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*A Review of
Current Developments*



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**National Academy of Sciences
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An Evolution in the Care of the Child Amputee

CHARLES H. FRANTZ, M.D.¹

During the past twenty years the child amputee has emerged as a clinical entity requiring specialized medical and paramedical services. Prior to World War II, no precise methods of management existed. Common practice in fitting a child amputee with a prosthesis involved procrastination.

The extent of the change that has occurred is well illustrated by two articles appearing in this issue of *Artificial Limbs: Recent Concepts in the Treatment of the Limb-Deficient Child*, by Cameron B. Hall, M.D., and the report of the Consultants to the Subcommittee on Child Prosthetics Problems on *Nomenclature for Congenital Skeletal Limb Deficiencies*. Dr. Hall's article presents an overview of current thinking on the subject, while the nomenclature focuses attention on the precise identification of congenital limb malformations. Many events have contributed to this evolution in thinking and practice.

In September 1946, under the aegis of the Michigan Crippled Children Commission, an amputee training center was inaugurated at the Mary Free Bed Guild Children's Hospital and Orthopaedic Center in Grand Rapids, Mich. This project was inspired by the late Carleton Dean, M.D., who was then Director of the Michigan Crippled Children Commission. In the early 1940's, Dr. Dean had recognized that something was amiss in the habilitation of child amputees. He was vitally interested in the amputee program that had been developed by the Armed Services and the Veterans Administration. The science of prosthetics was advancing at a phenomenal pace. New mechanical components were being developed and were proving to be superior to anything heretofore available. Plastic protheses were supplanting the old conventional wooden limbs. Dr. Dean argued that there was no reason why these advances could not be used for child amputees.

¹ Chairman, Subcommittee on Child Prosthetics Problems, December 5, 1955-June 30, 1966. When the Subcommittee was formed in 1955 it was a part of the Prosthetics Research Board, the predecessor of the present Committee on Prosthetics Research and Development. The Subcommittee became a standing subcommittee of CPRD when CPRD was formed in 1959. Dr. Frantz, an orthopaedic surgeon in Grand Rapids, Mich., is Medical Co-Director of the Area Child Amputee Program, Michigan Crippled Children Commission. On July 1, 1966, Dr. George T. Aitken, who also is an orthopaedic surgeon in Grand Rapids and Medical Co-Director of the Area Child Amputee Program, Michigan Crippled Children Commission, became Chairman of the Subcommittee on Child Prosthetics Problems.

Little (if any) literature on the management of the child amputee was available, although Dr. Atha Thomas, of Denver, had written a very interesting and instructive chapter entitled "Prostheses for Children" in his book, *Amputation Prosthesis* (3). In this chapter he advocated amputation in tibial hemimelia, foot removal in proximal femoral focal deficiency, and in pseudoarthrosis of the tibia. Dr. Thomas discussed overgrowth of the fibula as a complication of the child amputee and advocated osteoplastic procedures as described by Nikitin (2) and Barber (1). Of singular significance is the fact that Thomas advocated "early fitting."

Four years after the opening of the child amputee center in Grand Rapids, the professional personnel presented a formal paper on *The Juvenile Amputee* at the annual meeting of the American Academy of Orthopaedic Surgeons in February 1950. One hundred ninety-two cases were analyzed in detail. In addition to this presentation, a 28-minute motion picture depicted the problems of the child amputee and demonstrated fitting and training techniques. A scientific exhibit outlining the methods utilized in the care of the child amputee through the team approach was also displayed. Thus, for the first time, the child amputee was identified as an entity to the medical community. Five principles of treatment were stressed:

1. Physical examination and stump evaluation.
2. Utilization of physical and occupational therapeutic methods.
3. Detailed coordination of prosthetic fabrication and fitting.
4. Inpatient prosthetic training.
5. Regularly scheduled outpatient follow-up in an organized child amputee clinic.

In January 1954 a workshop was held in Grand Rapids to review the total child amputee problem. Representatives of the Children's Bureau of the Department of Health, Education, and Welfare, the University of California at Los Angeles, New York University, and the Army Prosthetics Research Laboratory (now the Army Medical Biomechanical Research Laboratory) attended. The individual members of the conference enthusiastically endorsed the proposition that an organized program of treatment for child amputees in the United States was definitely indicated. An attempt was made to define the child amputee as compared to the adult amputee. It was agreed that the child amputee could be described as a growing, immature, dependent individual whose long bone epiphyses were still "open."

In December 1955, in formal session, the Prosthetics Research Board appointed an *ad hoc* committee of seven members charged with developing recommendations relative to child amputees in the United States. The outcome of this effort was the formation of the Subcommittee on Child Prosthetics Problems. Its mission was to develop information, and to advise the Prosthetics Research Board on all aspects of the child amputee situation in the United States.

During March 1956 the Subcommittee on Child Prosthetics Problems mailed questionnaires to 84 prosthetists and 25 orthopaedic clinics throughout the United States. The response was prompt and enlightening. Analysis of the re-

turns indicated universal interest in child amputee treatment procedures. Shop practices were sharply individualized, and no precise criteria for training existed. At this time there appeared to be only four specialized juvenile amputee clinics in the United States.²

With this background of information, the Subcommittee proceeded to encourage the development of child-sized prosthetic components. This endeavor involved not only the miniaturization of adult-sized components but also the introduction of specially designed features so that the devices could be operated by young children. With the assistance of the Army Prosthetics Research Laboratory under the direction of Colonel M. J. Fletcher, the Child Amputee Prosthetics Project at UCLA under the direction of Drs. Craig Taylor and Milo Brooks, and the sound evaluation services of New York University under the direction of Dr. Sidney Fishman, components were gradually developed, fitted, and evaluated relative to their efficiency on child amputees.

Stimulated by Dr. Arthur J. Lesser of the Children's Bureau (who was then a member of the Subcommittee on Child Prosthetics Problems), significant steps were taken to encourage the formation of specialized child amputee clinics as a means of standardizing practices in the management of juvenile amputees throughout the country. With the ultimate goal of having a clinic within reach of every child amputee in the nation, definite criteria outlining the requirements for the operation of a satisfactory amputee clinic were formulated. As qualified clinics were established, the cooperative investigation of difficult clinical problems was undertaken. Since these clinics were devoting their efforts exclusively to the child amputee, techniques, appliances, and practices could be introduced and critically evaluated through New York University. Over the years the findings of these studies, which have been analyzed and published, have resulted in the evolution of standards of management never before attained. The fruitfulness of these endeavors is well illustrated by the fact that the Committee for Care of the Handicapped Child of the American Academy of Orthopaedic Surgeons, in conjunction with the Children's Bureau, recently published a document entitled *Standards for the Care of the Juvenile Amputee*. These standards, which have had nationwide distribution, are essentially the same as those that have evolved through the cooperative research program.

