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Audrey J. Calomino

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March 1970

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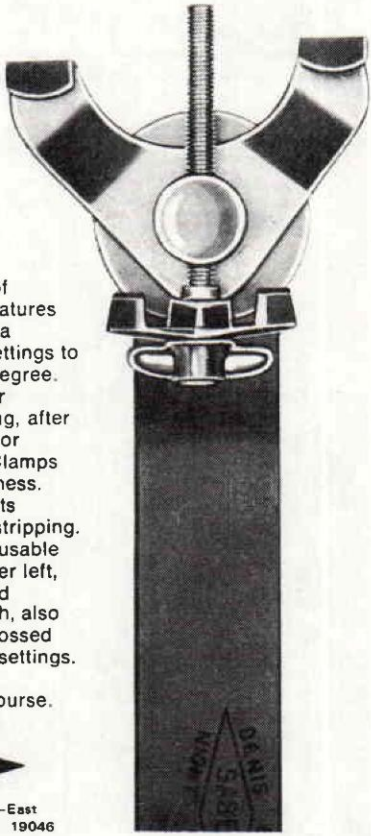

TOP VIEW

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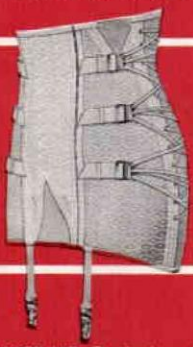
lumbar



#1169-HS

1169-HS Girdle-length sacro-lumbar support consists of a high, solid back, well-boned and equipped with removable, semi-rigid stays in cloth casings. Three sets of pull-straps on each side deliver pressure to this sturdy back. It is made of cool dacron mesh.

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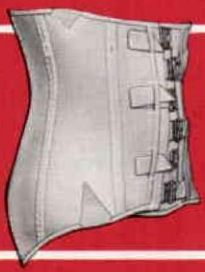

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430-EHS Lumbo-sacral support incorporates traction and two semi-rigid steels. The traction is controlled by three pull-straps. Maximum rigidity at the back is secured by semi-rigid steels.

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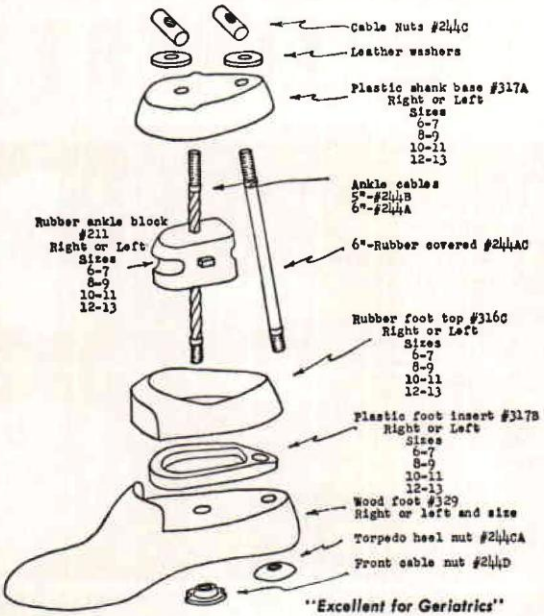

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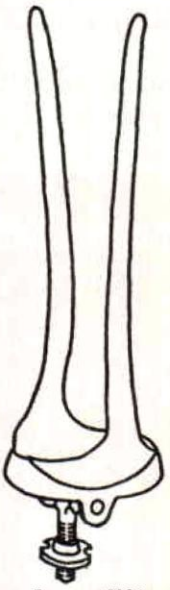
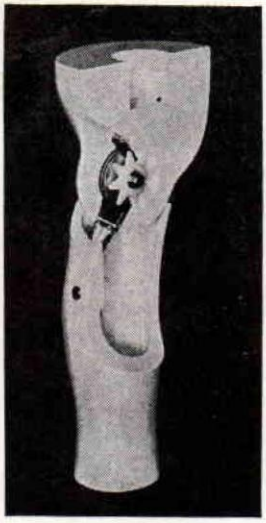


Symes Frame #270A with ankle joint, shaped to cast and measurements.



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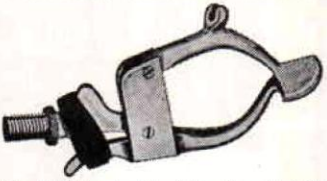

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The "Interface" in the Immediate Postsurgical Prosthesis[a]

Joseph H. Zettl, C.P., Director
Ernest M. Burgess, M.D., Principal Investigator
Robert L. Romano, M.D., Associate Investigator

Prosthetics Research Study
Eklind Hall, Room 409
1102 Columbia Street
Seattle, Washington 98104

The Prosthetics Research Study initiated investigation of the immediate postsurgical prosthesis by using as the primary rigid dressing, a hard conventional plaster socket without compressible interface. Our first 16 below-knee amputations in 1964 were treated with only a nonadherent silk dressing and sterile five-ply wool stump stock covering the wound. The initial plaster socket was then applied in PTB configuration leaving the knee free to move. Formation of edema, partial wound separation, abrasions, and distal anterior stump irritation in several cases made it evident that tissue support was inadequate with the plaster socket alone. Mobilization of the knee joint proved to be detrimental since it adversely affected cast socket suspension no matter how carefully the cast socket was applied. As a result of this early experience, we modified the technique to provide controlled pressure on the soft tissues of the stump using a compressible interface between the rigid plaster-of-paris dressing and the stump. Appropriate pressure proved beneficial to wound healing and promoted early stump maturation. During the past 4 years we have investigated in depth the effects of pressure on stump tissues. Basic research and correlated clinical studies have provided significant data highly relevant to the wound healing process.

In essence an effective pressure interface agent combined with the rigid dressing immobilizes and supports the fresh operative wound, markedly limiting the development of postoperative edema, improving circulation, minimizing inflammation response, and promoting wound

[a] Based on work performed under VA Contract V5261P-438

healing. Equally beneficial and advantageous are upright activities of the patient including controlled weight bearing through standing and walking early in the post-operative period. Detailed examination of these so-called "appropriate pressures" presents a number of important questions. How critical are these pressures? What are the desirable gradients? What variations can be tolerated to insure optimum healing, yet avoid tissue necrosis? What are the magnitudes of relatively constant or intermittent pressures and which is preferable? What are the volumetric stump changes in the immediate postsurgical period? What are the time requirements to achieve complete wound healing and stump maturation? The impressive clinical results obtained in our experience numbering well over 300 amputations provide some insight and conclusions which nevertheless require additional substantiating followup in the form of basic research studies. This investigation is continuing in our laboratory and by others. A preliminary report of such in-depth study of basic physiological questions derived through instrumentation was reported elsewhere and has provided some answers to the posed questions. In general our observations support the clinical requirements for an effective pressure interface agent between the amputation stump and immediate postsurgical rigid dressing.

OBJECTIVES

To achieve this desirable environmental factor, the ideal interface material should be compressible and maintain its elasticity over a predictable period of time. It should be capable of compensating for and adapting readily to volumetric stump changes if and when these occur. It should be controllable and adjustable manually through inflation or by other means to maintain the optimum pressure gradients in the postoperative period once these pressures are known and have been achieved. It should also be porous or ventilated to permit outflow of fluids and perspiration and have permeability for air circulation. Finally, it should be nonirritating to the skin and able to be sterilized.

Several materials or combinations of materials meeting the described requirements to varying extents were studied and clinically tested. They consisted of the following sterilized items (Fig. 1):

1. Inflatable rubber balloon or bladder.
2. Well-fluffed surgical gauze.
3. Lamb's wool.
4. Stryker gel pads.
5. Machinist's cotton waste.
6. Foam rubber.
7. Steel and brass wool.
8. Perforated Silastic foam pads.
9. Reticulated polyurethane distal pads.

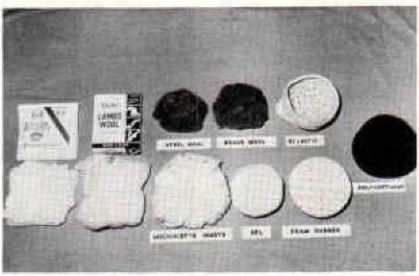

Figure 1

METHODS

Most of these materials were reasonably effective when properly applied. However, the various techniques of application required considerable judgment to estimate the proper quantity for any given case. Need for considerable skill in precise application technique of the surgical dressing and initial plaster wrap added another variable. Only three of the materials, Nos. 4, 8, and 9 were preformed and molded to stump contour thus assuring continuous uniformity of the pads and simplicity in their application.

APPLICATION TECHNIQUES

Interface materials 2, 3, 5, and 6 were applied directly to the distal stump end over the nonadherent silk dressing and were held in place with the Orlon Lycra stump sock. Materials 4, 6, 7, and 8 were applied to the outside of the Orlon Lycra stump sock and retained in position with a thin one-ply cast sock. In addition, materials 4, 6, 7, and 9 were retained over the outside of the Orlon Lycra stump sock solely by the application of the elastic plaster wrap.

For evaluation purposes, materials 4, 6, and 7 were applied both with and without the thin cast sock to study the effect of an additional variable which proved negligible. One material, "Dri-Site" (Johnson and Johnson) was included in category number 6 (foam rubber) but only used directly over the nonadherent silk dressing over the wound.

RESULTS

Early consideration and attempts to introduce an adjustable inflatable balloon or bladder between the stump and the cast socket were abandoned since nonabsorbability of fluids presented serious problems in the form of unhealthy skin maceration, the result of insufficient porosity and poor air ventilation. Theoretical advantages of closed fluid or gas pressure systems are great. We intend to exploit this source of pressure management in future studies.

Fluffed gauze and machinist's waste provide some initial compressive quality which, however, is lost quickly when absorbed fluids dry into a hard, crusty, nonelastic mass.

Lamb's wool does not absorb or retain fluids due to its lanolin content. It allows secretions to pass through freely and to be absorbed by the rigid plaster dressing itself which acts similar to a sponge effect resulting in a relatively dry wound. However, the effective compression factors of lamb's wool are very low initially and we suspect shortly thereafter will become nonexistent.

Stryker gel pads lack the very basic requirement of porosity and being nonabsorbent permit skin maceration by restricting the outflow of fluids and causing the formation of additional moisture through perspiration. The elasticity of this material, however, is considered within an acceptable range. Stryker gel pads compared with other materials are expensive.

Foam rubber of various densities and porosities including related materials tends to create a relatively warm or hot environment, stimulating the formation of perspiration. Another basic inherent characteristic of foam rubber is the absorb-

ing and retaining of secretions which, of course, is not desirable. Perforations or vent holes provided are usually occluded when the initial plaster wrap is applied under necessary tension. Elasticity in various forms of foam rubber is excellent. "Dri-Site" (Johnson & Johnson), a wound dressing which behaves as its name implies, neither provides the required body uniformity nor sufficient compression.

The major difficulty experienced with steel and brass wool was in the form of occasional temporary wound and skin irritation as a result of suspected splinters which penetrated the Orlon Lycra stump sock during weight-bearing activities. Again a lack of uniformity also required skillful application into the rigid dressing. Elasticity was regulated by selection of material density.

The preformed foam pads consisting of a combination of Silastic 386 Foam Elastomer and Silastic 388 Denture Release were molded in four different sizes. The resulting end pads were uniform and simple to apply. Density was controllable by the mixture ratio of Silastic and resulted in excellent compression over the distal stump end. Nevertheless the inherent characteristics of the material, including occlusion of vent holes during application under tension, resulted in heat and accompanying perspiration. Also, manufacture of these pads was considered expensive and time consuming. The experience gained with this particular approach, however, set the stage for evaluating reticulated polyurethane foam.

Currently, the most suitable material is the reticulated (skeletonized) polyurethane foam of 20 pores per inch density. This material envelopes most of the desirable characteristics described earlier and has been clinically applied for more than 1 year on over 100 patients with remarkably good results.

