Autumn 1964

Artificial Limbs

A Review of Current Developments

COMMITTEE ON PROSTHETICS RESEARCH AND DEVELOPMENT

COMMITTEE ON PROSTHETIC-ORTHOTIC EDUCATION

National Academy of Sciences

National Research Council

Artificial Limbs

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Collaboration for Rehabilitation

MARY E. SWITZER[1]

I WELCOME the opportunity to express my appreciation for the wonderful cooperation and assistance that the Vocational Rehabilitation Administration has enjoyed in our many close relationships with the National Academy of Sciences—National Research Council. Our associations with the Committee on Prosthetics Research and Development and the Committee on Prosthetic-Orthotic Education have been long and fruitful, and the contributions of these committees have been substantial in the development and coordination of the research and informational programs for the fields of prosthetics and orthotics.

VRA is glad to be associated with the National Institutes of Health—which is another agency of the Department of Health, Education, and Welfare—and with the Veterans Administration in supporting the CPRD program; and, naturally, we look with special pride on the CPOE program since we are its primary support.

In our search for the judgment of the most knowledgeable people in each field which we support, the members of our National Advisory Council on Vocational Rehabilitation and the consultants on our Medical Advisory Committee have come to respect the professional competencies of the engineers, physicians, therapists, prosthetists, and orthotists who serve on CPRD. The professional advice and recommendations available to the Academy—Research Council on this basis assure impartial excellence in judgment and accessibility to professional skills that are not readily available from any other source in this country.

I have been particularly impressed with the extensive informational program that CPOE has developed, especially the brochures, films, and slides for use in schools of medicine, physical therapy, and occupational therapy and for the work that has been initiated in the development of new amputee clinics in several of our State programs.

There are special reasons why the functions of the Committees continue to hold special significance to our total rehabilitation program: State-Federal, research and demonstrations, and training activities.

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A recent study was made of the 120,000 persons who were rehabilitated in the State-Federal program during 1964, and it was found that the classifications of amputations, absence of extremities or other orthopedic deformities, accounted for a total of 42,352 persons rehabilitated. Approximately 35 per cent of the total group, therefore, were orthopedic rehabilitants. Thus, it is obvious that, even with the changing emphases in disability groups needing service, the thread of orthopedic disabilities runs through the entire program of rehabilitation, and orthopedic cases are almost four times as large as the next largest category of disability.

The VRA program of research and demonstrations, which began with a trickle ten years ago, has broadened into a flow of new ideas, methods, and patterns of service to facilitate and improve the restoration of the disabled to worthwhile lives. There have been approximately 850 VRA research projects approved during the period 1955–1964, and about seven per cent of these projects have been for studies primarily concerned with problems caused by or related to orthopedic disability. Thirty-one universities, hospitals, or rehabilitation centers have sponsored 55 research projects relevant to this field of work.

During fiscal year 1964, VRA awarded research grants to 13 new projects relating to the orthotic-prosthetic field and an additional 14 ongoing projects received continuation grants.

Some of the most imaginative and creative work in our total program is going on in this field of research, and we are constantly aware of the dramatic advancements that are taking place. The collaboration of medical rehabilitation and engineering with some of the discoveries in the space program should bring a whole new dimension to the war on disability.

So naturally we are pleased that CPRD has followed our recommendation to hold a conference on the Control of External Power in Upper-Extremity Rehabilitation so that leading engineers, physicians, and scientists can come together to formulate and coordinate their programs and assist us in developing future plans for support of their efforts.

Our training program, which continues to pour a steady stream of new professional rehabilitation workers into the ranks, has expanded so that professional training in all of the fields that contribute to rehabilitation has been influenced by VRA training grants: medicine, nursing, physical therapy, occupational therapy, rehabilitation counseling, social work, speech pathology and audiology, rehabilitation of the blind and deaf, the mentally ill and the mentally retarded, and recreation for the ill and disabled.