The growth in the number of child amputee clinics has been most gratifying. As of January 1966 they numbered twenty in the United States and two in the Dominion of Canada.

During the early years of the child amputee program, clinical statistics indicated a ratio of two post-traumatic or postsurgical amputees to one congenital amputee. However, in a period of eight to ten years, a dramatic change has occurred: *First*, because of the publicity given to the treatment program, chil-

² Area Child Amputee Center, Michigan Crippled Children Commission, Grand Rapids, Mich., George T. Aitken, M.D., and Charles H. Frantz, M.D. (1946); Kessler Institute for Rehabilitation, West Orange, N.J., Henry H. Kessler, M.D. (1949); University of Illinois Amputee Clinic, Chicago, Ill., Claude N. Lambert, M.D. (1952); Child Amputee Prosthetics Project, University of California, Los Angeles, Calif., Milo B. Brooks, M.D. (1953).

dren began to appear in clinics at a much younger age than previously. At this very young age, the majority of patients have limb deficiencies that are congenital in nature. *Second*, the logical consequence was a tipping of the scales of etiological incidence to the congenital type. At present, the majority of clinics report a ratio of five congenital types of deficiencies to two acquired types.

Thus the meaning of the term "juvenile amputee" has broadened to encompass post-traumatic amputees, postsurgical amputees, and congenital limb deficiencies and malformations.

In 1961 another significant step was taken by the Subcommittee on Child Prosthetics Problems. In that year it initiated publication of the *Inter-Clinic Information Bulletin*. The first issue was published in October 1961, and the *Bulletin* has appeared monthly ever since with articles written by the clinic chiefs pertinent to the child amputee. The success of this project is attested by the figures of March 1966 when 1,700 copies were printed and 1,565 were distributed; 351 individuals and institutions received 630 copies. In addition 400 copies were sent to the World Rehabilitation Fund for distribution to its members and 535 to the American Orthotics and Prosthetics Association for distribution to its membership.

The impact of the thalidomide tragedy in Europe (West Germany and England) in 1959-1962 focused attention again on the need to improve prostheses, especially when malformed limbs or the complete absence thereof made it difficult to fit conventional suspension and power and cable systems.

Heidelberg University had worked with pneumatic power and applied its principles very successfully to these children. Since then there has been a concerted effort in the United States to exploit external power, utilizing compressed carbon dioxide and electricity as power sources. At the present time, a significant number of children throughout the country are wearing externally powered prostheses on an experimental basis.

Laboratories are continuing to develop devices in an effort to decrease weight, provide easier application, and improve power sources. There is good reason to believe that as time goes on these endeavors will bear fruit in improved, practical prosthetic function. Interest in child amputees is growing steadily in all parts of the world. These children—many of them multihandicapped—now have a much greater hope for better appliances and services than they ever had in the past.

In retrospect, it is evident that much has been achieved by the Subcommittee on Child Prosthetics Problems during the past ten years, but also that much remains to be done. Hopefully, the foundations have been laid for further advances.

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3. Thomas, Atha, and Chester C. Haddan, *Amputation prosthesis*, J. B. Lippincott, Philadelphia, 1945.

The Evolution of the Georgia Warm Springs Foundation Feeder

ROBERT L. BENNETT, M.D.

Thirty years ago (March 1936) a young lady from Crawfordsville, Ga., was fitted at the Georgia Warm Springs Foundation with what was referred to in her medical record as "an

¹ Executive Director, Georgia Warm Springs Foundation, Warm Springs, Ga. 31830; member, Committee on Prosthetics Research and Development, National Academy of Sciences—National Research Council, Washington, D. C.

ingenious device" (Fig. 1). This apparatus was later called a "foot-operated feeder" because it required voluntary extension of her foot against a movable footboard on her wheelchair to bring about tilting of the seesaw cradle supporting her forearm. In this manner, she was able to feed herself. She used this device for twenty years and then returned to Warm Springs and was fitted with a far more efficient type with the imposing name "balanced forearm ortho-



Fig. 1. "An ingenious device" supplied in 1936 to a patient at Georgia Warm Springs Foundation; also known as a "foot-operated feeder "

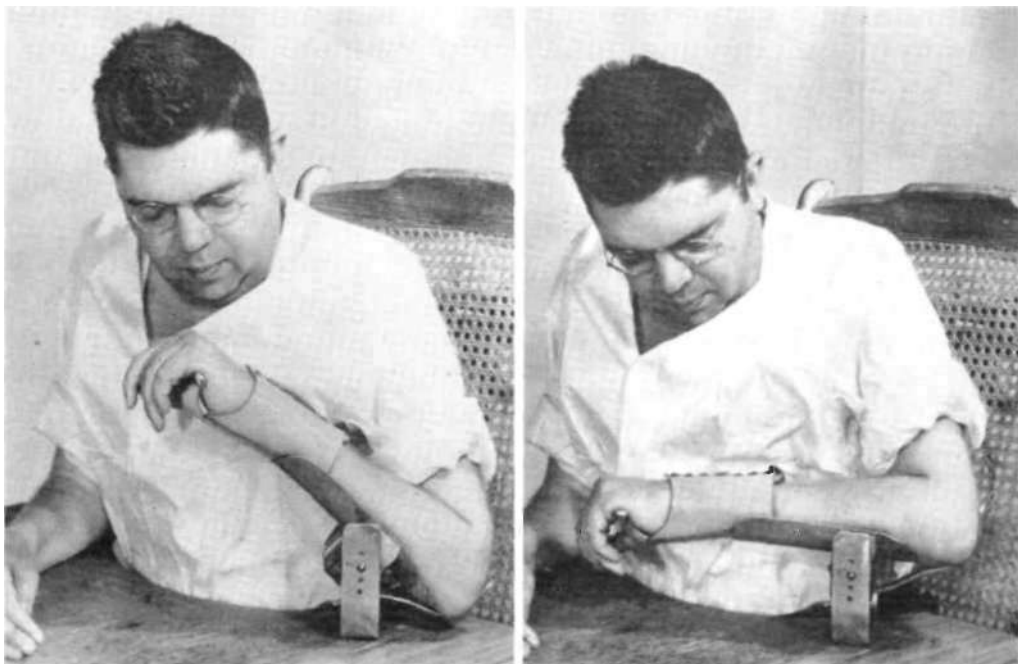


Fig. 2. Two views of the "Barker feeder" of June 1936. Perhaps the true ancestor of the present-day device, it required shoulder depression to bring the hand toward the head.