MANUFACTURER'S DESCRIPTION OF POLYURETHANE

Polyurethane is produced of chemicals derived from petroleum

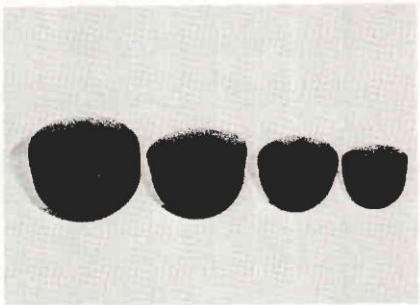

Figure 2

and is composed of 12-sided bubbles or cells that give it a foam-like appearance. Reticulation is the process of removing the walls of the cells. The remaining strands, thicker than were the cell walls, are left in a form that might be best described as a three-dimensional fish-net. Polyurethane foam has a temperature resistance up to 250 deg. F. and can be sterilized with boiling water, steam, or gas.

With the assistance of the manufacturer, we overcame the early problem of shaping the material to stump contours. The performed reticulated distal pads in sizes of 3, 4, 5, and 6 in. are suitable for most if not all stump sizes, (Fig. 2, 3, 4, 5, and 6). After careful evaluation 20 pores per inch density appeared

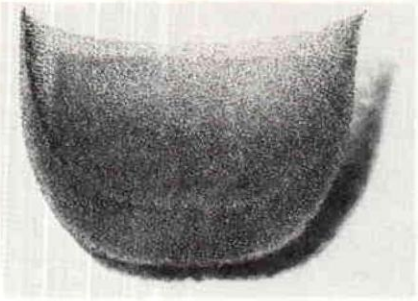

Figure 3

to be the most suitable. However, this does not imply that density of the foam is related to pore size. Our aim was for maximum pore size without sacrificing density or causing detrimental skin irritation due to coarseness of the material.

Aside from providing uniformity in each application, reticulated polyurethane distal pads provide the prosthetist with a greater range of safety over the critical distal-anterior stump margin than was before possible. They remove some of the guesswork and provide satisfactory results for individuals with less experience.

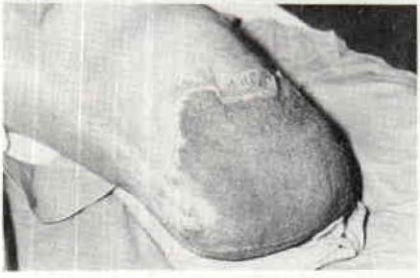

Figure 4

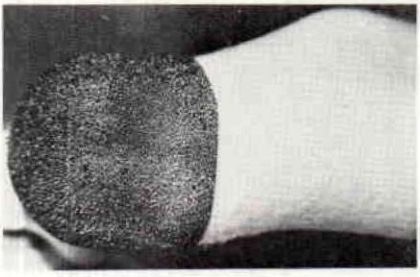

Figure 5

Figure 6

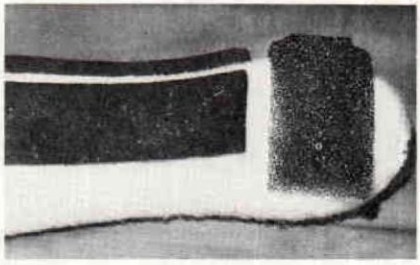

Figure 7

Reticulated polyurethane of the same density and porosity but in ½-in. thick sheet form is recommended as a compressive interface material for Syme and hip-disarticulation rigid dressings (Fig. 7 and 8).

Efforts are being made to substitute compressed polyurethane with identical density as felt for relief pads currently in use in the below-knee and Syme rigid dressings. Plans are to provide polyurethane relief pads with adhesive

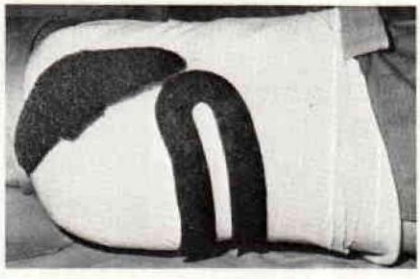

Figure 8

backing to eliminate the need for medical adhesive spray.

Aside from its many uses and applications in various industries and professions, it should be noted that reticulated polyurethane is also successfully used for conventional medical dressings.

SUMMARY

To achieve and maintain effective tissue support in a fresh amputation stump through controlled compression by means of an immediate postsurgical rigid dressing, an effective interface agent with certain fundamental and functional characteristics is required. Various types of interface materials have been evaluated both clinically and through instrumentation. The results obtained indicate the suitability of reticulated polyurethane foam, 20 pores per inch, which has the ideal characteristics of an effective interface material. Further use for this material in different forms and for related applications shows additional possibilities as a surgical dressing.

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Orthotics and Prosthetics Today As Viewed by an Orthopedist*

by Newton C. McCullough, III, M.D.**

It is a pleasure for me to be here this morning and have the opportunity of sharing with you some views regarding the current status of the profession of orthotics and prosthetics. In recent years, I have become rather closely associated with certain areas in your specialty, and hence am aware of at least some of the problems facing the field today.

With your indulgence, I would like to use this time to point out what to me seems to be the major problems confronting the prosthetic-orthotic profession today, and to offer some suggestions whereby these problems can be at least partially alleviated. It is a rare occasion for an orthopedist to give a talk and be unable to use slides for notes, so with apologies ahead of time, I will read to you some of my thoughts and ideas in this matter.

Problem number one is that there are too few of you to provide adequate service to the ever increasing handicapped population. This results all too frequently in undue delay in fitting patients with artificial limbs or orthotic devices. It also tends to lower the quality of appliances provided, in that the demands of time alter the care and skill of fabrication. I think that there will be little disagreement that more manpower is needed in the field. The following possible solutions to this problem exist.

1. An intensive and organized effort to attract intelligent young men into the profession is needed. This should be an all-out effort conducted as a function of your national organization and extending into all areas of the country. Young men at every high school and junior college in the nation should be made aware of the fascinating potentials which exist in this profession, being as it is, a common merging ground for the sciences of medicine and engineering. A library of sound-slide talks and movies demonstrating current developments in new fabrication

* This address was given at the Forum '69 seminar held at the Plaza Hotel, Miami Beach Florida prior to the 1969 AOPA National Assembly.

** Assistant Professor of Orthopaedics, Associate Director of Rehabilitation, University of Miami, Miami, Florida.

techniques, external power and myoelectric control should be established.

These audio-visual aids should then be available to local prosthetists and orthotists for use in high schools and colleges in their geographic areas. Other propaganda techniques at the local level could also be used, but there should exist a truly coordinated recruitment program directed from the national and regional levels.

2. The concept of prosthetic-orthotic technicians should be developed and encouraged. These individuals, given short-term basic training in fabrication techniques, would do much to lessen the load of the certified prosthetist and orthotist and improve overall delivery of services. This idea is already being employed in Vietnam and in other underdeveloped countries of the world, but has only a scant beginning in this country. The technician concept for the prosthetic-orthotic profession has it parallel in the current programs being developed at several institutions for training orthopedic technicians. You, no less than we, need an extra pair of hands to adequately serve the patient population.

3. In certain areas the concept of central fabrication may be worthwhile in an attempt to lighten the routine workload of practicing orthotists and prosthetists. An inherent danger to this approach, however, is that the patient depersonalized, and individual requirements may not be satisfactorily met. Any attempt at central fabrication should be predicated on the fact that local alterations and modifications can be made in the component or appliance to meet individual situations.

The second major problem facing your profession today is that, as professional people, your time and energies are not being properly directed. This of course is partially a result of problem number one, and can be partially alleviated when more technical help is available to you. There should hopefully arrive a time when your activities and your energies can be redirected toward a higher and more productive level. You should be able to spend less time in manual labor, and more time in clinics with patients and doctors. You should be able to spend less time in the business and administration of your shops, and more time in local research. To accomplish these things you will need increased help in the form of technicians and business managers, and perhaps from central fabrication techniques. It is important that you be able to develop a closer working relationship with the medical profession, gaining mutual understanding of patient problems and musculoskeletal deficiencies. This can be accomplish by attending clinics, participating in resident conferences and Journal clubs, and promoting your own educational activities for residents and other physicians in

areas of prosthetics and orthotics. It is essential that the importance of continuing education be recognized, and that local Journal clubs and regional meetings be held periodically for the exchange of information and ideas in addition to your attendance at national meetings. In those areas close to a medical school or residency training program, lectures or courses in anatomy and musculoskeletal disorders can be organized with resident help and participation.

Finally, in restructuring your time schedule, an effort should be made to engage in some research activities, should it be no more than trying to solve a problem by trial and error, or by getting together with the physician to figure out a new approach to an orthotic or prosthetic problem. Remember, many of the most practical and most applicable new ideas come, not from large research centers, but from the local level.

A third major problem is what I like to call the "orthotic lag." This lag in development of the orthotic field is a real one, and poses a major problem at the present time. Orthotics has taken a back seat to prosthetics, and perhaps for good reason. The needs of the amputee are more immediate and obvious, and the wars of the past thirty years have yielded untold numbers of young men in their prime whose productivity depended upon satisfactory functional restoration of their missing limbs. Medicine, engineering, and the prosthetic profession have responded to the needs of the amputee through extensive research and development, widespread educational programs, improved fabrication and fitting techniques, and better delivery of services. The field of orthotics remains in comparative disarray, with more limited though no less sophisticated research activities, few educational endeavors, and little improvement upon local fabrication and delivery services over the past fifty years.

There are no accurate statistics as to the number of persons in this country requiring orthotic services, but when one considers the sheer numbers of spinal cord injuries, stroke victims, congenital neuromuscular disorders, arthritic and post-traumatic neuromusculoskeletal disorders alone, it is obvious that there is a much greater need for progress in orthotics than in prosthetics. Why then, have there not been comparable advances in the orthotic field? I believe there are some definite reasons for this "orthotic lag." There is first of all the more obvious and immediate need for replacement of a missing limb as opposed to restoring function to a deranged limb which at least has not parted company with the remainder of the body. Secondly, a missing limb presents in many instances a more straightforward problem — that of replacing the entire missing part, duplicating mechanically as many normal functions as possible. One below-elbow amputee presents essentially the same problem in terms of functional replacement as any other below-elbow amputee. The same cannot be said for an impaired upper extremity. Specific missing functions must be substituted in the presence of

intact anatomy, and the variety of functional losses which one encounters means that design criteria must be correspondingly varied and adapted to each individual patient. I find it somewhat discouraging to realize at times that we can replace a missing extremity and secure a better functional result in some cases than we can get in a paralyzed limb with the orthotic options open to us today.

Perhaps the best indication of this lack of progress in orthotics is the fact that the American Academy of Orthopedic Surgery's Committee on Orthotics and Prosthetics is currently attempting to revise Volume I of the Orthopedic Appliance Atlas, which has gone unchanged since 1952, 17 years ago. Relatively little new in bracing will be added to the new Atlas. Rather, new approaches to orthotics are to be outlined, based on a systematic analysis of the patients' problem. In order to bring orthotics to a comparable point in development as prosthetics, we must first rid ourselves of the current mass confussion in terminology and meaningless approaches to prescription writing. We must then orient our thinking just as we did early in prosthetics research and development to basic biomechanical principles governing normal function of the extremities, and to the consequences of functional impairment upon the biomechanical system. An attempt is presently being made to devise a technical analysis form wherein one can diagrammatically plot the biomechanical losses present in an extremity. Once properly identified these losses can then be matched against specific components or component systems to substitute for the functions lost. In this way, a more rational and scientific approach to bracing will be achieved. It will also serve to identify areas or functions for which satisfactory components are not presently available, and thus become the basis for future design. In addition, it is to be hoped that such a systematic approach to the problem of bracing will be a valuable teaching tool for physicians and orthotists alike, and serve as a common meeting ground upon which to work out specific problems in bracing.

The last major problem which I want to mention is the matter of inadequate delivery of new and improved devices to the patient population. This is particularly a problem in orthotics and in child prosthetics. There exist in this country and Canada several research centers which are engaged in highly sophisticated research activities with the aim of improving upon our current braces and limbs. While entirely laudable and productive of intricate and ingenious design, these centers, with rare exception, have not succeeded in providing improved appliances which in turn may reach the general population. There is an urgent need at present for 1) more practical research activity at a local level, and 2) a means of putting into mass production effective components and devices developed at the research centers so that they may reach the public.

In summary, I have presented to you what I consider to be the major

problems confronting the prosthetic-orthotic field today. There are doubtless many others which will emerge during the course of this seminar. The problem areas as I see them include inadequate number of personnel, improper direction of talent, a disproportionate relationship between orthotics and prosthetics, and failure of delivery of new and improved devices to the masses of handicapped people.