Since 1953, over 600 short-term courses in prosthetics and orthotics with a total enrollment of about 9,500 trainees have been attended by physicians, surgeons, therapists, counselors, prosthetists, orthotists, and related rehabilitation personnel. Last year alone, over 1,500 persons were enrolled in 90 courses which were a part of the extensive offerings in upper- and lower-extremity prosthetics and orthotics, management of the juvenile amputee, and general orientation courses for these fields. The work of the University Council on Orthotic-Prosthetic Education has done much to achieve a more uniform approach in curriculum offerings, teaching materials and methods, and evaluation procedures for the courses.

The semester courses at UCLA and Northwestern, the Associate in Arts courses proposed at Cerritos College and Chicago City Junior College, and the undergraduate curriculum at New York University—all these attest to the professionalism that is developing in prosthetics and orthotics.

CPRD's and CPOE's paramount asset to us is a technical proficiency while ours is a resource of public funds and a wealth of experience which we try to combine through the State-Federal partnership and our research and training projects into a comprehensive program for helping the disabled to reach their physical, economic, social, and personal goals. Our task, as public servants, is to administer these Federal funds as wisely as we can, always bearing in mind the true function of the law and purpose of our program: to convert dependency into competence and independence. As we work together along the paths of rehabilitation, exchanging our knowledge and our resources, perhaps we can all share in the conviction expressed on the seal of the Department of Health, Education, and Welfare which reminds us constantly that Hope is the Anchor of Life.

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The Münster-Type Below-Elbow Socket, an Evaluation[1]

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HECTOR W. KAY, M.Ed.[3]

SHORT stumps have always presented fitting problems in both upper- and lower-extremity amputation sites for the obvious reasons of small attachment area and a lack of useful range of motion. In an attempt to alleviate these problems for upper-extremity amputees, Drs. O. Hepp and G. G. Kuhn (*1*) of Münster, Germany, developed fitting techniques for the below-elbow and the above-elbow amputee, respectively, that provide a more intimate encapsulation of short stumps.

For the below-elbow amputee, the general characteristics of this technique (Fig. 1) are:

1. The elbow is set in a preflexed position (average 35 deg.). Because of the reduced range of useful motion, the socket is flexed so as to position the terminal device in the most generally useful area.
2. A channel is provided at the antecubital space for the biceps tendon to avoid interference between socket and biceps tendon during flexion.
3. The posterior aspect of the socket is fitted high around the olecranon, taking advantage of this bony prominence to provide attachment and stability to the socket.

For the above-elbow amputee, the characteristics of the technique are:

1. The socket is fitted high on the acromian, utilizing this bony structure to retain the socket in position and provide stability.
2. The axillary section of the socket conforms closely around the tendons of the pectoralis major and latissimus dorsi muscles to enable the patient to exert the force of these major muscles in moving his prosthesis.

In an earlier study (*4*), amputee clinics reported a favorable experience in fitting preflexed arms (that is, arms bent to provide a certain amount of preflexion) to children with short and very short below-elbow stumps. Since the Hepp-Kuhn technique seemed to represent an improvement in fittings of the preflexed type, New York University initiated a preliminary investigation of the procedure for adult amputees of this type. This study took place in the early part of 1961 and was limited to two short-below-elbow subjects. This exploratory study yielded generally positive outcomes in terms of function and comfort. One short-above-elbow amputee was also fitted with encouraging results.

The present evaluation is an extension of the initial study with major emphasis given to below-elbow fittings. Concurrently, further exploration of the above-elbow fitting technique was undertaken and is continuing, although not reported in this article.

For lack of a better term, the fitting procedures employed in this study are referred to as the "Münster-type" techniques. It should be emphasized that no claim is made that the techniques are identical to those followed by Drs. Hepp and Kuhn. New York University

[1] Based upon *The "Müenster" Type Fabrication Technique for Below-Elbow Prostheses*, published by Adult Prosthetic Studies, Research Division, School of Engineering and Science, New York University, New York, N.Y., in June 1964 (*3*). The study reported was conducted under the auspices of the Subcommittee on Evaluation of the Committee on Prosthetics Research and Development, National Academy of Sciences—National Research Council, 2101 Constitution Ave., N.W., Washington, D.C. 20418. The research was sponsored by the Vocational Rehabilitation Administration, Department of Health, Education, and Welfare.