sis."² The "ingenious device" just mentioned appears to have been the first feeder ever used at Warm Springs, and perhaps the first ever used anywhere.³

² Dr. Bennett has a personal preference for the terms "orthesis" and "orthotics" (introduced by Dr. Bennett in an article entitled *Orthotics for Function* in the *Physical Therapy Review*, Vol. 36, No. 11, November 1956) rather than "orthosis" and "orthotics" (*Artificial Limbs*, Spring 1965). In 1959, at the request of CPRD, the American Orthotics and Prosthetics Association—then known as the Orthopedic Appliance and Limb Manufacturers Association—studied the question of "orthotics" vs. "orthotics," bringing together information from Greek scholars and lexicographers, as well as from members of CPRD, CPOE, and the fields of prosthetics and orthotics. At that time the terms "orthotics," "orthotist," and "orthosis" were adopted and have been generally used since.

³ In transmitting this article to *Artificial Limbs*, Dr. Bennett wrote: "Mrs. Hazel O'Connor, who should be given the major credit for the development of the modern Georgia Warm Springs Foundation feeder, is continuing to review the literature regarding similar devices and would be most appreciative of hearing from anyone with factual data, reprints, pictures, etc., of early feeders, particularly devices used before March 1936."

In June 1936 is found what appears to be the first feeder used at Warm Springs that required shoulder depression to bring the hands toward the head, and perhaps this feeder should be thought of as the true ancestor of our present-day device. As can be seen in Figure 2, the 1936 device consisted of a metal yoke bolted to the lapboard of a wheelchair but free to revolve horizontally. A metal forearm cradle fastened to the yoke by a wooden block moved vertically in a seesaw fashion. This was called a "Barker feeder," since Edward H. Barker was the first patient to use the device. Over the next few years, at least three patients were fitted with this type of feeder.

Reviewing the literature to determine the first feeder and then tracing the development of the feeder at Warm Springs has been an unexpectedly difficult and time-consuming job. It has been most difficult to separate mobile supportive devices used in the treatment of the paralyzed upper extremity from the functional seesaw devices used to assist the patient with a paralyzed biceps to flex his elbow.

Looking back over the years, one is rather amazed to find that it took so long to develop

the present-day balanced forearm orthosis. The excuse must be that the development of truly efficient orthotic devices comes only with persistent patient demands and long usage. Extensive patient demand for this type of apparatus did not come until the mid-1940's. Records indicate that perhaps as few as 20 feeders were made at Warm Springs between 1936 and 1946. It should be remembered that prior to the occurrence of large epidemics of poliomyelitis in the early 1940's there were



Fig. 3. The feeder of May 1943. The base of the "Barker feeder" has been replaced by a simple rod and collar. Several holes placed in the lapboard helped to determine the proper position for attaching the feeder.



Fig. 4. The stand feeder of March 1945. The aluminum base permitted the patient to move the feeder horizontally across the lapboard by body movements for best position.



Fig. 5. The "bird-cage feeder" of April 1946—so called because the trough was suspended in a yoke resembling the trapeze-like arrangement seen in many bird cages.



Fig. 6. Segmented-arm feeder used in December 1949.

really very few patients who survived the acute attack of poliomyelitis with massive involvement of upper extremities. As the incidence of acute poliomyelitis increased, the medical profession learned how to keep these patients alive. Rather suddenly, in the mid-1940's, Warm Springs was faced for the first time with the problem of large numbers of patients who had such weakness in their upper extremities that they could not bring their hands toward their head.

In May 1943 the bulky base of the "Barker feeder" was replaced by a simple rod and collar, the rod passing through a hole in the lapboard of the wheelchair and held in position by a simple collar (Fig. 3). Several holes were placed

in the lapboard to determine the proper position for attaching the feeder. In March 1945 the feeder was placed on a simple aluminum base (Fig. 4). This allowed the patient to move the feeder horizontally across the lapboard by body movements for best position.

The first real change in the design of feeders occurred in April 1946. The feeder was suspended from the upright of an overhead sling! Originally, it was called a "bird-cage feeder," simply because the trough was suspended in a yoke resembling the trapeze-like arrangement seen in many bird cages (Fig. 5). At this time, the Warm Springs treatment program dictated that no patient with severe upper-extremity involvement should use a feeder until late in the convalescent phase of care. Hence there was a natural transition from the use of overhead slings to protect the weakened shoulder girdle to the suspension feeder to develop functional capacity in the upper extremity. For the next ten years, there is record of 326 suspension feeders being fitted to a total of 197 patients. Only seven of this type were used after 1956, and none after 1961.

It was not until December 1949 that segmented feeder arms were used (Fig. 6). These arms were attached directly to the vertical tubing of the back of the wheelchair. Insofar as can be determined, hinged-spring control of the proximal link—seen in Figure 6—was used in

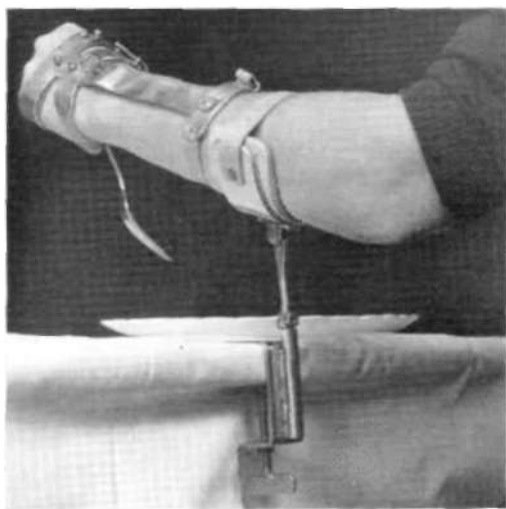


Fig. 7. C-clamp feeder developed in May 1950.



Fig. 8. Segmented-arm feeder of October 1952.



Fig. 9. Present-day Georgia Warm Springs Foundation feeder, the balanced forearm orthosis.

this instance only, and no further use of the mobile arms was made until October 1952.

The light and mobile C-clamp feeder that could be easily attached to the edge of a table, to the lapboard, or to a wheelchair arm rest was developed in the spring of 1950 (Fig. 7). Between 1950 and 1960, 61 were used on 45 patients.