I have suggested some ideas for improvement of the current situation. The solutions to the problems rest heavily on your shoulders and will not come easily. Those of us in the fields of orthopedics and rehabilitation stand ready to assist you in every possible way in meeting the challenges of the next few years, and we look forward to an ever closer relationship between our professions.

Development of Upper Extremity Orthotics

by Thorkild J. Engen, C.O.

PART I

RESEARCH AND DEVELOPMENT OF POWERED AND NON-POWERED SYSTEMS

Note: This paper will be presented in two parts. The second section, entitled Patient Applications and Functional Gains, *to be published in the June issue of this journal, will also include the Acknowledgements. Both sections are based on the findings reported in the Final Project Report of the four-year project supported in part by Social and Rehabilitation Service Grant No. RD-1564.*

ABSTRACT

The orthotic systems herein described, developed at Texas Institute for Rehabilitation and Research, 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 usefulness of the orthotic system.

As a result of application to and evaluation of nearly 100 individuals included in the evaluation phase of the project using pneumatically powered systems, it was established that the system affords a practical method in 85% of the individuals for 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.

This "system" has been designed to use the patient's own skeletal structure and biomechanical functions as an integral part of the orthotic mechanical system. This principle has proved to be very important, because its application avoids a "mechanical man" solu-

tion, and the patient has increased motivation and acceptance of the artificially powered movements which remain under his direct proportional control. This factor is of critical importance if the patient is to be properly assisted in achieving a satisfactory living and vocational adjustment when he is with non-impaired people.

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 arm unit which was developed provides important missing natural motions so that control of powered assisted movements need be directed primarily to shoulder abduction, elbow flexion, and finger prehension. The mechanical design also takes advantage of the skeletal structure, 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 to have useful function restored in a simplified manner that does not leave him overloaded with cumbersome equipment.

In order to improve design criteria for these systems, a kinematic study was undertaken to achieve an objective description of normal movements as they relate to acceleration, velocity, deceleration, and changing angulations. This study was extremely helpful in minimizing discrepancies of motion imposed by the devices themselves.

The functional usefulness in daily living of these powered systems is indicated by the fact that the majority of adaptations thus far made have enabled the quadriplegics participating in the project to increase their activities. Some of the gains made are self-feeding, caring for personal hygiene, writing, typing, handling a telephone, filing papers or cards, and operating a tabulator or computer. Many routinely perform avocational activities such as playing cards or checkers, drawing, or painting. Seven have become gainfully employed, and fourteen others are pursuing education and training directed toward vocational achievement.

While the project was primarily aimed toward the development of powered orthotics, non-powered systems harnessing the patients' residuals into useful function were also developed and found to have extensive utility. These had wider acceptability than was originally expected. 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 remaining muscle action can be effectively utilized. As a result of 450 clinical applications and evaluations, we established that such patients are able to gain considerable functional independence.

INTRODUCTION

Purposes of Project

When the project began in 1964, certain specific proposals were set forth as guidelines. Primary effort was to be devoted to further development and modification of practical, patient-controlled, pneumati-

cally actuated orthotic mechanisms for upper extremities.

While simplicity, functional efficiency, and cosmetic acceptability were the overall objectives, an orthotic system also had to be lightweight; to provide passive structural support to achieve near-normal musculoskeletal alignment, such as in a flaccid hand; and to fully utilize the skeletal articulations as a necessary component of the powered system.

Progressive developments in externally powered orthotic systems indicated a need for detailed analysis of the complex, synchronized musculoskeletal actions in normal upper-extremity motions involved in daily living. The main purpose of this kinematic study was to establish an objective description of normal movements as they relate to acceleration, velocity, deceleration, and changing angulations. The study also identified associated body movements, such as head and torso movements. The findings were extremely helpful in minimizing discrepancies of motion imposed by the equipment.

Although the development of externally powered orthotics was the primary goal, many modifications of existing systems were implemented in the process. These modifications included refinement of the plastic hand orthosis as it is used as a basic module in a systematic approach to correct or prevent deformities or to aid impaired functions. Another important modification was the further development of a reciprocal wrist extension finger flexion orthosis. While each of these was not specifically outlined in the original proposal, each has helped to serve the patients involved.

Facilities and Staff

This project involved many of the professional and non-professional staff and facilities of the Texas Institute for Rehabilitation and Research. Being the operational site of the Department of Rehabilitation of Baylor University College of Medicine, the Institute has specialized in chronic diseases and rehabilitation since its opening in 1959. The Institute has a bed capacity for fifty-five in-patients and facilities for 105 out-patients who are seen in the various clinics.

In addition to the departmental staff, an orthotic advisory board was established consisting of the following members: Dr. William Spencer, Dr. Paul Harrington, Dr. Lewis Leavitt, Dr. George Lane, and Thorkild J. Engen, C.O. Meetings were held routinely with the agenda prepared by the Project Director. The problems, progress, and sequence of developments were discussed, the decisions made were implemented, and the results of these decisions were discussed in follow-up meetings. This arrangement allowed excellent coordination between the various disciplines involved in orthotic research developments.

In conjunction with the project, physiological tests were administered by the Department of Physical Therapy before and after orthotic adaptation, while the patients were trained in the use of their orthotic equipment by the Department of Occupational Therapy.

The patients seen during this re-

search project were referred from the Orthopedic Clinic and consisted primarily of those with high spinal cord lesions, as well as some with a diagnosis of poliomyelitis. Patients who were seen in consultation and for evalution by faculty members of the Departments of Physical Medicine and Orthopedic Surgery throughout the affiliated hospital program were also seen for evaluation and potential application of externally powered orthotic systems in the Department of Orthotics. Through scheduled and non-scheduled clinics, ward rounds, and conferences, the patients were evaluated for pre-orthotic treatment. This early evaluation was to determine if reconstructive surgery or physical therapy were needed to regain the maximum neuromuscular function or to reverse deformities prior to actual orthotic adaptation.

Following adaptation, the patient was followed in the appropriate clinic by members of the medical rehabilitation team for subsequent re-evaluations.

Methodology

In the developmental phase of this research, a number of components were identified as necessary for the basic orthotic systems. Collectively, these components comprise one of four systems: the plastic hand orthosis; the reciprocal wrist extension finger flexion orthosis; the externally powered finger prehension orthosis with wrist friction joint; or the externally powered arm abduction elbow flexion orthosis.

The development of these components evolved from numerous experiments, tests, conferences, and clinical evaluations. The establishment of one component, such as the basic hand module, quite often led to development and modification of other systems.

Plastic Hand Orthosis

For successful restoration of function for a paralyzed extremity, it is important that skeletal alignment be restored, particularly in the fingers and forearm. Early in the project, it was found that it was impossible to restore digital function for a hand with severe muscle imbalance without first realigning the metacarpal arch.

To identify this alignment, an X-ray motion picture film was made of the skeletal structure of normal hands manipulating commonly used objects both with and without the plastic orthosis applied. (Fig. 1)

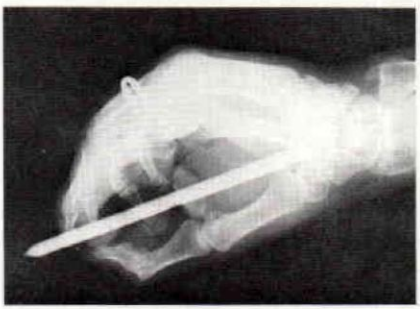

Figure 1

This enabled visual analysis in several planes of the structural skeletal arrangement in various holding and grasping patterns.

This study 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 mechanical hindrance to normal functional patterns.

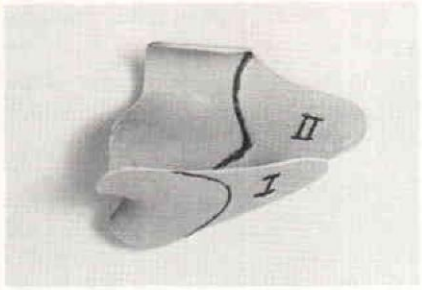

Figure 2

Further modification of the plastic hand orthosis followed as a direct result of this analysis. (Fig. 2) This semi-flexible orthosis, made from molds of various sizes of normal hands, is easily reshaped by heat for individual adaptation. This advantage, plus the incorporation of related components, makes the orthosis adaptable for a variety of patients' needs. (Fig. 3)

The basic orthosis as it comes from the mold incorporates the

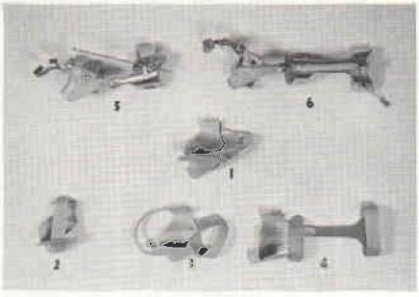

Figure 3

non-restrictive metacarpal support principle and includes both radial and volar extensions which may be eliminated or used singularly according to the nature of individual adaptations. (Fig. 4)

The orthosis may be made into an opponens and metacarpal support by trimming away both radial and volar sections. The addition of a lumbrical support provides another adaptation.

The volar portion of the basic orthosis extends slightly beyond the wrist joint to facilitate attachment of a wrist support. The radial portion extends to the wrist to facilitate the incorporation of a wrist joint when the orthosis used as a reciprocating finger flexion unit.

The plastic shell is now available in four sizes: small, medium, medium-large, and large for both right

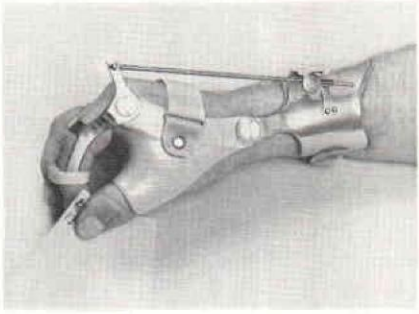

Figure 4

and left hands. By using the vacuum molding technique, the shells are made from nylon laminated polyester resin using a formula of:

75% Polyester resin 4116 Rigid
25% Polyester resin 4134 Flex
Caucasian epoxy reinforcer
3% Pigment
Approximately 12 drops Naugatuck per 100 grams of resin
5% Luperco ATC
Nylon stockinette

Reciprocal Orthosis

An excellent example of the versatility of the plastic hand orthosis is its use as an integral part of the reciprocal wrist extension finger flexion orthosis. Although this is not an externally powered system, it is a device designed to harness residual motor functions.

The unit is adapted for the patient with active wrist extension but

no finger flexion. Through mechanical linkage, the extensor motion is harnessed to provide a useful and practical finger prehension.

When the reciprocal orthosis was first developed, the functional gain was rather limited because of the fixed mechanical range of the unit. As stated previously, the X-ray

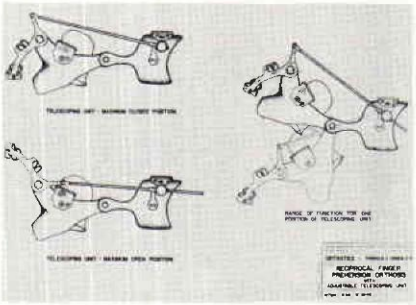

Figure 5

analysis emphasized the importance of the hand-forearm relationship as functional activities are performed. Based on these findings, an adjustable telescopic rod was developed during the project to expand the mechanical range. (Fig. 5)

This adjustable rod is activated by the patient's opposite hand or by pressing the activating button against a stable object such as a lapboard. A slight pressure releases the telescopic unit and enables new positioning of the hand. Release of the pressure locks the rod in the new position, thus permitting finely adjusted finger prehension so that a wide range of activities can be performed from holding a cup to picking up paper. With this feature, hyperextension of the wrist and fatigue are greatly minimized when the patient is manipulating small objects.

