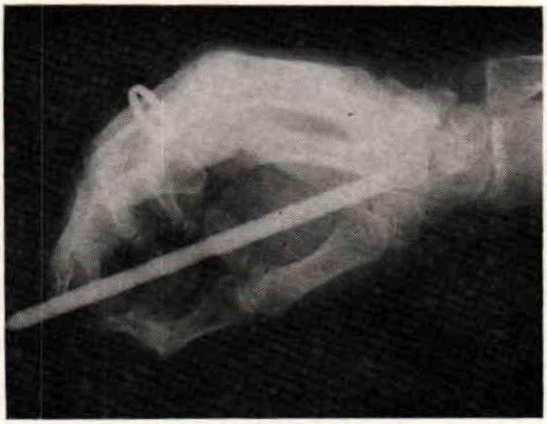

FIGURE 1

designed to serve as a standardized, mass-produced base unit that can be individually adapted. Various components can be added to meet the individual patient's requirements.

The present design of the plastic hand orthosis evolved from cineradiographic analysis [2] of normal hands in motion holding common objects (e.g., writing with a pencil (Fig. 1), self-feeding with an eating utensil, manipulating papers, pliers, and scissors, and using larger objects such as a drinking glass). This analysis provided a clearer understanding of the integrated musculoskeletal functions as they relate to normal activities and served to indicate where support could be given with the least hindrance to normal functional patterns.

With knowledge gained from the cineradiographic study, a standardized module was developed to serve as a foundation for various orthotic systems (Fig. 2[1]). Made of laminated polyester resins, this orthosis provides basic support to the metacarpal arch and the opponens muscle group, yet it allows passive digital mobility. The composition of the plastic permits the unit to be heat-reshaped to conform to the contour of the patient's hand. The orthosis is made in four sizes from master molds for both right and left hands.

Improvements have been made recently in the manufacture of the orthosis. A modified casting technique yields an extremely smooth inner and outer surface, eliminating the need for spray-paint finishing. Reinforcing pieces, made of fiberglass instead of Monel as formerly used, are laminated with epoxy resin into the radial side of the hand orthosis to assure structural stability and good joint surfaces.

Clinical experience verifies that the plastic hand orthosis is a practical way of meeting the patient's needs with minimum equipment. It can be adapted for the prevention or correction of deformities and can be incorporated into systems which utilize dynamic or external power (Fig. 2). The use of the prefabricated orthosis has greatly simplified individual fitting procedures. Although many problems were encountered in the early phase of its development, the practicality and soundness of the concept of using a prefabricated hand orthosis has been demonstrated in approximately 500 clinical applications.

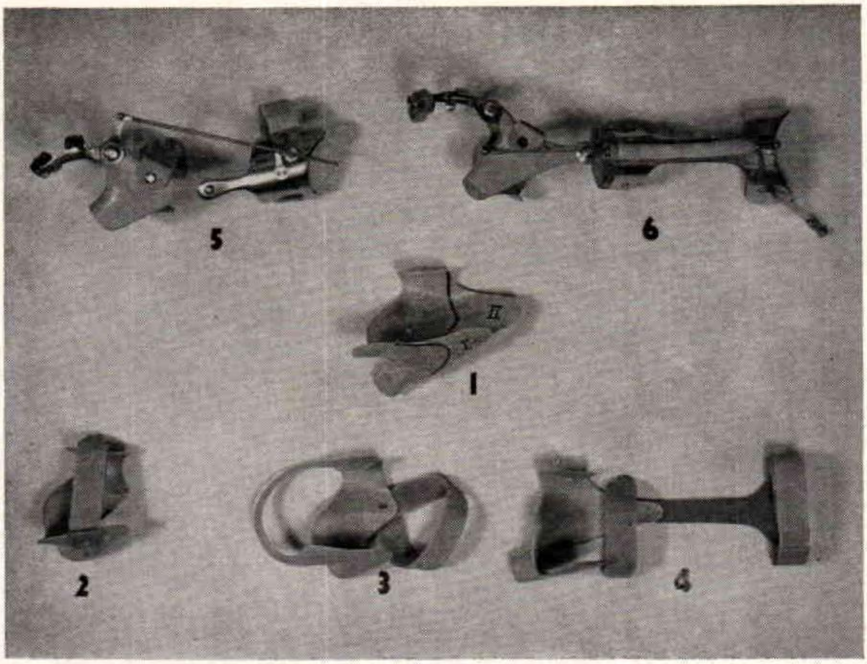

FIGURE 2

Illustrative Uses of the Plastic Hand Orthosis

Muscle imbalance due to neuromuscular disorders often results in malpositioning of the thumb and hyperextension of the metacarpophalangeal joints. Correction of this deformity may require permanent orthotic assistance, although temporary therapeutic or functional assistance during retraining is often adequate. By a simple trimming procedure, the plastic orthosis can be adapted into a short opponens and metacarpal support to realign the metacarpal arch and thumb opposition, thus preventing undesirable deformities and restoring useful function of the hand (Fig. 3).

Because of its form-fitting characteristics, the orthosis can be used for attachment of additional devices, such as a lumbrical support, or in conjunction with dynamic finger-extension assistance (Fig. 4). It can correct existing problems while preventing others, a factor that is vital to the patient's total program.