In October 1952 the segmented-arm feeder was again used but without the spring hinge at the attachment of the proximal link to the back of the wheelchair. The proximal link was rigidly clamped to the upright (Fig. 8), allowing horizontal motion only. This feeder was followed in 1953 (Fig. 9) by one to which ball bearings had been added to the base and to the moving joints of the arms. The base could also



Fig. 10. Two views of a patient fitted with a corset-based feeder.

be tilted to assist movement of the proximal link. This was really the first of the present-day Georgia Warm Springs Foundation feeders. Between 1952 and 1964, 786 of these feeders were applied to 427 patients.

In September 1953 it was found that many patients with severe upper-extremity weakness had good musculature in the lower extremities and trunk; therefore, while they needed a feeder, they did not require a wheelchair. It was at this time that feeders were fitted directly to the trunk of the patient, either attached to a corset (Fig. 10) or to a belt. Between 1953 and 1961, 100 such feeders were fitted to a total of 53 individual patients.

During the years 1946 through 1964, for which the record is quite detailed and complete, a total of 1,334 feeders were applied to 773 patients. Some patients had several different

kinds of feeders, and so the latter number does not indicate that there were 773 different patients. In 1961 questionnaires were sent to 488 patients who had been fitted with feeders and who had returned to their homes with feeders. Two hundred nine replies were received; of this number, 139 (66.5 per cent) were still using their feeders.

The feeder, or balanced forearm orthosis, was developed primarily for patients with paralyzed upper extremities following acute anterior poliomyelitis; however, it is being used for many neuromuscular problems that result in lack of sufficient voluntary strength to bring the hand toward the head. More recently it has been used in conjunction with externally powered orthotic devices that activate elbow, forearm, and hand.

Preliminary Design Analysis of Linkage Feeders¹

HECTOR W. KAY, M.Ed.,² AND
NANCY V. APPOLDT, B.A.³

In 1962 the Committee on Prosthetics Research and Development authorized a survey of current orthotics research and development in a number of selected centers as an initial step in a proposed orthotics evaluation program. A prime purpose of the survey was the identification of orthotic devices and procedures as suitable subject matter for the evaluation program.

One of the devices selected as meeting the requirements for inclusion in the evaluation process was the linkage feeder designed at the University of Michigan. However, it was apparent that this device, plus a number of others, was essentially a variant of the ball-bearing feeder designed and developed two decades ago by the (Georgia Warm Spring Foundation. Hence, a review of existing feeder designs was undertaken as a prelude to any formal evaluation program.

¹ Based upon a report entitled *Preliminary Design Analysis of Linkage Feeders*, published by Prosthetic and Orthotic Studies, Research Division, School of Engineering and Science, New York University, New York, N. Y., in May 1965. The report was prepared under the general supervision of Sidney Fishman, Ph.D., Project Director, Prosthetic and Orthotic Studies, New York University. The study reported upon was supported by funds from the Vocational Rehabilitation Administration, Department of Health, Education, and Welfare.

² Assistant Executive Director, Committee on Prosthetics Research and Development, National Academy of Sciences—National Research Council, 2101 Constitution Ave., N.W., Washington D. C. 20418.

³ Assistant Research Scientist, Prosthetic and Orthotic Studies, Research Division, School of Engineering and Science, New York University, 317 East 34th Street, New York, N. Y. 10016.

The systems involved were those currently in use at the Georgia Warm Springs Foundation, Rancho Los Amigos Hospital, the University of Michigan, the Texas Rehabilitation Center, and the Texas Institute for Rehabilitation and Research. Two prefabricated units that were available commercially were also reviewed, but these units resemble the Rancho Los Amigos Hospital feeder so closely that separate consideration is not warranted.

Ideally, a feeder supports the weight of the arm and permits the patient with severely weakened or paralyzed upper extremities to position the hand with a minimum of muscular effort. The extent of a patient's performance with a feeder and his method of performance are, of course, contingent on the nature and extent of his disability.

The feeders considered in this article have numerous structural features and operational principles in common. An aluminum forearm trough and two stainless-steel swivel arms that rotate on ball or needle bearings support the weight of the upper extremity and provide useful motion when activated by a slight residual motor power in the head, neck, trunk, or arms. The joint cylinders may be rotated to bring the feeder assembly into an inclined plane which provides gravity assistance to the horizontal motions of the extremity. The trough pivot may be positioned to give a bias to both vertical motions of the forearm, namely, raising the hand to the head or lowering it to the table top.

A number of accessory components may be attached to a feeder to adapt the equipment to individual requirements without modifying the basic design. Among these are metal clips, straps, and foam-rubber liners to prevent slip-

page of the forearm; horizontal and vertical stops to restrict feeder motions to a controllable range; elastic-band and supinator assists to aid motion; and double T-bars to support the hand and provide attachments for self-help devices.

The basic principles of the various feeders being the same, a matter of interest is the significance of the points on which they differ. In Appendix A the distinctive features of each of these systems are identified and illustrated in detail. The Georgia Warm Springs Foundation model is presented as the basic design, with its apparent advantages and disadvantages. The other four designs are then compared with the Georgia Warm Springs Foundation item.

SUMMARY AND CONCLUSIONS

Linkage feeders were received from the Georgia Warm Springs Foundation, the University of Michigan, Texas Rehabilitation Center, the Texas Institute for Rehabilitation and Research, and Rancho Los Amigos Hospital. With the Georgia Warm Springs Foundation balanced forearm orthosis as the frame of reference, the design and operational features of each feeder were subjected to critical examination. In summarizing the findings of the examination, two points must be emphasized:

1. All feeders are in current and apparently successful use at the centers from which they were obtained
2. The feeders were not applied to *bona fide* patients, but were analyzed in relation to use by a normal adult.

Thus the validity of the advantages and disadvantages cited in this report might require further verification.

It is of value, however, to identify the *apparent* strengths and weaknesses of each feeder in relation to the Georgia Warm Springs Foundation balanced forearm orthosis. This feeder was the first of its kind, and its basic design served as a model for the subsequent feeders. The question that this review attempts to answer is: In what respects do the features of the other feeders appear to be superior or inferior to those of the Georgia Warm Springs Foundation Feeder?

UNIVERSITY OF MICHIGAN

The multiple adjustment features of the University of Michigan feeder appear to make

it the most versatile of those reviewed. Moreover, this adjustment capability is maintained throughout the life of the feeder, in contrast to the reduced adjustability of the "permanent" feeder which is the end product in some of the other designs.