Patients with relatively weak wrist extension in addition to excessive radial deviation could not achieve a reasonable proportional gain, as the radial deviating movement of

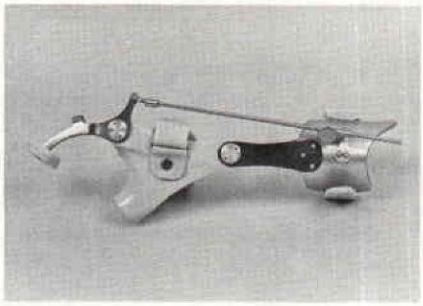

Figure 6

the hand in active extension worked against the joint alignment of the orthosis. To solve this problem of mechanical hindrance, a modified, leaf-spring was incorporated in the forearm cuff joining the plastic portion at the wrist. (Fig. 6) This mechanical arrangement permits the patient's biomechanical range of radial deviation to occur in combination with dorsiflexion of the wrist. It was necessary to change the attachment points of the telescopic rod so it would swivel in harmony with the newly incorporated deviation movement. (Fig. 7)

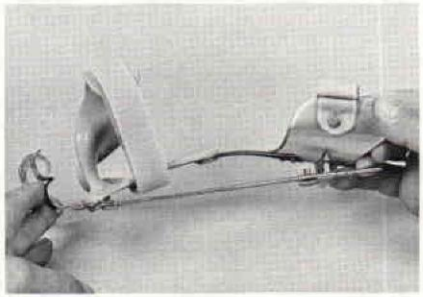

Figure 7

A method of analyzing a patient's residual functional status was also developed in order to achieve optimal matching of a particular device with a particular biomechan-

ical performance. Three factors of primary importance in determining the choice of equipment for restoration of hand function are: 1) degree of residual strength; 2) degree of radial deviation; and 3) range of motion between flexion and extension. A form was developed for recording these three factors, plus the patient's active dorsiflexion of the hands, using a standard muscle test. The radial deviations are recorded, and the range of motion between flexion and extension is determined using standard goniometric procedures.

Externally Powered Orthoses

This project dealt primarily with the development of orthotic systems employing pneumatic power. Two types of orthoses are used routinely for the patients seen at the Institute, an externally powered finger prehension orthosis with wrist friction joint, and an externally powered arm abduction and elbow flexion unit.

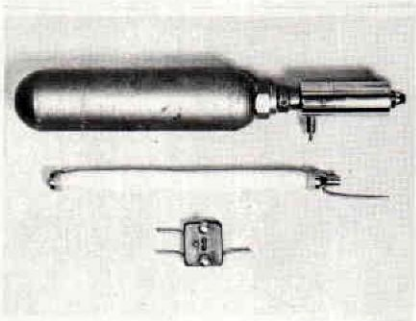

Figure 8

The major components of both systems are the power actuator in the form of the McKibben muscle substitute, compressed carbon dioxide as the power source, and a specially designed control valve for activation. (Fig. 8)

1. **Power Actuator.**—The McKibben muscle substitute is the power actuator used in these orthoses. A variation of the original design which is now used consists of a bladder made of fine grade latex with a diameter of 5/16", two

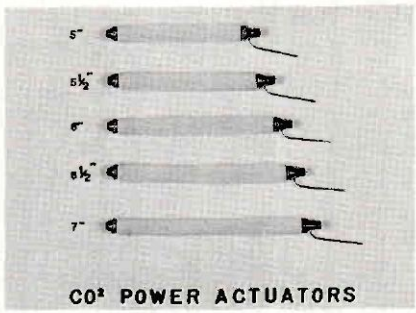

Figure 9

fiberglass helical sleeves, and single groove deeply cut end fittings which are sealed with polyester resin. One end fitting is left open for pressurization.

The size of the power actuator itself is determined by the function it is to perform since, for example, the contraction range required varies between finger prehension and elbow flexion. (Fig. 9)

Cycling testing devices were made during the project, and as a result of these efforts, some modifications were made. However, the power actuator still remains somewhat inconsistent in its durability. Extensive research and experimentation was done with different power actuators such as pistons, air bellows, and electro-pneumatic actuators. However, the McKibben muscle substitute was found to be preferable from the standpoint of patient acceptance, due to the smooth, proportionally controllable, combined motions it provides.

2. **Power Source.** — Compressed

carbon dioxide is used as energy for the power actuator. As a power source, it has proved to be practical because it is generally available, the small cylinder can easily be refilled, and it is non-toxic and inexpensive.

When filled with carbon dioxide, the cylinder weighs approximately three pounds. Since all powered applications thus far have been for wheelchair-bound patients, the size and weight of the tank are of little importance. The tank is routinely mounted either on the chair itself or beneath the lapboard surface. A pressure regulator is used to reduce the tank pressure from approximately 750 psi to a working line pressure of 65 psi.

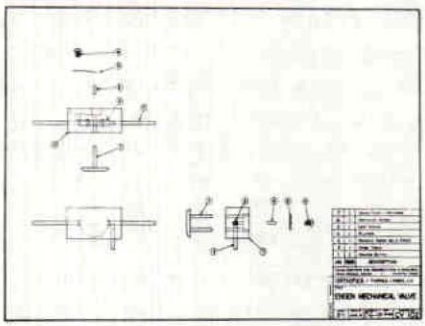

Figure 10

3. **Control System**—The success of useful, functional assistance through means of any powered orthotic or prosthetic system primarily depends on the simplicity and efficiency of the control system. It was determined through patient applications that a mechanical system offered greater simplicity and reliability. Therefore, efforts were made to develop a simple mechanical valve. The detailed report of those efforts was outlined in the final report for project RD-542.

The basic concept has been maintained with only a few modifications. This design resulted in an extremely reliable system which has been used in all patient applications to date. This type of valve

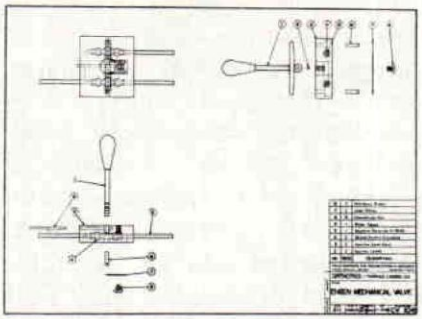

Figure 11

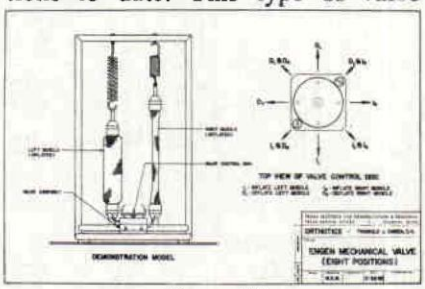

Figure 12

also was used in a power actuator testing device and completed approximately 800,000 cycles which is well within the scope of desired durability for this system.

The control valve consists of a flexible silastic tube and a spring-loaded pinching arm capable of depressing the tube sufficiently to stop the flow of gas at a maximum of 75 pounds per square inch. Three basic, lightweight valves are used for patient applications, a single valve (Fig. 10), a double valve (Fig. 11), and a stacked double valve (Fig. 12).

Depending on particular circumstances, it is at times necessary to separate the control for inflation and deflation of the same power actuator. In such instances, two

single valves are used. The double valve is used in conjunction with a rocker bar activator and produces both inflation and deflation. The four-way, or stacked, valve is used to control multiple actions. It consists of two double valves stacked together, and permits eight different actions to be synchronized or individualized using a single control site.

The most important features of this type of control valve mechanism are:

1. A line pressure of 65 psi can be controlled by a mechanical linkage of a force of a few grams.
2. Admission and release of gas to the actuator can be controlled by the patient to perform a smooth, gradational movement that is proportional to the controlling action.
3. The valve is leakproof because the flow of gas is controlled from the reservoir to the actuator without internal mechanical interruption of the system.
4. The cooling effect associated with the flow of carbon dioxide does not adversely affect the operation of the system, as the valve will tolerate great variations in temperatures.
5. The material used in the valve will also allow it to be used to regulate the flow of any gas or liquid not corrosive to silastic.
6. The undesirable noise associated with the escaping gas from the deflating actuator is minimized effectively by a small cotton muffler attached at the exit of the deflation tube.

With any powered orthotic 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 accidentally.

Finger Prehension Orthosis

The powered finger-prehension orthosis is designed for individuals with a chronic functional deficit of the hand and wrist, which is seen most often in patients with diagnosed spinal cord lesions at the C-5, 6 level. (Fig. 13)

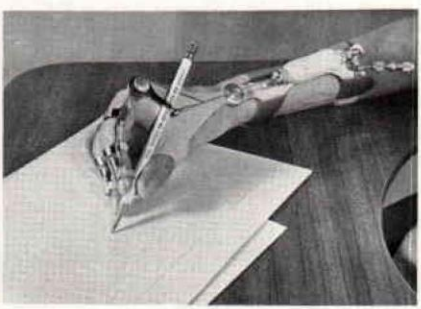

Figure 13

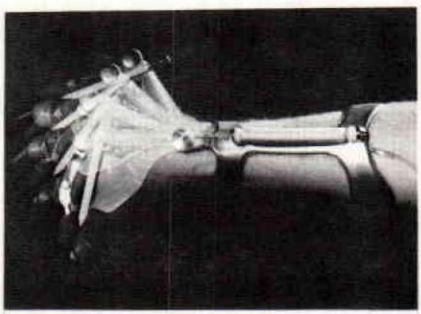

Figure 14

The standardized plastic hand orthosis is used as a foundation for this prehension device. Versatility of function is increased in incorporating a friction joint at the wrist, permitting voluntary prepositioning of the hand in relation to the forearm. (Fig. 14)

A finger unit, which moves the index and long fingers, is hinged at the proximal joint of the orthosis, permitting flexion toward the opposed and mechanically stabilized thumb. A coil spring, also located at this fulcrum point, assists the finger extension movement. The power actuator is located on the radial side of the orthosis. A cable, attached to the distal end of the power actuator, passes through a teflon bushing at the wrist joint and connects with the level arm of the finger piece. Upon contraction of the power actuator, the index and long fingers are flexed toward the thumb.

Figure 15

Occasionally, individual modifications of the powered prehension orthosis must be made to compensate for musculoskeletal problems that interfere with functional activities. For example, patients who hyperextend the distal phalangeal joints of the index and long fingers because of instability are aided when distal finger stops are added to finger unit.

When the problem concerns involuntary flexion of the ring and little fingers, an ulnar guard is attached to the finger unit to prevent these fingers from interfering with functional activities.

Considerable effort has been expended toward the development of a self-contained, lightweight powered finger prehension system designed to be used by ambulatory patients with hand and forearm paralysis. However, these efforts, although promising, never passed the evaluation stage.

Arm Orthosis

The powered arm orthosis is designed for patients who have lost all major function in the upper extremities except the motion of raising and lowering the shoulder girdle. This problem is often seen in postpoliomyelitis patients or those with spinal cord lesions at the C-4, 5 level. (Fig. 15)

The powered arm orthosis consists of two major parts, an abduction unit and an elbow flexion unit. 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. This system has the following functions:

1. To allow horizontal movements of the extremity
2. To provide vertical movements of the extremity

3. To act as a swivel arm and to support the elbow flexion unit in perpendicular alignment regardless of its elevated position.

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* has its fulcrum point located on the medial side of the elbow and corresponds to the axis of the epicondyles. The unit is linked with the abduction unit by means of a swivel arm which has a fulcrum point corresponding to the location of the olecranon. This permits inward and outward horizontal movements of the forearm.

A telescopic rod and tube connected to the flexion unit serves as an attachment for the hand support and also allows voluntary pronation and supination. 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.

The shoulder abductor and elbow flexor components are made from stainless steel. Teflon, needle thrust and roller bearings are incorporated in the joints to produce low frictional resistance. A molded elbow and forearm trough made of laminated polyester resin is attached to the unit. A cutout is located at the olecranon to permit firm seating of the elbow and prevent the forearm from sliding when the elbow is fully flexed. This is very important because of the critical location of the fulcrum points of the unit, which must correspond closely with those of the extremity. The forearm is stabilized in the trough with a Velcro strap.

Kinematic Studies

To establish improved design criteria for the artificially powered arm movements, the kinematic studies were undertaken to achieve an objective description of normal movements as they relate to acceleration, velocity, deceleration, and changing angulations. This study was extremely helpful in minimizing discrepancies of motion imposed by the devices themselves, and was initiated in collaboration with the staff of the Bioengineering Laboratory, Veterans Administration Prosthetics Center, New York.

Staff members from the center served as the normal subjects. Those who were chosen as subjects ranged from slightly obese to tall, thin individuals. Nine subjects were filmed while performing five basic functions of table-to-mouth feeding, hair grooming, page turning, writing, and diagnal reaching. These activities encompass the three important levels of hand movement, table, mid-torso, and head, utilizing the most functional range of motion of an upper extremity.