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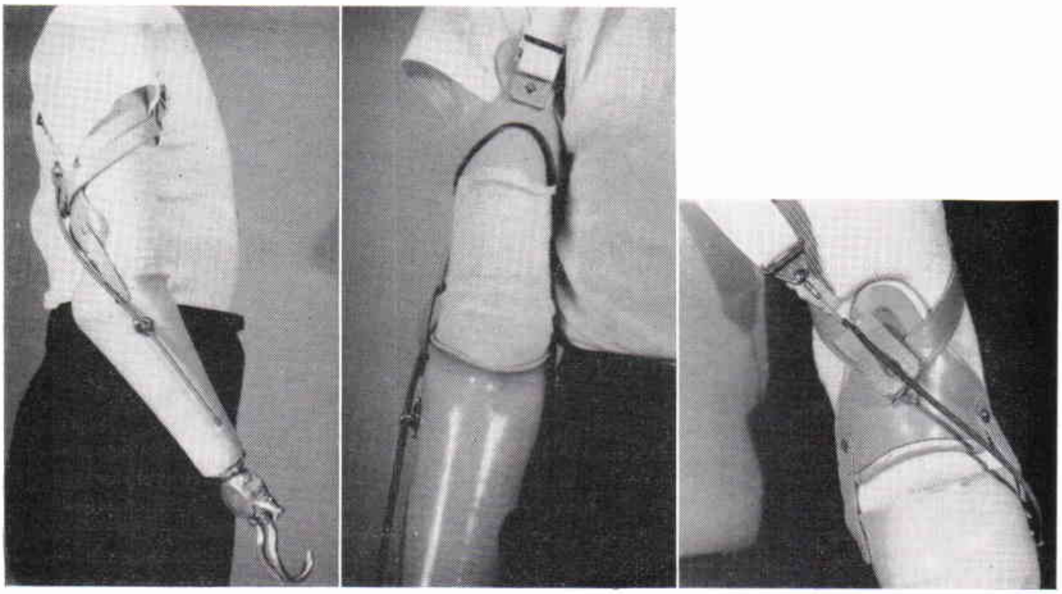


A B C

Fig. 1. Münster-type fitting for below-elbow amputee. *A*, Lateral view indicating the preflexion angle; *B*, anterior view indicating high trim line; *C*, posterior view indicating high olecranon fit and the small triceps pad.

personnel witnessed a demonstration of the techniques given by Dr. Kuhn in 1960 and had available the cited reference. However, none of the New York University fittings were either directly or indirectly supervised or checked by the developers.

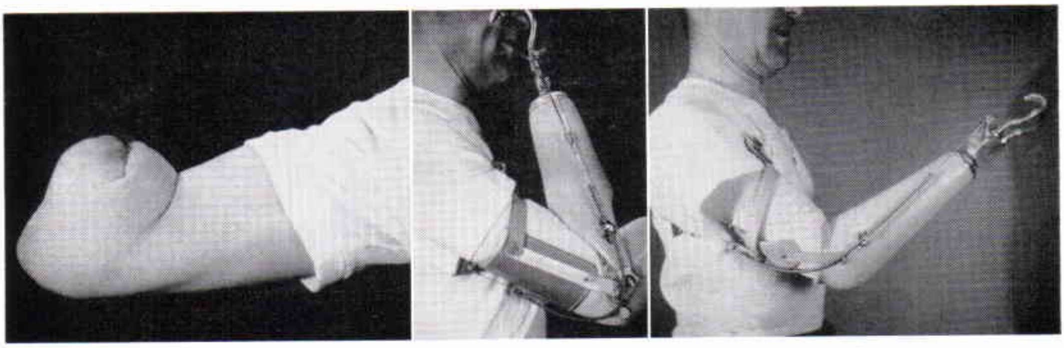
Both logic and prior experience suggest that the greatest benefit from the Münster-type below-elbow fitting technique may accrue to subjects with short and very short below-elbow amputations in that the step-up hinges and split sockets characteristic of typical United States fittings for these categories could be eliminated. Historically, step-up hinges have lacked durability. Moreover, a price is paid for the step-up characteristic by a corresponding decrease in lifting power. Contrariwise, it is apparent that the range of elbow flexion is reduced by the Münster-type fitting. This reduction may or may not be significant in terms of amputee function (Fig. 2).