The significant additional adjustment involves the rocker-arm assembly and allows the trough, and consequently the forearm, to be raised or lowered with respect to the trough pivot. The fore-and-aft adjustment found in other feeders is also available. Thus the forearm may be balanced against gravity in two dimensions, permitting maximum control of the forces acting about the trough pivot in horizontal, vertical, and intermediate positions of the forearm. The use of ball bearings in the distal link and trough pivot, as well as in the first and second joints, minimizes frictional forces in the system. The screw-adjustment system permits precise adjustment without the use of tools. The lateral location of the rocker-arm assembly, combined with the use of a triceps strap, permits a closer relationship between table top and trough, while the lateral space required for feeder operation is reduced by the use of a relatively short proximal link.

The prime limitations of the University of Michigan feeder are:

1. It is bulky and has a nonaesthetic appearance.
2. The nondetachable proximal link imposes the necessity for removing the entire feeder from the wheelchair when it is to be collapsed, transported, or stored.
3. The triceps strap may bind, reducing or eliminating elbow support.

TEXAS REHABILITATION CENTER

The outstanding characteristic of the Texas Rehabilitation Center feeder is its simplicity. The adjustability of link lengths should also be useful for applications to children during the growth years.

The absence of ball bearings in the proximal joint makes this feeder more difficult to maneuver in horizontal motions. The short swivel arms and stationary elbow dial restrict extension of the arm and thereby limit function to a reduced zone of motion. Contact of the elbow dial with the distal link obstructs lateral trough motion, while the rocker-arm assembly restricts the upward tilt of the trough. Because the trough is offset from the distal link

vertically, placement with relation to a table top is more distant than with the Georgia Warm Springs Foundation, University of Michigan, or the Rancho Los Amigos Hospital system, each of which has horizontally offset troughs. In order to change tilts at the first and second joints, the device must be returned to the orthotics shop.

TEXAS INSTITUTE FOR REHABILITATION AND RESEARCH

The Texas Institute for Rehabilitation and Research model is notably streamlined in appearance. Frictional resistance is minimized in horizontal feeder motions by the use of needle bearings at the end of the distal link.

As with the Texas Rehabilitation Center feeder, an orthotist must make any tilt adjustments. This lack of ready adjustment might tend to hinder a patient's performance if his wheelchair were on uneven terrain. It might also delay accommodation to improvement or regression of his disability. The trough's vertical offset from the distal link and relatively long vertical rod limit the closeness of trough placement to the table top. Moreover, to bring the trough as close as possible to the table top, clearance of the distal link is minimized (1/2 to 1 in.) and the link may strike objects on the table.

RANCHO LOS AMIGOS HOSPITAL

In the Rancho Los Amigos Hospital feeder a unique tilt adjustment is provided at the distal end of the proximal link. Adjustment of the second joint, therefore, is easier and more precise. The rocker-arm assemblies permit greater ranges of motion at the trough pivot than those

of the Georgia Warm Springs Foundation model. The outside rocker-arm assembly, which has a ball-bearing unit at the trough pivot similar to that of the University of Michigan feeder, minimizes friction in vertical motions and permits two-dimensional adjustment of the pivot relative to the forearm. A ball-bearing unit may also be added to the joint at the end of the distal link to minimize friction in horizontal feeder motions.

Each of the feeders, when compared with the Georgia Warm Springs Foundation system, appears to have both positive and negative features. On the basis of the available data, resolution of the various pros and cons as to which feeder is the best is not feasible. Certainly the thought that the most advantageous characteristics of the five feeders might be combined in one superior system has appeal.

However, selection of the optimal feeder for a particular patient depends primarily on the purpose for which the device is prescribed. Purposes may range from support of the arms in a comfortable position for the most severely disabled to increased functional independence and participation in vocational activities for others. Thus a single feeder, even one incorporating the best elements of the various designs, may not serve the needs of all patients.

Nevertheless, the similarities and differences of the five feeders identified in this review, and particularly the significance of the differences, are worthy of further study. If patients' needs in relation to the functions offered by the various components could be precisely defined, an individual's requirements might best be met by using selected components from one or more of the available feeders.

APPENDIX A

A DETAILED COMPARISON OF FIVE FEEDERS

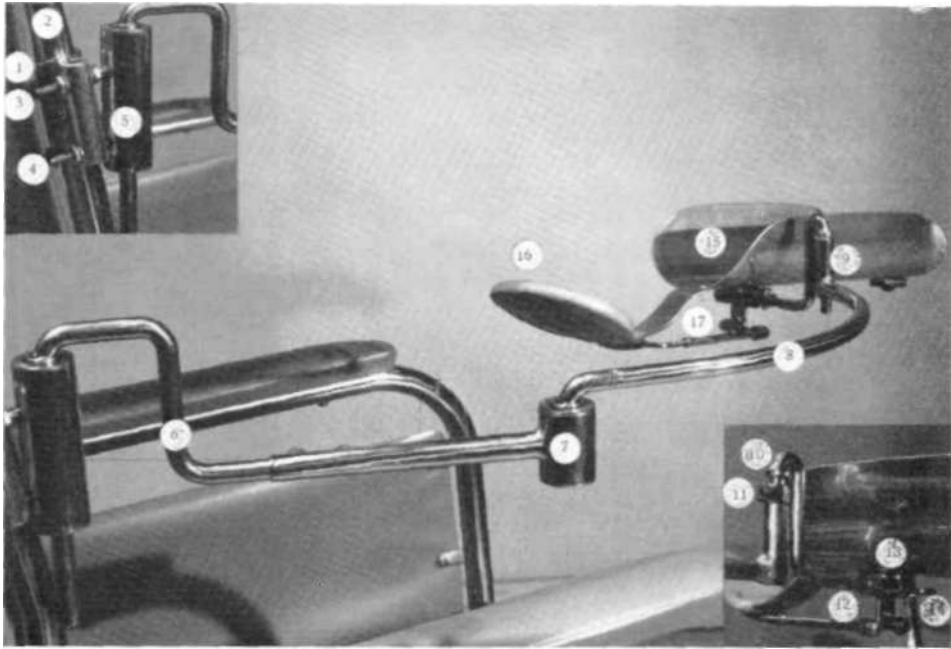


FIG. 1. The Georgia Warm Springs Foundation (GWSF) balanced forearm orthosis.