Figures 5 and 6 illustrate the plastic hand orthosis adapted to a patient presenting severe ulnar deviation of the metacarpalphalangeal joints due to rheumatoid arthritis. Passive volar and dorsal phalangeal support is incorporated for the purpose of correcting and preventing further deformity. The orthosis provides an excellent foundation for these corrective forces.

Another example of the systematic use of the plastic hand orthosis is seen in the patient with peripheral nerve injuries such as radial palsy. During the recovery and retraining period of such a patient, dynamic assistance is usually needed in thumb abduction, wrist extension, and the proximal volar phalangeal joints. This impairment may be either a temporary or a permanent condition, but in either case the type of device shown in Figure 7 is extremely helpful in maintaining or recovering hand and forearm functions.

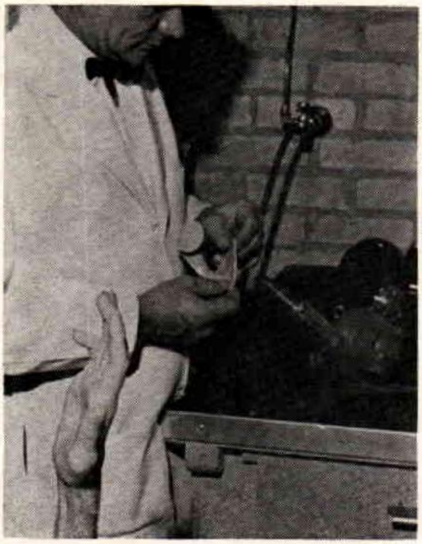

FIGURE 3

When the problem is one of restoration of function, it is important as always to utilize the patient's residuals as much as possible. For example, the patient with active wrist extension but no finger movement can have hand functions restored by reciprocal wrist extension-finger flexion orthosis. The action of wrist extension is utilized to bring about finger flexion by a simple mechanical linkage. Again, the plastic hand orthosis forms an integral part of the system.

The reciprocal unit has been improved as a result of knowledge and experience gained in the present research project. The functional limitations of the original orthosis were a confined range of motion within a fixed structural alignment of the hand in relation to the forearm. The cineradiographic analysis mentioned above served to emphasize the importance of the hand-to-forearm relationship in functional activities and resulted in the design of an adjustable telescopic rod which was developed in 1963 and described in 1964.[3] This orthosis gives the patient prepositioning ability and permits finely adjusted finger prehension so that a wide range of activities can be performed from holding a cup to picking up paper (Figs. 8 - 9). The adjustable telescopic unit is activated by the patient's opposite hand or by pressing the activating button against a stable object such as a lapboard. This releases the telescopic rod and enables new positioning of the hand. Release of pressure locks the rod in the new position. Approximately 375 adaptations of this orthosis have been applied and clinically evaluated. At
ties can be performed from holding a cup to picking up paper (Figs. 8 - 9).
TIRR, the patient who is a candidate receives his finger prehension orthosis as early as possible, even while in bed or in a reclined position. This has proved to be of great psychological value by permitting the patient to be engaged in purposeful activities during some part of the day.

Patients can be divided into three categories which typify the objectives of application of the reciprocating finger flexion orthosis. In the first group, the orthosis is applied in an early stage of convalescent care, and the patients gain enough residual movement so that eventually the orthosis is not needed. The second category use the orthosis for therapeutic value and