The Sample

The sample in this study consisted of eight adult below-elbow amputee subjects (including one bilateral amputee) whose stumps were relatively short—from 3¼ in. to 5½ in. measured from the medial epicondyle to the end of the stump. The physical characteristics of the sample and a description of their previously worn prostheses are given in Tables 1 and 2.

Methodology

The Münster-type techniques for fitting below-elbow prostheses, as understood by New York University personnel, were followed in fabricating experimental arms for the eight subjects in the sample. In one case (WP), however, the anterior trim line (channel for biceps tendon) was reduced in order to provide this bilateral amputee with a greater range of elbow flexion. All prostheses incorporated triceps pads, leather hinges, and figure-eight harnesses. Six of the eight subjects (OB, PL, TM, WP, ES, and PW) were fitted with polyester porous sockets fabricated in accordance with the technique developed at the Army Medical Biomechanical Research Laboratory (formerly the Army Prosthetics Research Laboratory) (*2*). The other two subjects (DC and QS) were fitted with nonporous plastic sockets.



A B C

Fig. 2. Comparison of split socket and Münster-type fitting of very short below-elbow case. *A*, Very short below-elbow stump—$3\text{-}\frac{1}{4}$in.; *B*, split socket with step-up hinge provides 140 deg. of elbow flexion; *C*, Münster-type fitting permits less elbow flexion but enables the amputee to carry considerably greater weight with flexed prosthesis unsupported by harness.

Table 1. Characteristics of the Sample ($N = 8$)

Subject	Sex	Age	Site	Stump Length (in.)	% of Sound Side	Occupation
OB	M	64	LBE	$5\frac{3}{8}$	54	Salesman
DC	M	35	RBE	$3\frac{1}{4}$	34	Administrative Research Assistant
PL	M	60	RBE	$4\frac{7}{8}$	51	Unemployed
TM	M	41	RBE	$3\frac{1}{2}$	33	Public Relations Representative
WP	M	40	LBE	$5\frac{1}{2}$	52	Social Worker
			RBE	4	37	
ES	F	38	LBE	4	47	Teacher
QS	M	53	LBE	$4\frac{1}{4}$	40	Unemployed
PW	M	45	LBE	$5\frac{1}{2}$	56	Attorney

Table 2. Characteristics of Conventional Prostheses

Subject	Terminal Device	Wrist Unit	Socket	Hinges	Harness
OB	APRL Hand	Friction	Plastic Porous Laminate	Single Pivot	Half-Cuff Figure-8
DC	Sierra 2-Load Hook	Friction	Plastic Split-Socket	Step-up	Half-Cuff Figure-8
PL	Becker Hand	Friction	Wood	Single Pivot	Full Cuff None
TM	APRL Hook	Quick Disconnect	Plastic Porous Laminate	Single Pivot	Half-Cuff Figure-8
WP					
R	English Hook	Quick Disconnect	Leather	Single Pivot	Half-Cuffs
L	English Hand	Friction	Leather	Single Pivot	Modified Bilateral Figure-8
ES	Passive Hand	Friction	Wood	Single Pivot	Half-Cuff No Harness
QS	Dorrance Hook	Hosmer FM-100 Quick Dis-connect	Plastic	Polycentric	Half-Cuff Figure-8
PW	APRL Hand	Friction	Plastic Porous Laminate	Flexible Leather	Half-Cuff Figure-8

The evaluation consisted essentially of a "before" and "after" comparison of status. The prosthetic status of all subjects in this study was assessed prior to their fitting with the Münster-type prosthesis in order to obtain a basis for later comparison. At one month and at six months after delivery of the experimental prosthesis, the prosthetic status of the subjects was reevaluated and comparisons between the conventional and experimental prostheses were drawn.