Wheelchair Assembly	Proximal and Distal Links	Rocker-Arm Assembly	Trough
DESCRIPTION			
A round clamp 1 attaches to the chair upright 2. Two screws 3 and 4 extend from the clamp to provide attachment for, and anteroposterior angular adjustment of, a ball-bearing tube 5.	The detachable swivel arm 6 terminates distally in a ball-bearing tube 7. Length of proximal link is adjustable during fitting, nonadjustable in the finished unit. The proximal link is either a drop-type 6 or straight (not shown). Accessory collars (not shown) may be used to raise the proximal link. The distal link 8, curved approximately 90 deg., terminates in a vertical tube or post 9, the height of which may be increased by height extenders (not shown).	A drop 10 or straight (not shown) offset rod inserted in the tube permits rotation of the trough. Accessory collars 11 increase rod height. The distal end of the rod fits into two sleeves 12 which rotate on the rod. The sleeves are brazed to a 1-in. flat bar with threaded holes for attachment to the underside of the trough 13. An L-shaped bar 14 soldered to the rod between the sleeves holds the movable sleeve unit on the rod.	The forearm cradle 15 has prepunched holes interiorly for anteroposterior adjustment on the sleeve bar. The elbow dial is stationary (not shown) or hinged 16 to the stem of the cradle and connected to the rocker-arm assembly by a linkage rod 17.
ADVANTAGES			
The proximal joint may be independently tilted anteroposteriorly and rotated mediolaterally to	The feeder may be removed from the chair upright without disturbing the base assembly. Mini-	The offset rod provides additional trough-link clearance. Additional height adjustment is use-	The hinged dial permits full elbow extension.

Wheelchair Assembly	Proximal and Distal Links	Rocker-Arm Assembly	Trough
provide a gravity assist or to compensate for an inclined chair upright or for slopes. There is minimal joint friction.	mal friction is present between proximal and distal links. Drop-type proximal link is useful in obtaining proper feeder height for short patients (without clamp adjustment). The straight proximal link may be used with collars to provide elevation of the feeder for taller patients. The curved distal link reduces interference between elbow and distal link. Height extenders are useful for gaining additional trough height and increasing elbow-distal link clearance.	ful in accommodating tall patients.	
DISADVANTAGES			
	Benders must be used on the proximal link to provide anteroposterior tilts at the second joint.	The L-shaped bar imposes a "down" stop on trough motion.	The stationary dial restricts elbow extension.

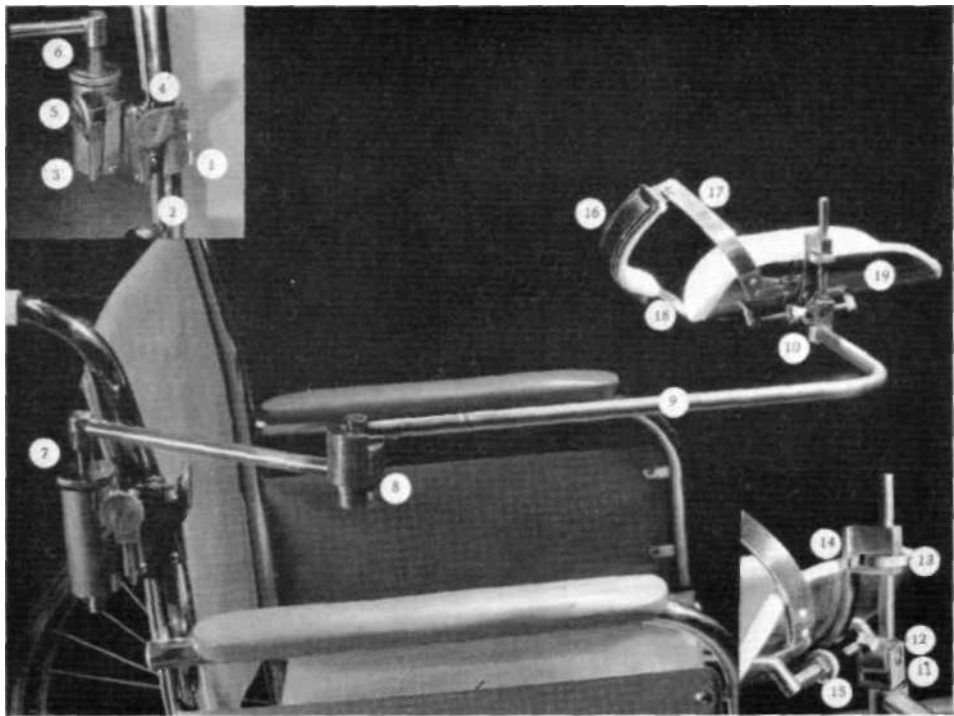


Fig. 2. The University of Michigan (U of M) feeder.

Wheelchair Assembly	Proximal and Distal Links	Rocker-Arm Assembly	Trough
DESCRIPTION			
A round clamp <i>1</i> similar to the GWSF item attaches to the chair upright <i>2</i> . An adjustment assembly connects the clamp with a ball-bearing cylinder <i>3</i> and allows positioning anteroposteriorly by screw <i>4</i> and mediolaterally by screw <i>5</i> . Feeder height may be regulated by an adjusting nut <i>6</i> incorporated into the ball-bearing tube.	The vertical portion <i>7</i> of a straight swivel arm is threaded to accommodate the height-adjusting nut. The proximal link, which terminates distally in a ball-bearing tube <i>8</i> , is relatively shorter than the GWSF item. The distal link is angled distally 90 deg. and has a ball-bearing tube <i>10</i> attached. The distal link is proportionally longer than the GWSF item.	A short vertical rod fits into the ball-bearing tube to permit horizontal rotation of the trough. Affixed to the superior end of the rod is a U-shaped housing <i>11</i> which supports a ball-bearing unit <i>12</i> . Extending from this unit is a threaded shaft which is mounted by a grooved block and adjusting screw <i>13</i> . Affixed to the block is a curved supporting arm <i>14</i> which extends under the trough and attaches to another grooved block and screw assembly on the inferior lateral aspect of the trough <i>15</i> .	A triceps strap <i>16</i> has hinged attachments to two outriggers <i>17</i> and <i>18</i> which are riveted to the inferior and lateral aspects of the forearm cradle <i>19</i> .
ADVANTAGES			
Greater precision in mediolateral, anteroposterior, and height adjustments than the GWSF feeder. No tools are required for adjustments. Minimal joint friction.	Short proximal link decreases space required (laterally) for feeder excursion. Minimal friction present at second ball-bearing joint. Angled distal link provides trough-link clearance. Minimal friction present between distal link and rocker-arm assembly.	Minimal friction present in vertical motions of the trough. Screw-type adjustments permit finer control of elbow-hand balance. Balance of the feeder may be adjusted in two planes, vertical as well as anteroposterior. No tools are required for adjustments.	Triceps strap permits full elbow extension. Posterior protrusion of elbow is less with triceps strap than with elbow dial.
DISADVANTAGES			
Bulky, conspicuous. Weight of unit must be supported when attaching clamp to wheelchair.	Benders must be used on the proximal link to provide anteroposterior tilts at the second joint. Linkage is not readily detachable from the wheelchair assembly.	Conspicuous, crude appearance.	Triceps strap may be displaced from support position with repetitive motion.