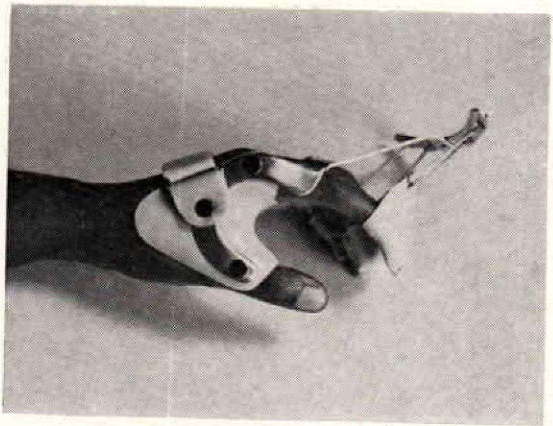

FIGURE 4

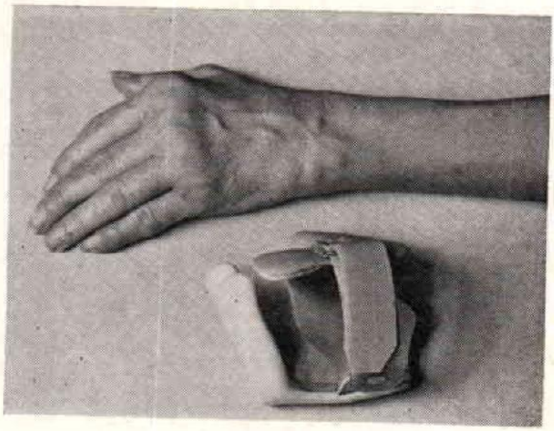

FIGURE 5

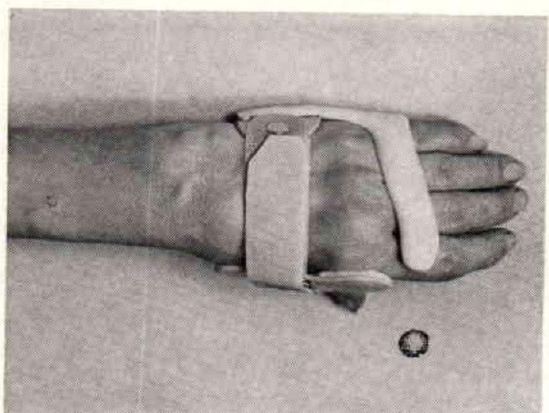

FIGURE 6

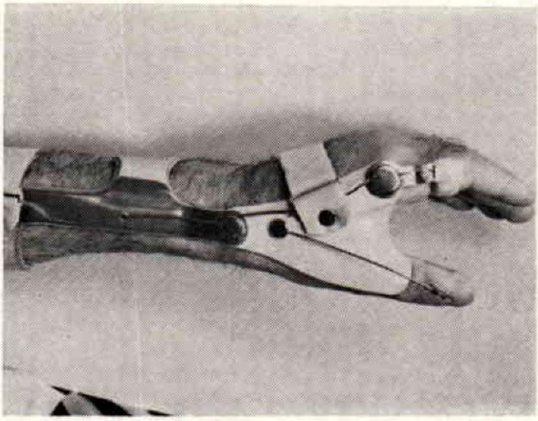

FIGURE 7

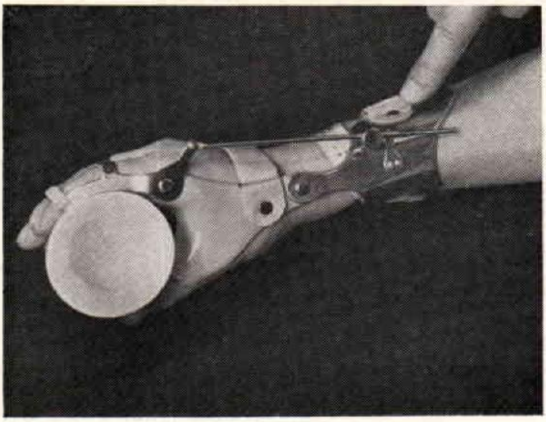

FIGURE 8

FIGURE 9

FIGURE 10

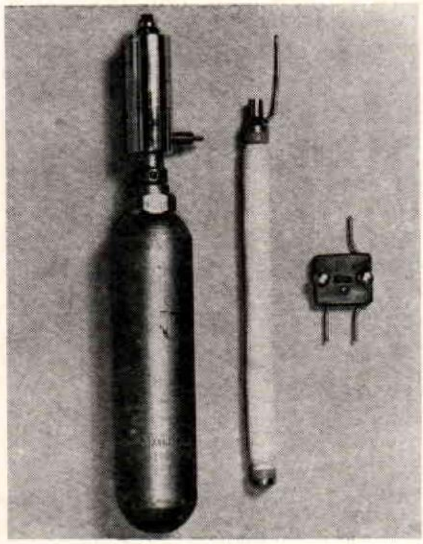

FIGURE 11

find that while they have enough residual function to carry out gross activities, they depend upon the orthosis for writing and manipulating small objects. The third group of patients, which constitute the majority, remain totally dependent upon the orthosis for all functional activities (Fig. 10).

In all the applications it is imperative that the patient be thoroughly trained in the practical use and limitations of the equipment. This essential phase of the rehabilitation program is carried out at this institution through close collaboration of the Orthotics Department with Physical Therapy and Occupational Therapy.

External Powered Orthotics

Many patients survive with severe functional deficit of the upper extremities as a result of trauma in the cervical region of the spinal cord, polio, or other pathological reasons. The only practical method of dealing with the functional problem in these cases is by the use of external power. Several extremely promising and significant programs in the development of externally powered systems are being conducted, nationally and internationally, in the fields of both orthotics and prosthetics.[4, 5, 6, 7, 8, 9, 11, 12] The project discussed here has dealt exclusively with the development of orthotic systems employing pneumatic power.

Patients with spinal cord severance at the C-5, 6 level maintain almost normal movement in the shoulder and upper arm but have a chronic functional deficit of the hand and wrist. An externally powered finger prehension orthosis with wrist friction joint has proved beneficial in restoring function to this group of patients. The major components of the system (Fig. 11) consist of the power actuator in the form of the McKibben Muscle Substitute,[10] compressed carbon dioxide as a source of energy, and a specially designed control valve for activation.[4] The activating mechanism is a simple mechanical valve consisting of a spring-loaded arm which occludes a small silastic tube to stop or permit the flow of gas under pressure. The control is located wherever the patient can operate it with the least conscious effort.