A 35-millimeter, 25-frame per second movie camera was used and placed 20 feet from the subject. Two mirrors were positioned at 45-degree angles to show three perspectives of the subject simultaneously: front, side, and top. Time clocks indicating one second and one-hundreth of a second intervals provided references for the indication of velocity and acceleration of each motion as reflected in change of position of reference landmarks

during fixed intervals of time.

A black felt pen was used to identify landmarks on the subject at the metacarpophalangeal joints, the styloid processes, the lateral epicondyle of the elbow, and the shoulder joint. The tip of the nose was used to record the head movements.

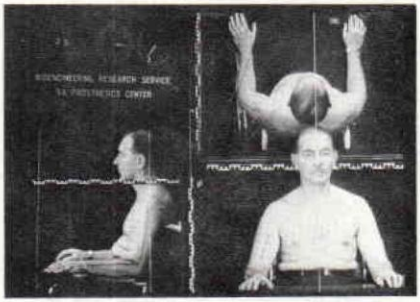

Figure 16

For comparative purposes, two identical sequences were taken of each subject, first *without* orthotic equipment (Fig. 16), and second, with the arm othosis but without the use of external power (Fig. 17), to determine if the equipment hinders normal upper-extremity movement. Recording mechanisms were not placed directly on the subjects to insure minimal mechanical hindrance being imposed on the extremity.

The negative film was made into a positive print in order to obtain a clearer image. A special mirror arrangement and a standard film strip projector were used to project the three perspectives of the subject on to a glass screen which also served as a viewing table. The screen was covered with tracing vellum to facilitate plotting. (Fig. 18)

The selected landmarks were

Figure 18

identified in each frame in black on the vellum. Once the action was analyzed, the points were connected with black lines to identify the pattern of movements, and the relating angulation and acceleration between each point. The time interval between each connected point remained constant at .13 second.

Photographs were then taken of the completed diagram which was superimposed over both the beginning and end motions for each activity. (Fig. 19) This represented a single plane, rectangular coordinate

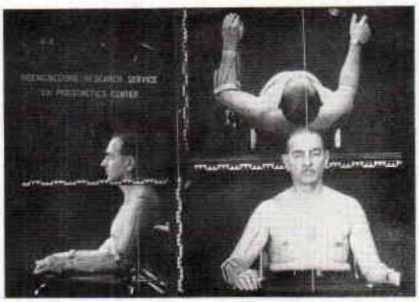

Figure 17

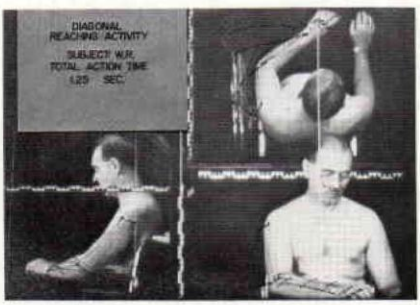

Figure 19

projection of landmarks that are, in fact, being rotated spatially during the real movement.

While this report is not intended to discuss skeletal anatomy in detail, but is instead an attempt to identify

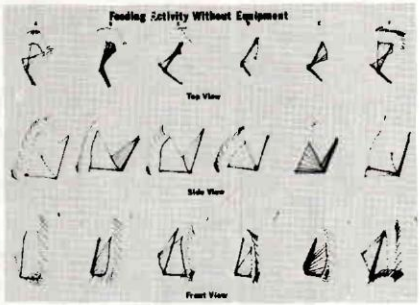

Chart 1

the sequence range and gross pattern of biomechanical actions, it should be kept in mind that the resulting diagrams are visual and are approximate data reductions of extremely complex and finely synchronized multiplane upper-extremity movements.

These limitations must be accepted because of the difficulty in externally locating the precise center of rotation of movements in a particular subject. In particular, the axes of shoulder and head movements and supination and pronation of the forearm cannot be located precisely because of the arrangement of the skeletal joints and differing location of various articulating structures within muscle tissue among individuals.

Despite these difficulties, the plots illustrate the character of synchronized, biomechanical articulations as purposeful, functional activities, which are performed both with and without the orthotic arm unit applied.

Because of the massive volume of data available from photographic techniques, two typical examples were selected from the nine subjects for this discussion. This resulted in four diagrams of the five typical activities both with and without the arm unit. For simplicity in comparing the various activities, the diagrams were correlated within each activity according to the view represented: top, side, or front. The two diagrams for each subject were then compared in order to identify evidence of mechanical hindrance or interference, or differences in the pattern of the movement as compared to the normal degree of upper-extremity freedom, which may have been imposed by the orthotic arm unit.

As an illustration of the data obtained from one activity, the diagrams of six subjects engaged in the *feeding activity* are presented in *Charts 1 and 2*.

In comparing the data from each subject, certain similarities of motion patterns are evident which are characterized by the range and angulations of each joint motion.

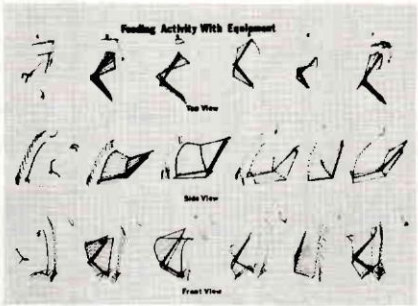

Chart 2

The diagrams studied strongly suggest that the function of the shoulder complex is crucial to the major upper-extremity actions tested. Relative consistence in selective

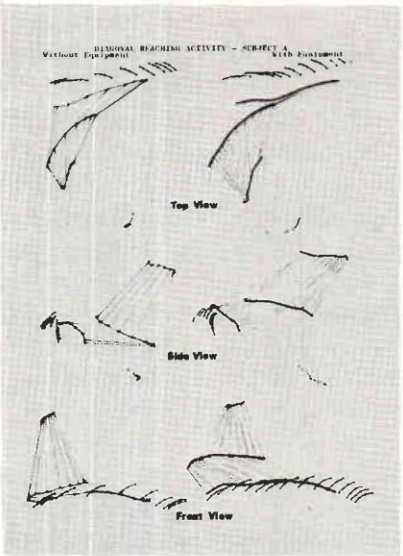

Chart 3

joint fixation is also evident as a vital part of whatever activity is being performed.

Joint movements and/or joint fixation is apparently finely synchronized by eye-hand coordination, as evidenced in the characteristics of *diagonal reaching* performed by two typical subjects in *Charts 3 and 4*. In this important function, the major movement occurs in the shoulder complex, consisting of elevation, abduction, and forward rotation. It is noted in all views of this activity.

An excellent example of selective joint fixation is also illustrated in this activity. The position of the hand and forearm and the angle of the elbow remain fixed throughout the subjects' performances without equipment.

In comparing the functions with equipment, the performances of subject A appears to be almost identical in timing, eye-hand coordination, shoulder movements, and wrist, forearm, and elbow positioning. Some differences are noted, however, in the performance of Subject B in all three views with equipment. In order to minimize the gravity forces imposed on a flaccid extremity, dynamic assistance is routinely incorporated in the arm orthosis. This arrangement does provide some degree of assistance, which is quite evident in comparing the two sets of data on Subject B.

One of the most desirable functions that a quadriplegic wishes to perform is that of *independent writing*. This is an activity which can be avocational, but often evolves into vocational endeavor.

The subjects used in this study were instructed to pick up the pencil from the lapboard, position it properly, and begin writing in their normal fashion. The diagramatic patterns demonstrate an expected uniformity between the individuals in *Charts 5 and 6*. In particular, the sequence of joint movements in-

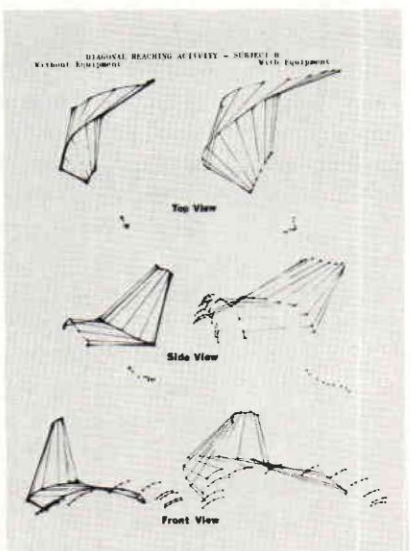

Chart 4

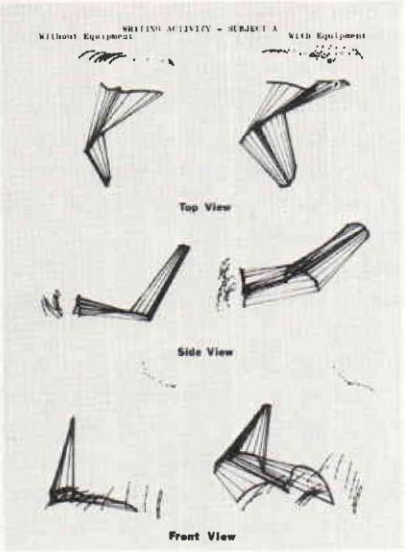

Chart 5

cludes shoulder rotation and elevation, head movement, slight wrist movement, and a considerable degree of supination while the elbow remains in a semi-flexed position throughout the activity.

In comparing the two sets of diagrams, a combination of mechanical hindrance and mechanical assistance is evident. The weight of the forearm is minimized by the dynamic assistance given by the arm orthosis as it was in the diagonal reaching activity. Some mechanical hindrance is noted, however, in the important wrist function. This is caused by the device itself not allowing wrist movement. As a result of these findings, a mechanical wrist friction joint was incorporated in the arm orthosis, thus permitting a patient using this type of device to voluntarily preposition the hand-forearm alignment which is so important to writing.

In *page-turning activity,* the eye-hand synchrony is clearly illustrated in the front view, as shown in *Charts 7 and 8.* In the diagrams for both subjects without equipment, the functions were performed with the major movements occuring in the shoulder complex as seen in diagonal reaching *Charts 3 and 4.*

When comparing both subjects' performances with equipment, the patterns of movements appear less coordinated with increased shoulder motion and a time lag which may be caused by frictional problems.

The *hair grooming function,* as shown in *Charts 9 and 10,* includes the range of motion needed for neck and facial hygiene. This activity employs the greatest motional range of synchronized articulations of the various skeletal joints composing the upper extremity and upper torso of all functions studied. In comparing the subjects' diagrams, the performance with equipment is slightly different. A maximum range of elbow flexion is necessary to bring the hand to the upper facial

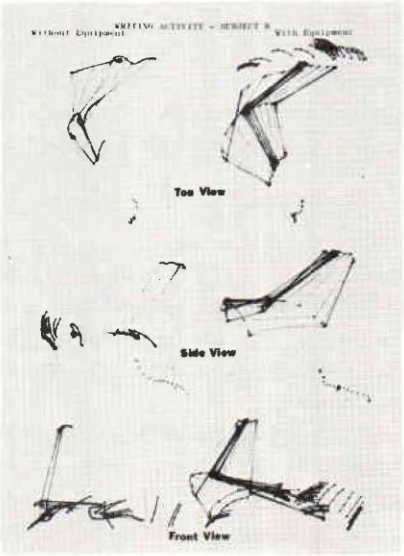

Chart 6

area in order to perform the function of hair grooming with the arm unit in contrast to the more closely organized normal movement. Some mechanical restraint imposed by the arm orthosis is also identified in this activity.

In the studies of *feeding activity, Charts 11 and 12,* a significant difference (which may be due to heredity reasons) was noted between the normal subjects performing the same type of feeding activity. In this action alone, the variation in

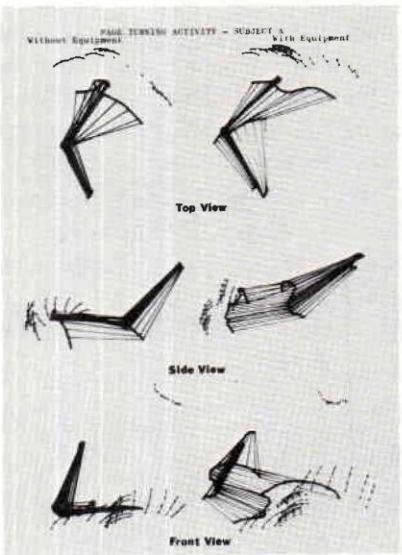

Chart 7

physical stature and acquired cultural styles of feeding cause significan natural variations in the pattern of self-feeding. This is the most obvious when, for example, there is an excessive forward head movement, showing an anticipation of the arrival of the loaded feeding instrument as an integral part of the overall feeding movement.