Fig. 3. The Texas Rehabilitation Center (TRC) feeder.

Wheelchair
AssemblyProximal and
Distal LinksRocker-Arm
Assembly

Trough

DESCRIPTION

One arm of a U-shaped rod 1 inserts into the round clamp 2. The other end is brazed to a vertical tube 3 so that bending of the U-rod tilts the tube anteroposteriorly). Rotating the rod within the clamp tilts the joint mediolaterally.

A detachable straight swivel arm 4 is adjustable in length from 4-3/4 to 8 in. and terminates in a ball-bearing tube 5. The distal link 6 is a straight swivel arm, adjustable in length from 4-3/8 to 8 in., and terminates in a vertical tube 7.

A rod, Y-shaped distally 8, swivels within the tube and articulates with pre-drilled holes in the trough fenders 9 to form the trough pivot.

The trough 10 has anteroposterior adjustment on pre-drilled holes. Forearm cradle as stationary dial 11.

ADVANTAGES

Simple and inconspicuous. The effect of increased friction from absence of ball bearings in the proximal joint is uncertain. Some friction at this point may be advantageous, for example, to lend stability at the shoulder so that motion imparted to the feeder will occur at the elbow first. It may, however, be disadvantageous if the impedance cannot be readily overcome, particularly in the zone of hand motions about the head,

Feeder can be removed from chair without disturbing the base assembly. Ball bearings reduce joint friction. Short proximal link reduces lateral space required for feeder excursion.

Pivot joints are easily adjusted on the trough without tools. The location of the trough pivot, being higher with respect to the trough than that of the GWSF feeder, more closely approximates the center of gravity of the forearm.

DISADVANTAGES

Benders must be used to obtain anteroposterior tilt adjustments.

Short linkage lengths limit reach and permit joint toggle. As with the GWSF unit, benders must be used on the proximal link to obtain tilts at the second joint without affecting the plane of motion of the first joint. When the forearm is inclined vertically, the distal link interferes with horizontal excursion of the dial.

Y-shaped rod imposes "up" stop on trough.

As with the GWSF stationary dial assembly, elbow extension is limited.

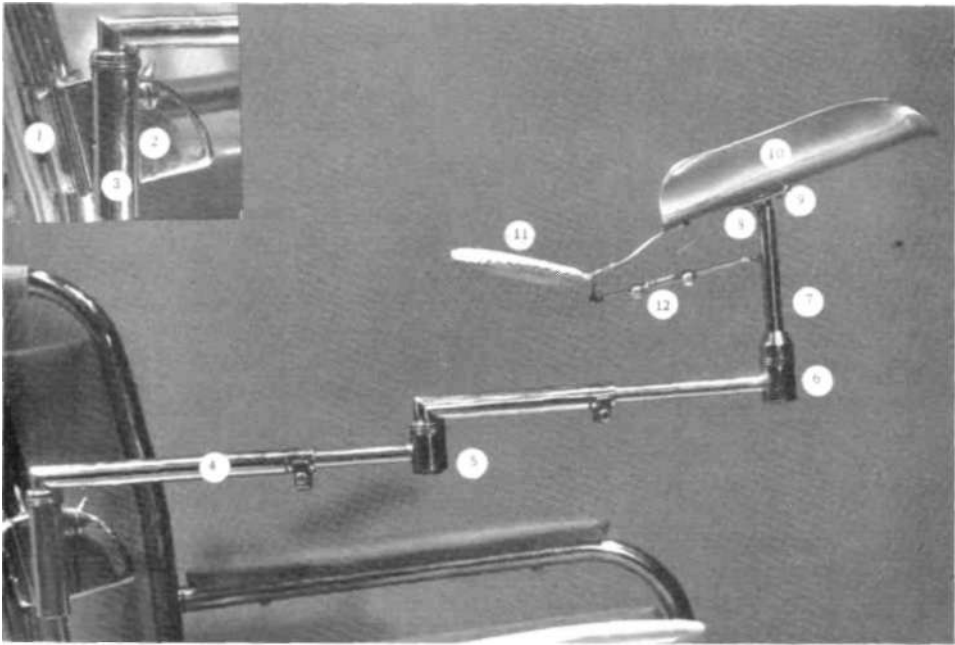


Fig. 4. The Texas Institute for Rehabilitation and Research (TIRR) feeder.

Wheelchair Assembly	Proximal and Distal Links	Rocker-Arm Assembly	Trough
DESCRIPTION			
A round clamp 1 is attached to the chair upright. An offset plate 2 affixed to the clamp provides the mounting for the needle-bearing tube 3, which is adjustable anteroposteriorly in the trial feeder, nonadjustable in the permanent model (not shown). The tube is tilted mediolaterally by rotation of the round clamp.	The proximal and distal links are straight and terminate in needle-bearing tubes 5 and 6. The proximal link is detachable and the length of the links is adjustable in the trial model, nonadjustable in the permanent model.	A relatively long vertical rod 7 terminates superiorly in a clevis hinge 8. A rectangular bar 9 bearing two threaded holes for trough attachment is brazed to the movable portion of the hinge.	The forearm cradle 10 and hinged elbow dial 11 are similar to the GWSF unit's trough. The linkage rod 12, which is adjustable for fitting purposes, is nonadjustable in the permanent feeder (not shown).

ADVANTAGES

Smaller tube with needle bearings reduces bulk of unit and provides an unobtrusive appearance. Minimal joint friction.

Feeder may be removed from the chair without disturbing the base assembly. Minimal joint friction.

Permits full elbow extension.

DISADVANTAGES

In the permanent feeder, mediolateral adjustments cannot be made without affecting anteroposterior tilt which has been established.

As in the GWSF unit, benders must be used to effect tilts at the second joint without altering the base assembly.

The length of the vertical rod is not sufficient to prevent interference of the distal link with the lateral excursion of the elbow dial when the trough is in the "up" position. This means of offsetting the trough from the distal link positions the terminal end of the link approximately 1/2 in. above the table top. The path of feeder motion is obstructed by objects on the table.