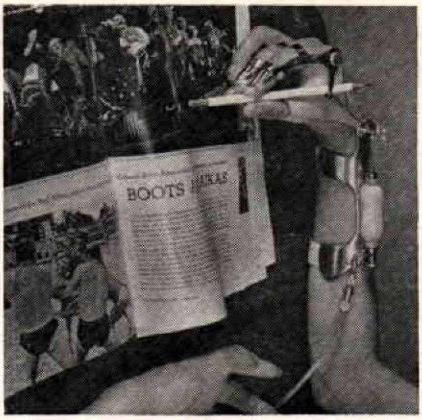

FIGURE 12

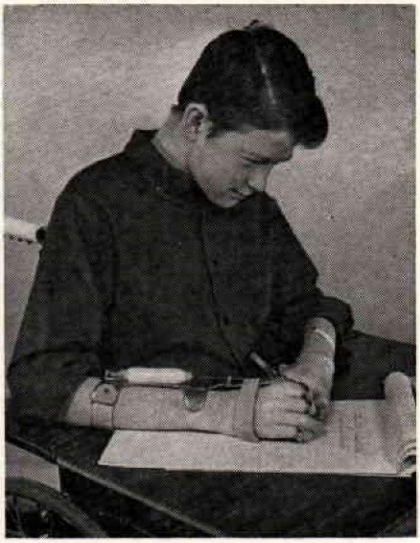

FIGURE 13

This system permits the patient to obtain smooth, gradual, and finely controlled movements of the powered functions that approximate normal motion. Four years of experience with this system has given convincing evidence that it provides the patient with substantial and reliable functional gain with minimal mechanical complexity, an important factor in meeting the requirements of cosmesis and acceptability by the patient.

The standardized plastic hand orthosis is routinely used as a Foundation for this finger prehension device. Versatility is increased by incorporating a friction joint at the wrist, permitting the patient to pre-position his hand voluntarily. The power actuator is located on the radial side and is attached by a cable to the distal end of the spring-loaded finger unit (Fig. 12). Upon contraction of the power actuator, the index and second fingers are moved toward the opposed stabilized thumb, resulting in a chuck-type prehension. This externally powered prehension orthosis has been adapted to 40 patients (Fig. 13). The unit is generally applied to the dominant extremity, though some have been used bilaterally.

An externally powered arm orthosis has been developed for patients who have lost all function in the upper extremities except the motion of raising and lowering the shoulder girdle. This situation occurs in patients with spinal cord lesions at the C-4, 5 level. Again, the patient's musculoskelatal structure is utilized as the biomechanical part of the device. Two power actuators are used in this system, one to flex and supinate the forearm and another to abduct the extremity. These are activated by the patient separately or in combination, depending on the movement he wishes to perform. The abduction unit utilizes the vector parallelogram principle, permitting horizontal movements independent of the powered elevation movement. A coil spring which minimizes the gravity forces imposed by the extremity is incorporated into the system to assist the power actuator in attaining maximum efficiency. The elbow flexion unit is linked to the abductor by a swivel arm. The proximal end of the power actuator is located slightly above the fulcrum of the elbow joint, and the distal end is attached near the radial side of the orthosis. When contracted, the orthosis produces the combined motion of elbow flexion

FIGURE 14

and supination (Fig. 14). Twelve arm units have been adapted and are being evaluated.

Patients will usually respond favorably to treatment programs while hospitalized, using their devices under supervision. It was desirable, however, to ascertain whether the equipment was being used as intended in their home environment. Questionnaires were therefore devised requesting information from patients at home regarding the powered equipment. Questions concerned functional use and acceptance of the system, problems encountered with the unit, and suggestions for improving the orthosis in design or usefulness. The questionnaires were mailed to 30 patients, and the replies strongly indicate the soundness of the external power concept.

Reported activities employing the orthosis include self-feeding, personal hygiene (brushing teeth, washing face, shaving, applying make-up, combing hair), and avocational activities such as playing cards, checkers, or dominoes, typing with electric or manual typewriter, turning pages, writing with ball point pen or pencil, and handling a telephone. Four patients are employed. Their occupations include account executive, computer programmer, office assistant, and housewife. Six others are attending school. Two of these are in high school and the rest are in college studying art, computer science, civil engineering, and electrical engineering.

The average length of wearing time at home is approximately five hours a day. Suggestions for improvement made by questionnaire respondents reflect individual needs and desires, since the goals the patient wants to accomplish determine the aid he expects from the unit. For example, one patient suggested that the lapboard be designed more individually to meet work requirements by adding a small drawer for utensils and other articles. It was gratifying to note that no one mentioned problems with discomfort or skin breakdowns.

Just a few years ago, restoration of worthwhile function to individuals with severe upper extremity impairment was mere wishful thinking. Today, although further research is needed to improve them, powered systems have already proved to be of great usefulness. External power has enabled the majority of quadriplegics seen in this project to at least perform activities of living from a wheel chair level. Many of them can perform avocational activities and some have become gainfully employed.

We have reached a plateau with our adaptations where numerous functions can be restored by these devices; but in order to establish a foundation for further progress, more knowledge is needed of joint relationships that occur in musculoskeletal action during normal upper extremity movements.