The stumps of all subjects were examined prior to the experimental fitting in order to identify their condition (scars, irritations, discolorations, etc.). This examination was repeated at the specified intervals to see what effect, if any, the experimental socket had had on the physical condition of the stump.

Two self-administering rating scales completed by all subjects elicited their opinions regarding prosthetic comfort, function, and cosmesis. A questionnaire was administered prior to the experimental fitting to assess the amputees' opinions regarding their conventional prostheses. A comparative questionnaire was administered in the post-fitting evaluations to compare the experimental and the conventional prosthesis in the factors previously rated.

A prosthetic-usefulness schedule (*3*) was applied to the six subjects who had previously worn a functional prosthesis to investigate their opinions concerning the relative value and comparative ease of performance of the conventional and experimental prostheses in the areas of work, home tasks, social life, dressing, and eating.

Three evaluation procedures were administered to the six subjects who had previously worn functional prostheses, as follows:

1. The angles of preflexion and maximum flexion were measured on both conventional and experimental prostheses, as well as the amount of vertical downward force the amputees could resist with their elbows flexed at 90 deg. (live lift) and fully extended (axial load).
2. The accuracy of positioning control exhibited by the amputees was measured with both conventional and experimental prostheses. Scoring of performance on the positioning control test (*3*) was in terms of accuracy and speed.
3. The amputees' ability to perform a series of 12 bimanual practical activities was rated on a seven-point scale. For each activity, six factors were rated independently but simultaneously by two experienced examiners. This evaluation was administered initially to the amputees with their conventional prostheses and then repeated with the experimental prostheses at the one-month and at the six-month post-fitting evaluations.

Results

STUMP EXAMINATIONS

In all cases a period of two to three weeks was required for the subjects to become adjusted to the more intimate fit of the Münster-type socket. During this initial wear period, the usual complaint was of an irritation in the medial epicondylar area, which was corroborated by visual examination. However, after this adjustment period, the experimental socket had no observed or reported effects on the amputation stump, although amputees were generally aware of increased pressure on the olecranon when the forearm was flexed.

AMPUTEE REACTIONS

Comparative reactions to the conventional and experimental prostheses were obtained from the eight subjects in the sample. The factors investigated and the amputees' ratings are presented in Table 3.

It is clear from Table 3 that, with few exceptions, the amputees reacted very favorably to the Münster-type prosthesis. Sixty per cent of the responses were favorable toward the experimental item while only five per cent were unfavorable. The two factors which brought forth negative reactions were comfort (two subjects) and adjustments (two subjects). These negative reactions reflect difficulties experienced by these two amputees in adjusting to the intimate fit of the Münster-type socket. However, all seven subjects in the sample who had previously worn rigid hinges of one type or another cited the elimination of these hinges as a definite contribution to comfort.

No differences in reactions which could be attributed to socket porosity, or lack of it, were noted. The fact that the wear period for most of the subjects was confined to the winter months may explain this lack of difference.

The data on effort and control are of particular interest. All subjects in the sample reported improvement in these factors as a result of wearing the experimental prosthesis. Further questioning revealed that the ampu-

TABLE 3. AMPUTEE REACTIONS, EXPERIMENTAL VS. CONVENTIONAL ($N = 8$)

Factors Compared	Composite Opinions				
	Much Better	Somewhat Better	Same	Somewhat Worse	Much Worse
Comfort	—	5	1	2	—
Weight	5	1	2	—	—
Effort	5	3	—	—	—
Function	5	2	1	—	—
Control	7	1	—	—	—
Noise	1	1	6	—	—
Adjustments	—	—	6	2	—
Cosmesis	2	4	2	—	—
Activities	4	1	3	—	—
Durability	1	—	7	—	—
Totals	30	18	28	4	—
Percentage	37	23	35	5	—

tees' opinions regarding improved prosthetic control with less expenditure of effort appeared directly attributable to the more intimate fit of the Münster-type socket. This reaction was commonly expressed by such statements as: "The prosthesis feels a part of me" and "I feel right-handed again." Several subjects reported that the Münster-type sockets did not tend to slip off their stumps under load, as was the case with their conventional sockets. One subject cited the more secure fitting of the Münster-type socket to be particularly advantageous in performing overhead activities because his stump did not slip out of the socket when he performed a pulling motion with the prosthesis.