A normal feeding function is accomplished by a complex synchron-

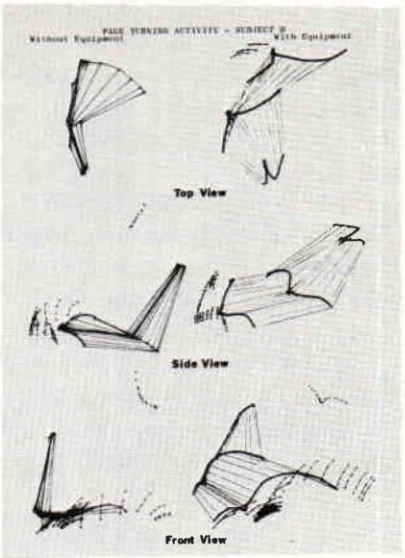

Chart 8

ization of shoulder abduction, elevation, internal rotation, scapular abduction, elbow flexion, and hand supination. In comparing the action with equipment, it should be noted that the elbow flexion has been replaced in some instances by the need for increased shoulder elevation, which then prolongs the pattern of the extremity action to some degree. Despite these differences, the arm orthosis still permitted these complex skeletal articulations to be performed by each subject without major mechanical hindrance as illustrated by the more complete graphs *Charts 1 and 2* showing six subjects' diagrams. Also, the device tended to force the subjects into a more comparable pattern of movement.

In summary, this study has been useful in identifying, diagramatically and graphically, the biomechanical actions of synchronized, coordinated eye-hand movements occuring while common, normal upper extremity functions were performed by usage

of a new and simple form of data reduction. Based on the information gained, a more realistic understanding of the mechanical requirements needed for functional substitutes for the quadriplegic patient has been achieved, and some were implemented in equipment design revisions. In addition, it also appears that the findings may be useful to the field of prosthetics.

The shoulder joint, with its magnitude of multiple extremity position combinations, appears to be extremely important to preserve

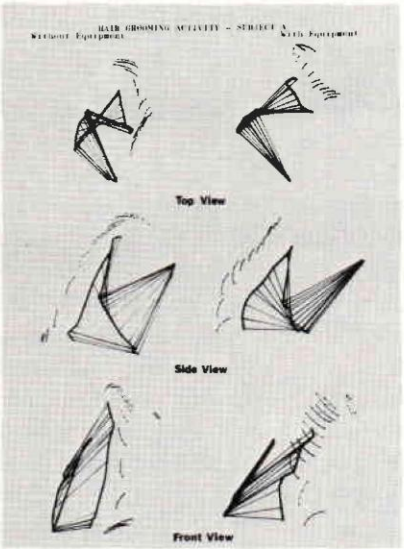

Chart 9

and to actively utilize in consideration of prosthetic equipment design. Movements in that area are spatially amplified at the terminal point of the hand. Potentially useful residuals in the scapular area in a shoulder disarticulated patient are often immobilized or minimized because of the method of suspending the prosthesis from a rather rigid torso plastic shell. This study would indicate that this is undesirable.

Furthermore, it is evident that functions, such as those studied, which are performed from a sitting position require, in fact, minimal active elbow movement. Based on this observation, it appears feasible to design a free elbow with an instant easily operated locking mechanism which would allow the amputee to pre-set the angulation of the elbow to correspond with the requirements of the kind of activity being performed. Also, it appears that greater effort should be directed toward providing powered assistance in the area of supination and pronation and flexion and extension of the wrist in order to allow a "fine-tuning" of the gross movements provided by the shoulder complex.

With the massive data available from this study, further analysis appears to be not only possible but also practical. While it was beyond the scope of this project to continue

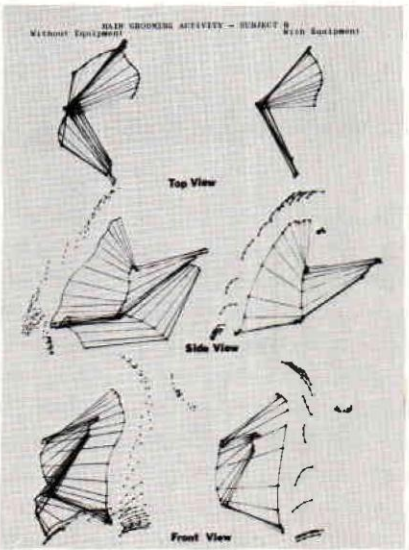

Chart 10

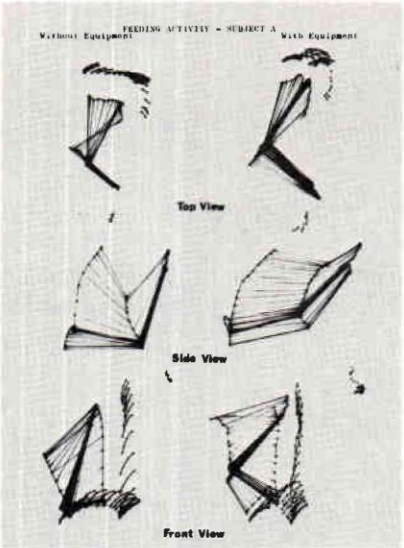

Chart 11

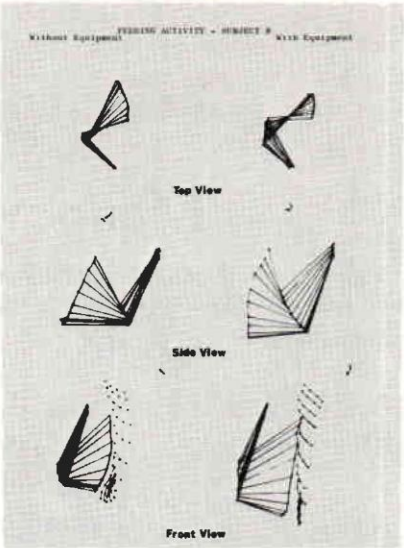

Chart 12

this analysis in depth, it is recommended, however, that further study and analysis of this kind be implemented and given research priority.

A useful methodology has been developed and evaluated which should provide a basis for improved design of orthotic and prosthetic devices and permit data collection of the effect of mechanical designs based on natural movement patterns, once these patterns and their variences are properly identified.

This approach to design follows the philosophy that, initially, it has been valuable to concentrate on providing a limited number of useful upper-extremity movements rather than providing a system permitting all degrees of freedom encountered in the natural movements. Such an approach can be expanded in terms of degrees of freedom as new methods of control are refined.

This first portion of the paper has to some degree summarized the most important aspects in the development of powered and non-powered upper-extremity orthotic systems under project RD-1564. Part II will concentrate on the functional gains achieved by patients with various physiological impairments using the systems described in Part I.

LEGEND:

Figure 1. One movie frame of a normal hand holding a pencil, showing the structural arrangement of the metacarpophalangeal joints.
Figure 2. Basic orthosis which included radial and volar extensions.
Figure 3. Plastic hand orthosis (center) and its use in various orthotic systems.
Figure 4. Reciprocal wrist extension finger flexion orthosis.
Figure 5. Diagram of the reciprocal orthosis with the adjustable telescopic rod.
Figure 6. In order to reduce mechanical resistance, a leaf-spring was incorporated in the forearm cuff joining the plastic portion at the wrist.
Figure 7. Attachment points of the telescoping rod were made to swivel in order to permit radial deviation.
Figure 8. The major components of the externally powered systems are (from top) the power source, power actuator, and control valve.
Figure 9. The power actuator used is available in varying sizes, depending on the function it is to perform.
Figure 10. The single valve, weighing 4.5 grams, is used to control either inflation or deflation of the power actuator.
Figure 11. The double valve weighs 8.2 grams and produces both inflation and deflation.
Figure 12. Diagram of the stacked valve control system which weighs 19 grams.
Figure 13. The externally powered finger prehension orthosis with distal finger support as used in a functional activity.
Figure 14. Incorporation of a wrist friction joint permits voluntary pre-positioning of the hand in relation to the forearm.
Figure 15. Powered arm abduction elbow flexion orthosis.
Figure 16. Mirrors were used to show front, side, and top perspectives of the subject simultaneously.
Figure 17. A second sequence was taken with the arm orthosis but without the use of external power for comparative purposes.
Figure 18. A special mirror arrangement and a standard film strip projector were used to project the three perspectives of the subject onto a glass screen.
Figure 19. Photographs were taken of the completed diagrams which were superimposed over the beginning and end motions of each activity.

Manpower Survey

(This report is an addendum to the **Manpower Survey** which appeared in the December 1969 issue of this publication. It represents the second and final part of that paper.)

SALARIES IN THE FIELDS OF PROSTHETICS AND ORTHOTICS

J. Warren Perry, Ph.D.[1]
Barbara R. Friz, M.S.[2]

Information relative to salaries in the fields of prosthetics and orthotics was reported on 1,183 of the 1,374 persons entered in the Manpower Survey.[3] The item on annual salaries included in the questionnaire form was completed on 95 prosthetist-orthotists, 245 prosthetists, 217 orthotists, 235 prosthetic technicians, 216 orthotic technicians, 120 corsetieres, and 55 shoe specialists. Reported here are findings on salaries of 1,008 persons in the first five categories. A report of the survey on corsetieres and shoe specialists is found immediately following the salary data.

The figures in this study pertain to basic annual salaries. No attempt was made to obtain information on fringe benefits, bonuses, or other types of remuneration.

RESULTS

Table I presents the annual salaries of the five categories according to:

1. The salary range in which the middle 50 percent of the group fell.
2. The median salary.
3. The mode.

As in other sections of this study, the similarity of the findings related to prosthetists and those related to orthotists is noteworthy. A similarity of findings is likewise manifested in the two technician groups.

Salaries were analyzed as above for two combined categories of personnel:

(1) prosthetists-orthotists, prosthetists and orthotists, and

(2) prosthetic technicians and orthotic technicians. (Table II.) The median salaries of these two combined groups are shown for each region in Table III. The number in each salary range for the two groups, again according to region, are shown in Tables IV and V.

SALARY BY YEARS IN FIELD

In this survey, orthotists were the only group whose median salaries showed a continuous upward

trend commensurate with the number of years in field (Figure 1). Prosthetists' salaries started at the same level as those of the orthotists, rose more sharply following the first period, but declined earlier. (The last two periods are not significant because of the small sample.)

Salaries of prosthetist-orthotists showed increases up to the 20-29-year period, subsequently dropped, and then rose again to a second, although lesser, peak in the 40-49-year period.

Orthotic and prosthetic technicians started at approximately the same salary level, after which both levels showed a gradual upswing. (Figure 2.) The salary level of orthotic technicians showed a sharper rise than that of the prosthetic technicians after the first 9-year period and maintained a somewhat higher level most of the time. Both reached a peak in salary level in the 30-39-year period. (Again, the last periods are not significant.)

SALARY RANGES BY EDUCATIONAL LEVEL

Although salary ranges were analyzed for each group according to educational level, this factor did not appear to affect salary level. When more graduates from degree courses enter the field, the effect of educational background will become clearer.

DISCUSSION

This brief report represents a first attempt to report salaries within the fields of prosthetics and orthotics. To obtain accurate and precise information on salaries is difficult. The economics situation constantly changes, the personnel picture fluctuates, and frequently a reluctance to divulge the proper information distorts the findings. In this survey, for instance, approximately 15 percent of the respondents failed to complete the question on salaries, and few did not enter precise figures.

This type of information serves a useful purpose, however, and health professions, as well as other professions, make a practice of periodically conducting a salary survey of their members. Professional associations are usually committed to promote the economic welfare of their membership, in which case such surveys are essential. This type of information is also needed to advise and perhaps guide employers in determining salary scales for employees. Finally, in the important business of recruiting students into the field, it is only fair that they should have available accurate information on salary scales within a particular field.

This study, in spite of certain shortcomings, does provide a general idea of salaries in prosthetics and orthotics and enables comparisons to be made with salaries in other health professions. It also provides a baseline with which future findings in this area may be compared.

It is recommended that a more sophisticated study be done for the purpose of more accurately documenting salaries, fringe benefits and miscellaneous remunerations. Distinction should be made between the gross income of the self-employed and the income of those employed on a salary basis. The effect of the educational level on salary

should become more evident at a later date.