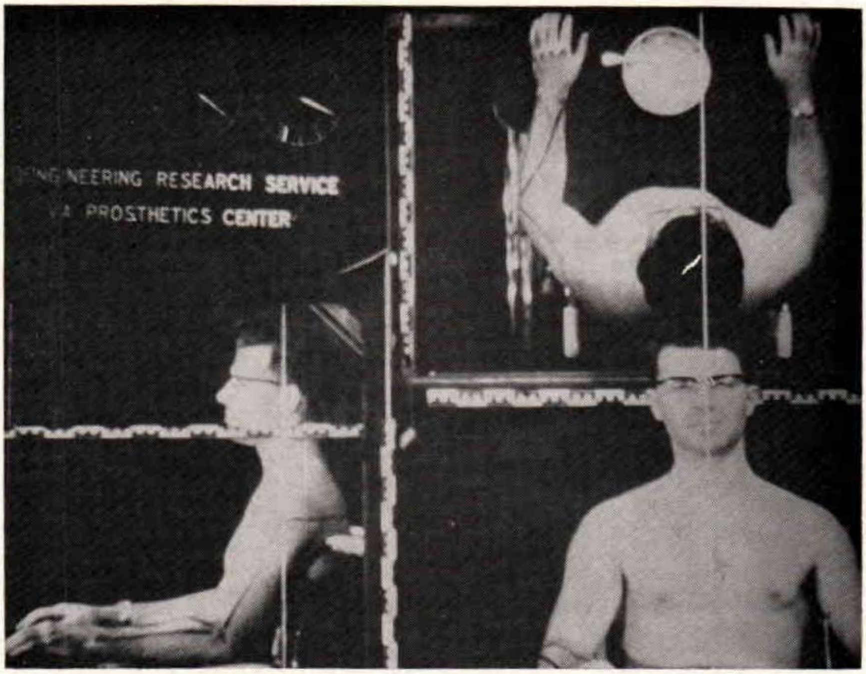

FIGURE 15

It is questioned whether our present designs incorporate sufficient degrees of mechanical range of motion and whether these motions are as well coordinated as in normal movements. Furthermore, lack of knowledge concerning head and upper torso involvement in these normal movements may result in the supplantation rather than maximum use of residual body functions. Attention to these issues will facilitate continued progress in the fields of orthotics and prosthetics.

Kinematic Studies

To investigate the aforementioned issues, the Department of Orthotics at TIRR is conducting studies of velocity and acceleration of the biomechanical functions of the upper extremities while purposeful daily activities are being performed. The objective is to study the functional coordination between the eye and the hand to obtain a better understanding of the requirements of orthotic components for maximum integration with residual body function.

In collaboration with the Bio-Engineering Laboratory of the Veterans Administration in New York, nine normal subjects have been photographed performing the five basic motions of table-to-mouth feeding, hair grooming, page turning, writing, and diagonal reaching from a sitting position. These activities involve three of the most important levels of hand movement: table, mid-torso, and head. To obtain a fairly representative sample of human physiology, subjects ranging from slightly obese to tall, thin individuals were used in the study. To determine whether the equipment hinders normal upper extremity movement, two identical sequences were taken of each subject, first without orthotic equipment and then with the arm orthosis without external power.

A 35 mm. movie camera was placed 20 feet from the subject. The addition of two mirrors positioned at 45-degree angles to the subject, one above the head and one at the side, made it possible to obtain three visual perspectives simultaneously: front, side, and top. Time clocks calibrated to one second and one hundredth of a second provided references for determining the velocity and acceleration of each motion. A black felt pen was used to identify the landmarks on the subject at the metacarpophalangeal joints, the styloid processes, the lateral epicondyle of the elbow, and shoulder joint (Fig. 15).

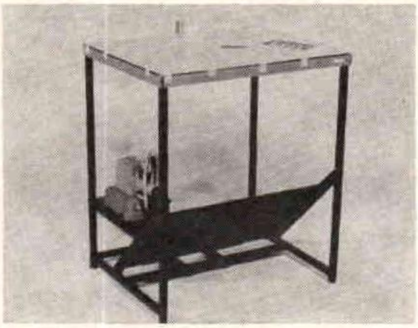

FIGURE 16

In analyzing the volume of film data, a special mirror arrangement and a standard film strip projector are used to project the three perspectives of the subject onto a glass screen covered with translucent acetate for plotting (Fig. 16). As the film is advanced frame by frame, the selected landmarks in each view are identified in black on the acetate. Once the action is completed, the plotted points are connected with lines to delineate the pattern of movements and the related angulation and acceleration between successive points.

The analysis utilizes only those motions whose points of reference are clearly visible in each view from beginning to end of the sequence. Figures 17 and 17a show the beginning and ending views of the diagonal reaching activity. The head movement is visible throughout the sequence, as are shoulder flexion and adduction and elbow extension. The plotted diagram, superimposed on both the beginning and ending view, graphically illustrates the sequential pattern of biomechanical activity. One notes the correspondence of acceleration and terminal deceleration between the head and forearm. The forearm accelerates rapidly in the beginning of the action and slows as it reaches the terminal point. The head moves similarly, while the hand remains in a neutral position throughout the activity. As the detailed analysis of these diagrams continues, measurements will be taken of the degree of angulation of the lines at each point of reference separated by equal time intervals but varying distances.

Another function being studied is hair grooming. This activity was separated into two phases, phase one showing the activity being performed on the right side of the head and phase two showing the subject grooming the left side. The beginning and ending motions of phase two are shown in Figures 18 and 18a with the interim movement pattern superimposed. In the begining motion, the hand is in the middle of the forehead; the shoulder is adducted horizontally, flexed and elevated; the forearm is slightly supinated; and the head is turned slightly to the right. It is evident that most of the activity occurs in the shoulder joint, but significant participation of the head and upper torso is also readily apparent, indicating the important