The reactions of the two subjects (ES and PL) who had previously worn nonfunctional prostheses (for 15 and 20 years, respectively) are noteworthy. Neither became especially skillful prosthesis users in the course of the study, but both did come to use their terminal devices for grasp, which they had not previously done. Their highly positive responses to the experimental item and the fact that it changed their prosthetic status from that of nonusers to users after so long a period were considered quite unusual. Since both patients were fitted with porous laminate sockets, the role of the Münster-type fitting is not completely "pure" but, at least, must be regarded as contributory.

Of the six subjects who had previously worn functional devices, five were able to perform the same number of activities with the experimental prostheses as with the conventional, while one subject reported increased prosthetic function with the Münster-type prosthesis (for example, he was able to carry a coat on his flexed forearm and was able to use his prosthesis in steering a car). However, all six amputees indicated that activities were easier to perform with the experimental prosthesis because the close-fitting socket afforded better control and the elimination of the rigid hinges provided greater freedom.

In no case was there any evidence that the decreased range of motion with the experimental prostheses caused an appreciable decrease in prosthetic function. Since unilateral amputees routinely use their prostheses as assistive devices, there are few activities that are performed prosthetically at the extreme ends of the flexion-extension range. Bilateral subjects, however, are dependent on their prostheses for all upper-extremity functions and therefore require a greater range of motion. To provide the bilateral subject in our sample with an increased range of elbow flexion on his dominant side (40 deg. to 120 deg.), the anterior trim line was lowered. In addition, a wrist-flexion unit was provided to facilitate the performance of tasks close to his body.

FUNCTIONAL EVALUATION

Biomechanical Data

The Münster technique provides an intimate encapsulation of the amputated stump

TABLE 4. COMPARISON OF ELBOW-FLEXION RANGE (N = 9)

Subject	Preflexion		Maximum Flexion	
	Conventional deg.	Experimental deg.	Conventional deg.	Experimental deg.
OB	12	20	97	85
DC	15	34	135	95
PL	15	45	120	110
TM	15	32	105	97
WP				
R	15	40	110	100
L	15	40	135	120
ES	30	35	125	116
QS	15	30	135	113
PW	15	35	135	104
Means	16.33	34.55	121.88	104.44

TABLE 5. COMPARISON OF HOLDING FORCES (N = 7)

Subject	Live Lift (ft./lbs.)		Axial Load (lbs.)	
	Conventional	Experimental	Conventional	Experimental
OB	18	22	40	50
DC	2	10	35	70
TM	18	24	50	60
WP				
R	4	12	35	30
L	9	31	40	29
QS	9	10	40	21
PW	14	23	30	45
Means	10.57	18.85	38.57	43.57

which results in a decreased range of motion. Forearm rotation is virtually eliminated, and the elbow flexion-extension range is significantly reduced. However, this type of fitting frequently increases the amputees' ability to resist moments about the elbow and to sustain axial loads.

A comparison of the flexion ranges of the conventional and experimental prostheses is presented in Table 4.

The preflexion angle of the Münster-type socket ranged from 20 deg. to 45 deg., with an average of 35 deg. The exact preflexion angle was planned for each subject contingent on such factors as stump length, natural elbow motion, and amputee preference. Maximum flexion of the experimental sockets ranged from 85 deg. to 120 deg. with an average of 105 deg.

Table 5 compares the maximum holding forces that amputees (the six who had previously worn functional prostheses) were able to maintain with both prostheses. "Live lift" refers to the amount of vertical downward force (applied at the terminal device) that an amputee can resist while maintaining his elbow at 90 deg. (Fig. 3). To allow for different forearm lengths, the data are expressed in foot-pounds. "Axial load" refers to the amount of vertical downward force applied at the terminal device that an amputee was able to resist with his elbow in an extended position. A complaint of pain or one-inch slippage