SUMMARY

This paper reports findings related to salaries entered in the Manpower Survey. Salaries are analyzed for five categories, and the median salaries of these groups are correlated with The American Orthotic and Prosthetic Association regions and with the number of years in the field.

CORSETIERES AND SHOE SPECIALISTS

J. Warren Perry, Ph.D.[1]
Barbara R. Friz, M.S.[2]

INTRODUCTION

This paper will report the findings of the Manpower Survey[3] as they relate to corsetieres and shoe specialists. Two hundred and three facilities, institutions and military installations participated in the survey which was terminated January 31, 1969. Reported in the survey were 1,374 workers, 149 (10.8 percent) of whom were corsetieres and 62 (4.5 percent) shoe specialists. (Table I) All corsetieres except nine were female; all shoe specialists except one were male.

ESTIMATED PERSONNEL NEEDS

Estimates by survey respondees showed that the overall demand for personnel at the time of the study was somewhat greater for shoe specialists than for corsetieres. (Tables II and III) A requirement of 21.3 percent increase in personnel was reflected for shoe specialists and 16.7 percent for corsetieres. In five years, according to estimates, the number of shoe specialists would have to be doubled and the number of corsetieres increased by 57.3 percent in order to meet personnel demands.

Regional samples are small, and no attempt is made to analyze the findings in this section. The reported figures are presented in Tables II and III as a matter of interest.

YEARS IN FIELD

Seventy-three (49 percent) of the corsetieres reported in this study

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[2] Executive Secretary, Committee on Prosthetic-Orthotic Education, Division of Medical Sciences, National Research Council, National Academy of Sciences, Washington, D.C.

[3] J. Warren Perry and Barbara R. Friz: "Manpower Survey," *Orthotics and Prosthetics,* 23:207-226, December 1969.

had less than ten years' experience in this type of work. (Figure 1) Twenty-three (37 percent) shoe specialists had less than ten years' experience. The numbers in both categories diminished in inverse proportion to the number of years' experience. This pattern is similar to that of the prosthetic and orthotic technicians.

SALARIES

The median salary reported for shoe specialists was $6,000.00; for corsetieres, $4,900.00. The median salary for shoe specialists showed two relatively sharp rises, one after the first four-year period, the other following the 10-14 year period. (Figure 2) The median salary for corsetieres peaked between 5 and 9 years' experience and showed little increase thereafter.

In this study, the level of median salaries for corsetieres was highest in the northeastern and western parts of the country. The regional samples were small, however, and generalizations should not be made on the basis of this study. The regional samples were even smaller for shoe specialists, and no analysis is attempted.

EDUCATION

Seventy-three percent of both corsetieres and shoe specialists reported in this study were high school graduates. The remainder, in the corsetiere category, was equally divided between those having less than a high school education and those having more. Of the remaining 12 shoe specialists, two had an educational level above that of high school.

Over half of the respondees to the survey recommended a high school level of education for both corsetieres and shoe specialists. (Table IV) However, technical school was favored for shoe specialists by 45 percent of the respondees.

The effect of educational background on salary level cannot be discerned from the findings in this study.

Table V gives the median age, salary, years in field, and average education for the two groups.

SUMMARY

Reported here are data related to 211 persons employed in two categories: corsetieres and shoe specialists. Manpower shortages, both current and projected, are also reported.

TABLE I
ANNUAL SALARIES

	CATEGORIES				
	Prosthetist-Orthotists	Prosthetists	Prosthetic Technicians	Orthotists	Orthotic Technicians
Middle 50%	$ 8,000-15,000	$ 7,000-12,000	$4,000-7,000	$ 7,000-12,000	$4,000-7,000
Median Salary	11,500	9,500	5,900	8,900	6,000
Mode	8,500 & 12,500	7,500	6,500	7,500	5,500

TABLE II
ANNUAL SALARIES
(Combined Categories)

	CATEGORIES	
	Prosthetist-Orthotists Prosthetists Orthotists	Prosthetic Technicians Orthotic Technicians
Middle 50%	$7,000 - $12,000	$4,000 - $7,000
Median Salary	9,500	6,000
Mode	7,500	6,500

TABLE III
MEDIAN SALARY BY REGION
(Combined Categories)

Regions	CATEGORIES	
	Prosthetist-Orthotists Prosthetists Orthotists	Prosthetic Technicians Orthotic Technicians
I	$ 8,500	$6,700
II	10,250	6,000
III	9,100	5,750
IV	8,700	5,500
V	10,100	6,850
VI	10,000	6,700
VII	8,900	6,100
VIII	9,000	5,500
IX	11,250	7,500
X	9,500	7,000
XI	9,700	6,510

TABLE IV

SALARY RANGE BY REGION

Prosthetist-Orthotists
Prosthetists
Orthotists

Salary Range	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Total
$ 2,000 - 2,999				1	1							2
3,000 - 3,999												
4,000 - 4,999				1				1				2
5,000 - 5,999			2	7	4			1	1	1	1	17
6,000 - 6,999	7	4	6	11	3		1	9	3	5	1	50
7,000 - 7,999	5	11	14	21	8	5	14	9	6	2	5	100
8,000 - 8,999	4	1	9	9	6	8	16	5	5	11	1	75
9,000 - 9,999	2	8	11	8	2	8	4	6	4	6	5	64
10,000 - 10,999	2	4	7	11	7	5	5	5	6	6	4	62
11,000 - 11,999	1	4	3	2	2	1	1		4	2		20
12,000 - 12,999	1	6		5	2	5	8	8	7	2	3	47
13,000 - 13,999	3	2			3	2			4	2		16
14,000 - 14,999		2	3		3	1	1		1	1		12
15,000 - 15,999	2	4	8	8	3	3	3	4	5		2	42
16,000 - 16,999			1	1							1	3
17,000 - 17,999					1	1						2
18,000 - 18,999		2		4	2				3			11
20,000 - 20,999	1			2	1		5	2	2	2		15
21,000 - 21,999				1		1						2
24,000 - 24,999				1								1
25,000+		2		3	1	1	1	1	1	4		14
Totals	28	50	64	96	49	41	59	51	52	44	23	557

TABLE V

SALARY RANGE BY REGION

Prosthetic and Orthotic Technicians

Salary Range	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Total
$ 2,000 - 2,999	1		1	1	2		1	2		1	1	10
3,000 - 3,999	1		6	11	5	1	1	3	1	1		30
4,000 - 4,999	7	12	19	21	10	7	11	5	2			94
5,000 - 5,999	4	8	17	27	8	4	10	7	1	4	3	93
6,000 - 6,999	10	11	18	18	5	11	15	7	4	1	7	107
7,000 - 7,999	4	6	4	7	12	8	5	1	9	1	2	59
8,000 - 8,999	1	2	7	6	4	3		2	5	3		33
9,000 - 9,999	2	1	4	1		2	1		1	2		14
10,000 - 10,999			1		2	1	1		3	1		9
11,000 - 11,999			1									1
12,000 - 12,999												
13,000 - 13,999	1											1
Totals	31	40	78	92	48	37	45	27	26	14	13	451

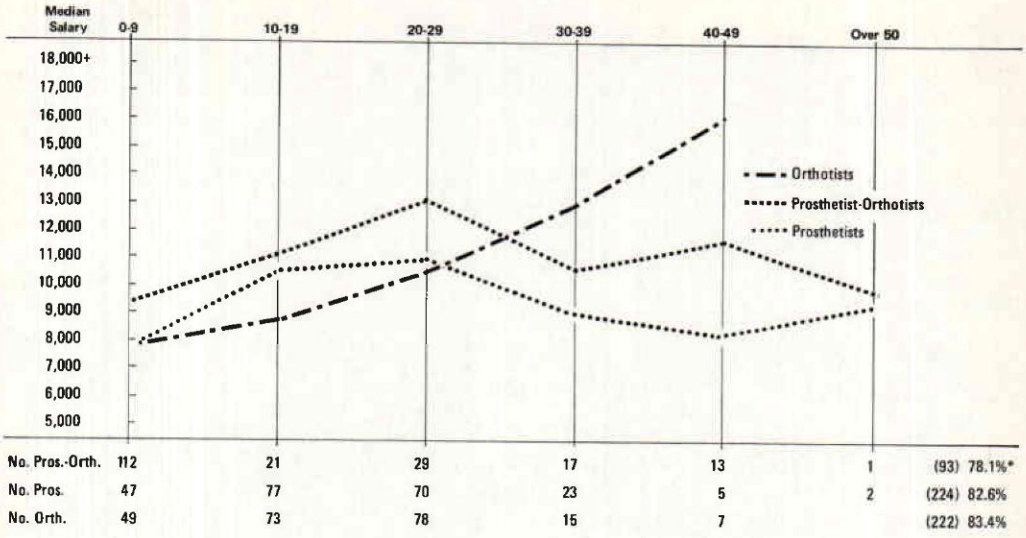

FIGURE 1

SALARY BY YEARS IN FIELD – PROSTHETIST-ORTHOTISTS, PROSTHETISTS AND ORTHOTISTS

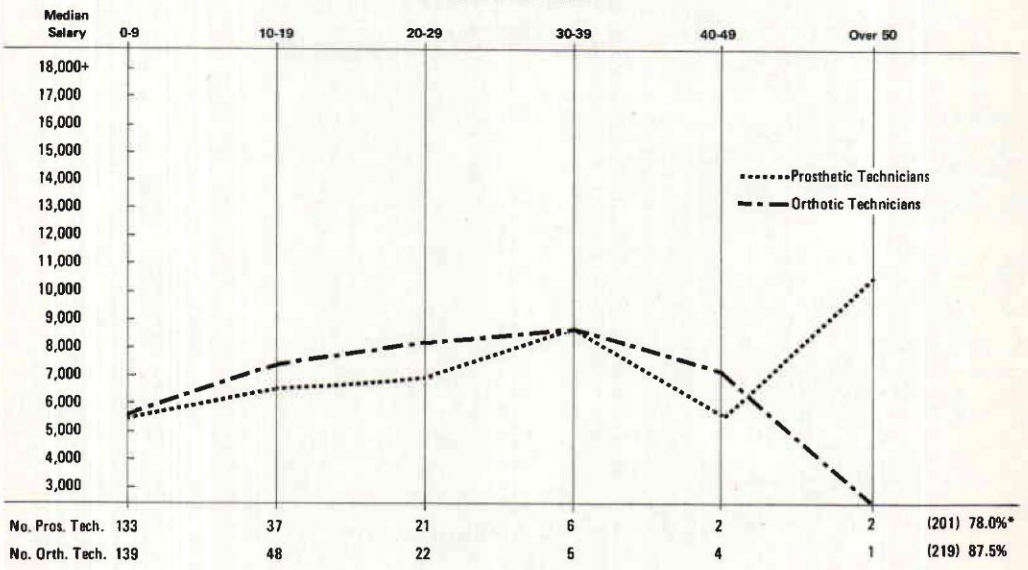

FIGURE 2

SALARY BY YEARS IN FIELD – PROSTHETIC TECHNICIANS AND ORTHOTIC TECHNICIANS.

*Figures represent the percentage of respondees who reported both salary and years in field. Some omitted one or the other; some omitted both.

TABLE I

CORSETIERES AND SHOE SPECIALISTS REPORTED IN SURVEY

	Total No.	Females	% of Total in Survey (1374)
Corsetiere	149	(140)	10.8
Shoe Specialist	62	(1)	4.5

TABLE II

ESTIMATED PERSONNEL NEEDS BY REGION

CORSETIERS

	REGIONS											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	TOTAL
CURRENTLY EMPLOYED	4	8	14	29	13	8	21	5	11	29	8	150
ESTIMATED PERSONNEL NEEDS												
Needed Now	5	10	19	34	18	9	24	5	13	30	8	175
*Percentage Inc.	25.0	25.0	35.7	17.2	38.5	12.5	14.3	–	18.2	3.4	–	16.7
Needed in 1 year	5	11	21	38	22	10	25	6	14	37	9	198
Percentage Inc.	25.0	37.5	50.0	31.3	69.2	25.0	19.0	20.0	27.3	27.6	12.5	32.0
Needed in 5 years	5	14	24	42	30	14	31	6	17	41	12	236
Percentage Inc.	25.0	75.0	71.4	44.8	130.8	75.0	47.6	20.0	54.5	41.4	50.0	57.3

*Percentage increase based on number of currently employed.