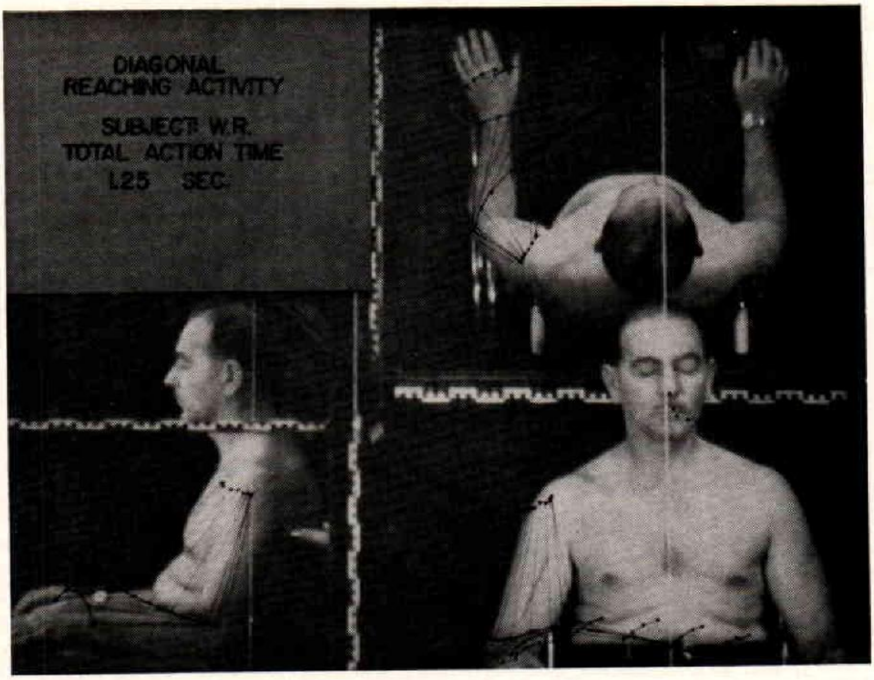

FIGURE 17

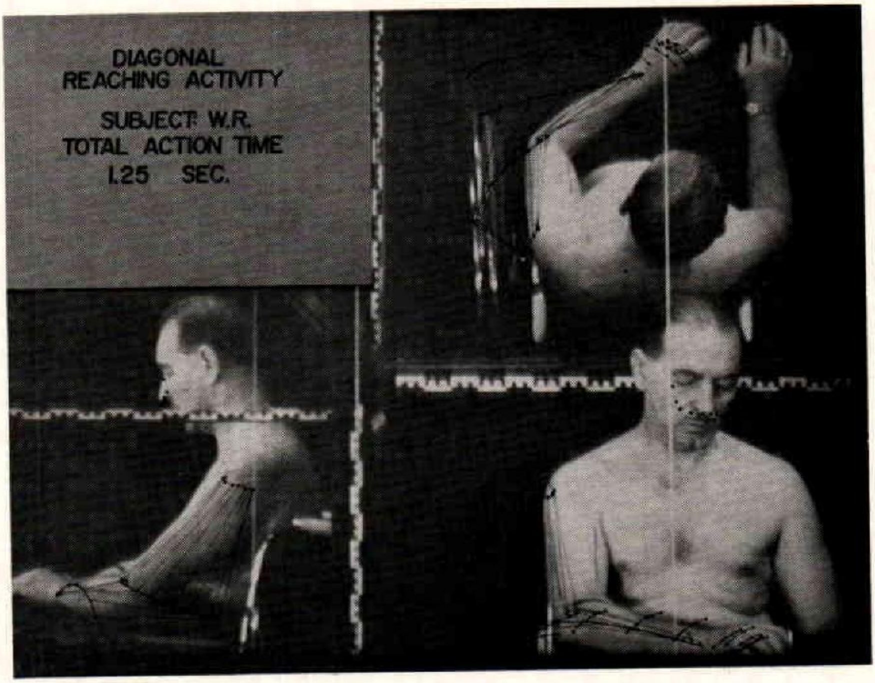

FIGURE 17A

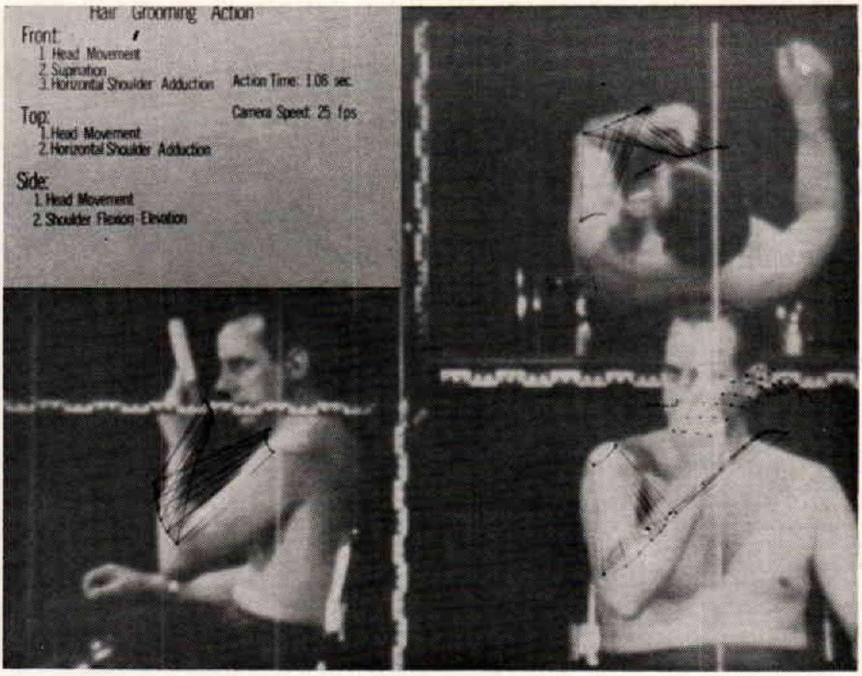

FIGURE 18

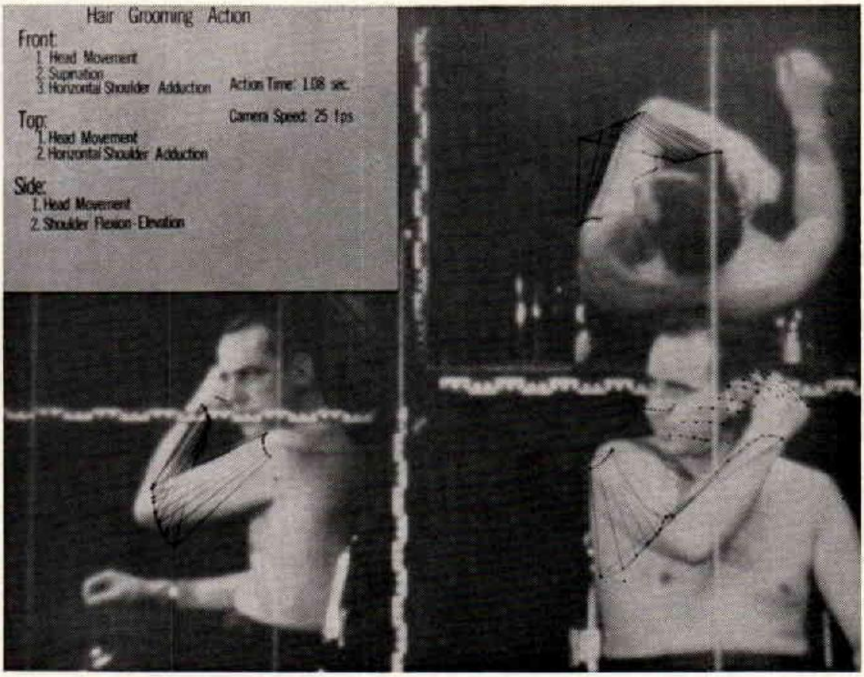

FIGURE 18A

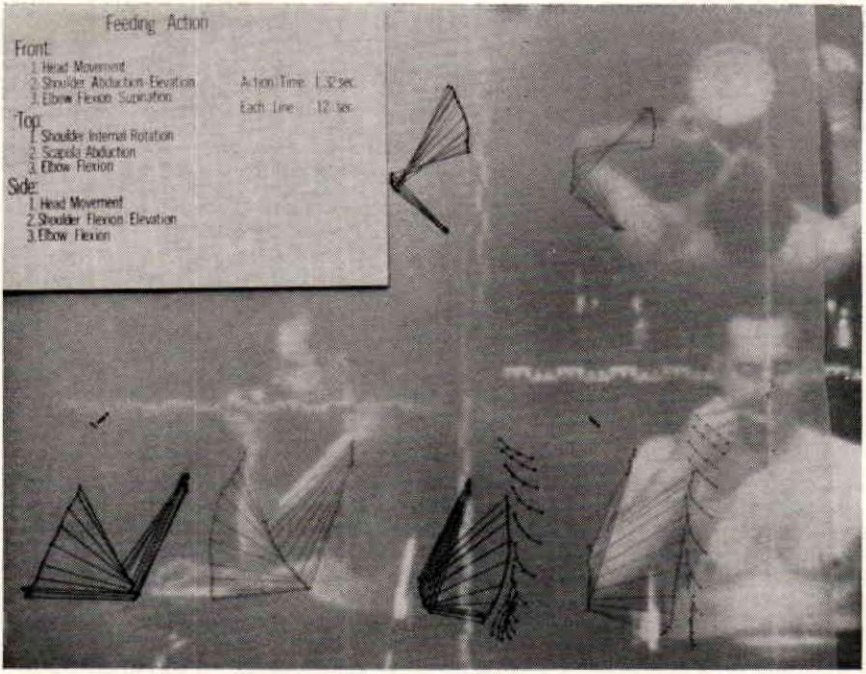

FIGURE 19

correlation of these functions. The head and torso movements are often overlooked as a part of the total pattern in this activity.

One of the functions most important to the severely impaired individual is self-feeding. This action is a combination of more synchronized joint motions than any other activity being studied. Head movement, abduction and elevation, internal rotation, and shoulder flexion are combined with elbow flexion, humeral rotation, and supination of the hand in this action. Figure 19 shows complete diagrams for two subjects performing self-feeding, the diagram for one subject superimposed adjacent to that of the other. Comparison of the two diagrams shows that the pattern of sequential movements is nearly identical in acceleration, velocity, and angulation. The only difference is in size of the diagrams, a factor determined by differences in the subjects' physical stature.

Analysis of the film data on three of the nine subjects has been completed. Analysis of the remaining data should establish a reasonably stable mean for each of the five patterns of movement. The same procedure will be followed in filming patients using powered assistance, and the diagrams thus obtained will serve as the basis for comparative analysis. Although this motion analysis is still in the preliminary stage, the evidence indicates that it will broaden our understanding of the biomechanical relationship between joints as purposeful activities are performed. It should identify the mechanical changes and design revisions needed to improve the overall function of the more sophisticated orthotic and prosthetic systems.

Adjunctive Developments

The plastic hand orthosis and its application in various upper extremity systems was selected by the National Research Council of the National

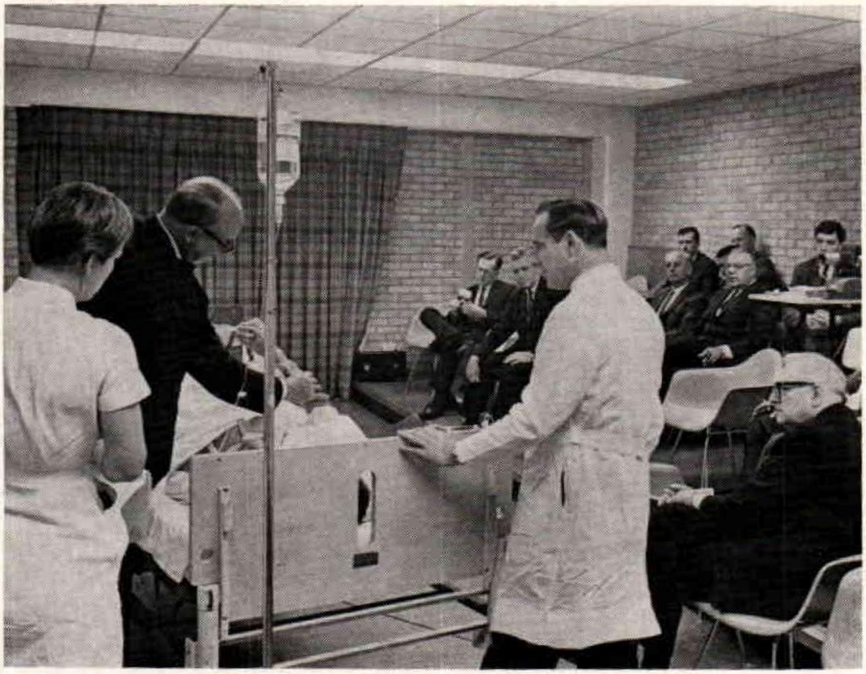

FIGURE 20

Academy of Science for inclusion in its field evaluation of research developments in orthotics and prosthetics. An orthotics course was held at TIRR in the Department of Orthotics in December, 1966. Four clinic teams of physicians and orthotists, selected by NRC, were given orientation to the clinical use of the plastic hand orthosis (Fig. 20). Detailed instruction was given in the fitting techniques for three devices in which the plastic orthosis is used: the short opponens, the long opponens, and the reciprocal wrist extension-finger flexion orthosis. These clinic teams were provided with a written project evaluation plan and components of orthotic systems to be applied and evaluated in their own institutions. At this writing the evaluation is still in process.

In August, 1965, a preliminary draft of an instruction manual was prepared which gave detailed instructions for utilizing and fitting the plastic hand orthosis and necessary components for a reciprocal wrist extension-finger flexion unit. This manual is now being revised because of recent equipment modifications and in the light of experience gained during the instruction course for the four clinic teams. This revision will involve expansion of the systematic approach to include application of the plastic hand orthosis as a foundation for numerous other orthotic systems. In addition, illustrations will be greatly improved through use of line drawings (Fig. 21).

Acknowledgments

This project could not have been conducted without the assistance and cooperation of the staff of Texas Institute for Rehabilitation and Research, especially the members of the Department of Orthotics. Special appreciation is extended to Dr. W. A. Spencer, Dr. P. R. Harrington, and Dr. L. A. Leavitt for their continued encouragement and technical advice at critical points

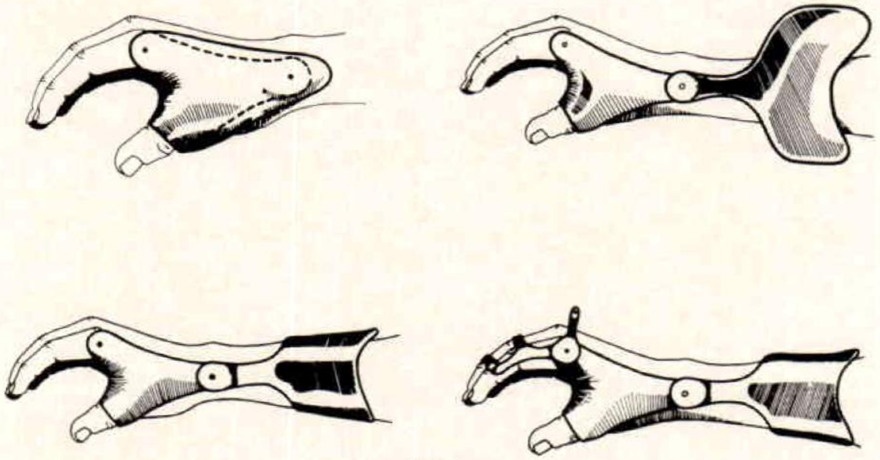

FIGURE 21

during the project, and in their consultative function on the TIRR Orthotic Committee. The editorial assistance of Dr. Kenneth E. Ware in preparation of the manuscript is gratefully acknowledged.

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