TABLE III

ESTIMATED PERSONNEL NEEDS BY REGION

SHOE SPECIALISTS

	REGIONS											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	TOTAL
CURRENTLY EMPLOYED	4	4	7	18	9	2	11	4	8	7	1	75
ESTIMATED PERSONNEL NEEDS												
Needed Now	5	6	8	23	13	3	11	5	8	7	2	91
*Percentage Inc.	25.0	50.0	14.3	27.8	44.4	50.0	–	25.0	–	–	100.0	21.3
Needed in 1 year	5	8	11	28	17	3	12	8	9	9	3	113
Percentage Inc.	25.0	100.0	57.1	55.6	88.9	50.0	90.9	100.0	12.5	28.6	200.0	50.7
Needed in 5 years	5	9	13	37	29	5	17	13	9	10	3	150
Percentage Inc.	25.0	125.0	85.7	105.6	222.2	150.0	54.5	225.0	12.5	42.9	200.0	100.0

*Percentage increase based on number of currently employed.

TABLE IV

EDUCATIONAL RECOMMENDATIONS

Category	M.A.	B.A.	A.A.	T.S.	H.S.	Elem.	Total
Corsetiere			3	39	81		123
Shoe Specialist			1	53	62	1	117
Total			4	92	143	1	240

TABLE V
PROFILE

Category	Age (Median)	Salary (Median)	Education (Average)	Years in Field (Median)
Corsetieres	52	$4,900	H.S.	10
Shoe Specialists	41	6,000	H.S.	13

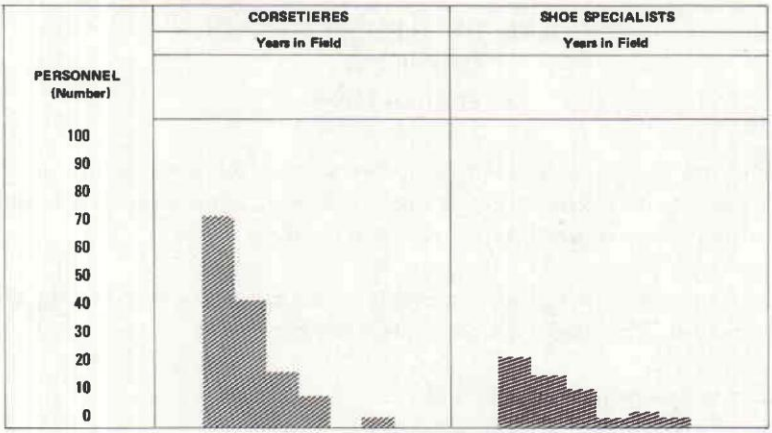

Figure 1. Number of years in field for corsetieres and shoe specialists.

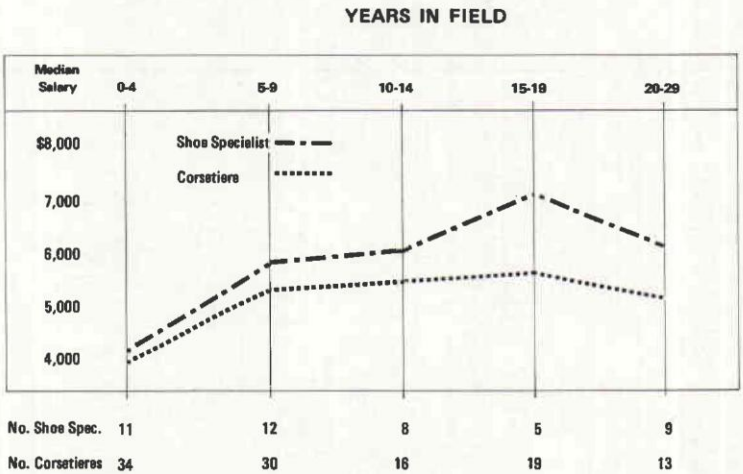

Figure 2. Salary by years in field.

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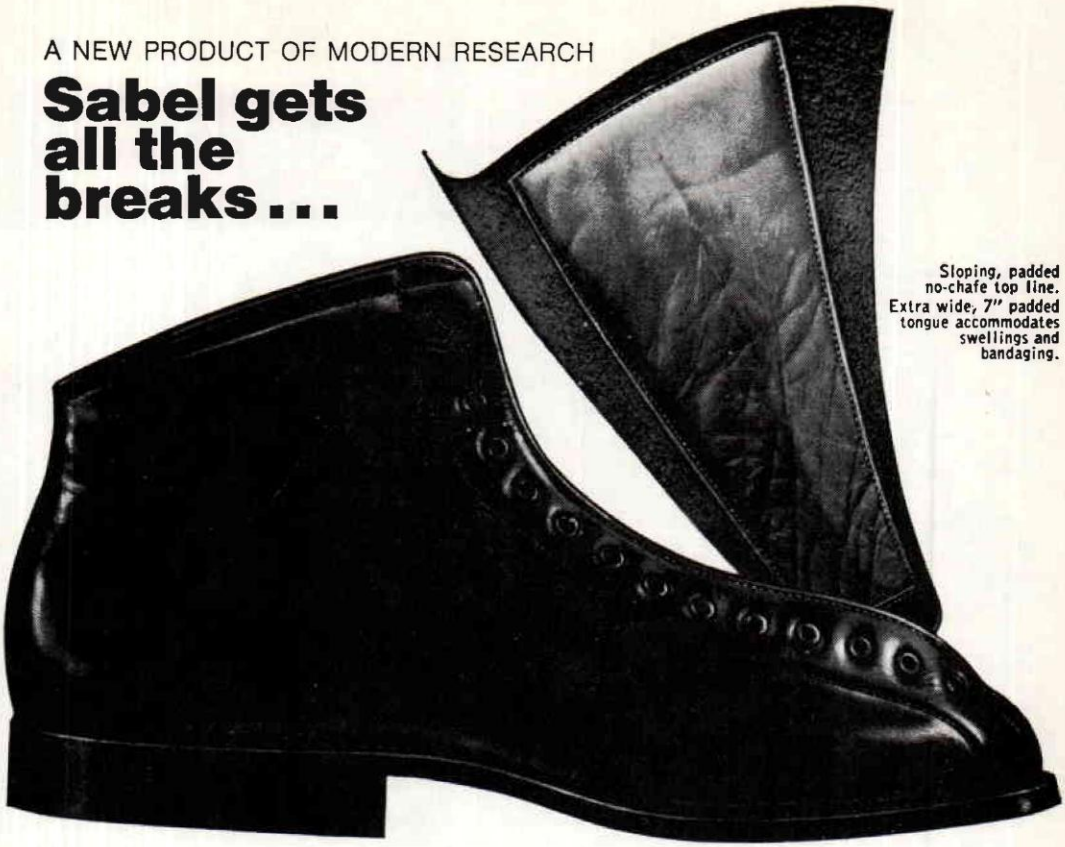

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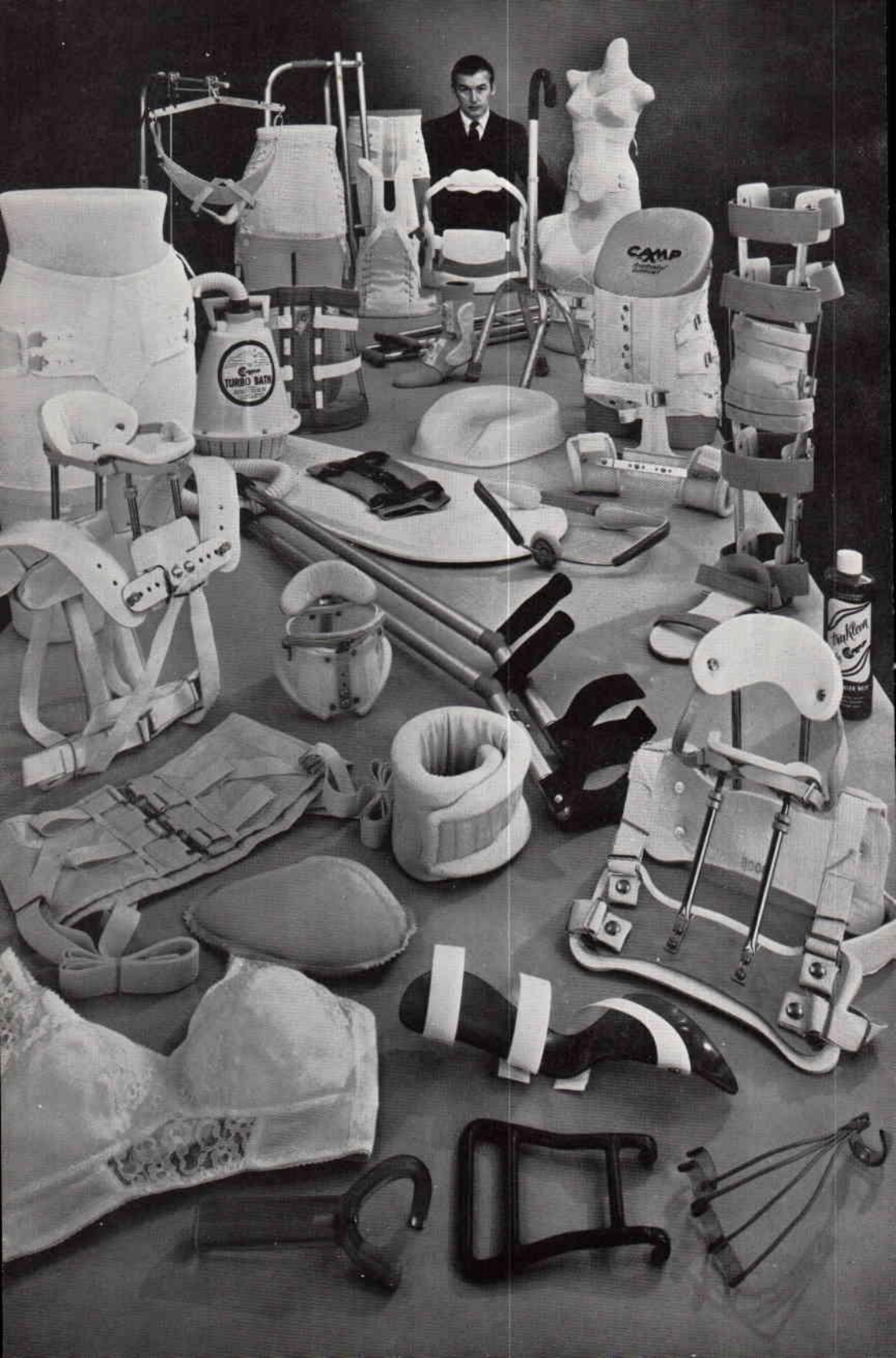
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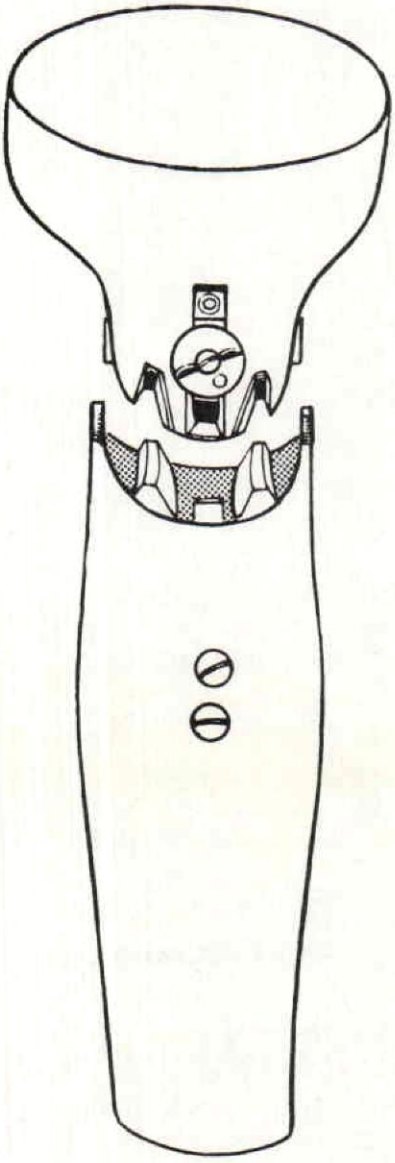

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