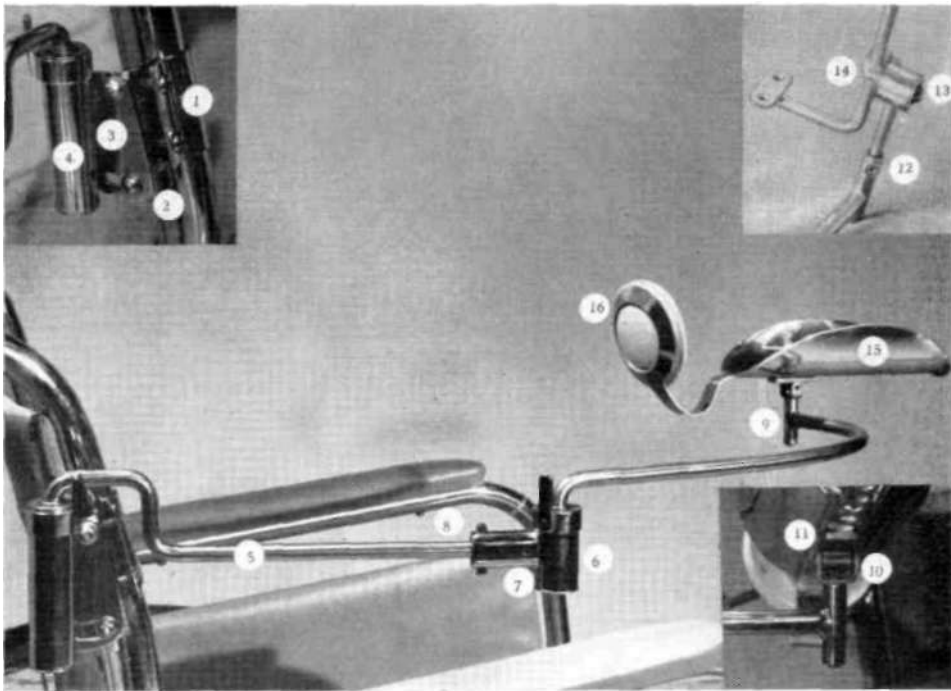


Fig. 5. The Rancho Los Amigos Hospital (RLAH) feeder.

Wheelchair Assembly	Proximal and Distal Links	Rocker-Arm Assembly	Trough
DESCRIPTION			
As in the GVVSF unit, a round clamp <i>1</i> attaches to the chair upright. An L-shaped bracket <i>2</i> extends from the clamp to provide attachment for and anteroposterior angulation of an adjusting plate <i>3</i> . A ball-bearing tube <i>4</i> is soldered to the posterior lateral aspect of the plate.	The detachable drop swivel proximal link <i>5</i> is similar to the GWSF item and terminates distally in an adjustable ball-bearing tube <i>6</i> . A small hinge unit <i>7</i> permits anteroposterior tilting of the tube. The selected tilt position is maintained by set screws <i>8</i> . The distal link, similar to the GWSF item, is curved 90 deg. and terminates in a vertical tube <i>P</i> . An alternate unit (not shown) for patients with limited motion in the horizontal plane replaces the vertical tube with a ball-bearing unit. Post height extenders, like those of the GWSF system, may be fitted into the vertical tube to elevate the trough.	The standard assembly consists of a vertical rod which swivels within the tube and is surmounted by a U-shaped hinge unit <i>10</i> . Fixed to the movable portion of the hinge is a 1-in. rectangular bar <i>11</i> . Threaded holes in the bar can be aligned with drill holes in the underside of the trough for attachment and anteroposterior adjustment. The outside rocker-arm assembly incorporates a height-adjusting collar <i>12</i> on a longer vertical rod and a ball-bearing trough pivot <i>13</i> . A clamp anchored to the hinge axis medially, attaches to an offset rod <i>14</i> to permit vertical adjustment of the trough with respect to the hinge.	The trough <i>15</i> and dial <i>16</i> are similar to but not identical with the GWSF forearm cradle and stationary dial.

ADVANTAGES

As with the GWSF unit, the proximal joint may be tilted mediolaterally by rotating the wheelchair clamp and anteroposteriorly by separate adjustment. The plate simplifies anteroposterior adjustment.	The tilt adjustment for the second joint permits greater ease and precision in providing assistance to horizontal motions of the forearm. As with the GWSF distal link, the curved offset permits adequate horizontal rotation of the rocker-arm assembly when the trough is in the "up" position. Ball bearings used at the end of the distal link reduce friction between the distal link and the rocker-arm assembly. Additional feeder height may be desirable for tall patients or for specific activities (for example, combing the hair).	The outside rocker-arm assembly reduces friction in vertical motions and permits greater control of elbow-hand balance by means of placing the trough pivot closer to the center of gravity of the forearm.
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DISADVANTAGES

Stationary dial restricts elbow extension.

Conclusions of a Conference on Linkage Feeders

HECTOR W. KAY, M.Ed.¹

FOLLOWING the preparation of the *Preliminary Design Analysis of Linkage Feeders* by Prosthetic and Orthotic Studies of New York University (J), it seemed desirable to explore the significance of the design similarities and differences identified in the NYU report.

Accordingly, a Workshop on Linkage Feeders was organized and conducted under the auspices of the Subcommittee on Evaluation of the Committee on Prosthetics Research and Development. Participants in the workshop conference, which was held at the University of Michigan, Ann Arbor, Mich., July 26-27, 1965, included representatives from the five centers whose feeder designs were discussed in the NYU analysis, plus unattached engineering and other consultants.²

At the conference, the design and applications of linkage feeders were discussed in considerable detail, both with respect to the major components (chair-attachment assemblies,

proximal and distal links, rocker-arm assemblies, and troughs) and the device as a whole. In the following presentation of major points emerging from the discussions, it will be noted that while there were areas of disagreement, a community of agreement on many considerations was evident.

ADJUSTMENT

AVAILABILITY TO THE PATIENT

A characteristic of the University of Michigan and the Rancho Los Amigos Hospital systems is that provisions for adjustment are retained throughout the life of the orthoses. At the other centers, apparently, a temporary feeder is used initially, with adjustments made during the course of training by physician, therapist, or orthotist. Before the patient leaves the center, the optimal adjustments are frozen, so to speak, in a permanent unit.

A basic difference in philosophy is evident here. The belief at the University of Michigan is that the patient's family can be taught to adjust the feeder and should have the privilege of doing so; for example, to accommodate changes in the status of the patient's muscular torques with time. The belief at the other centers is that the optimal feeder geometry established during training may be lost with patient-family manipulation.

Since proponents of both approaches are apparently satisfied with the results achieved, no categorical rule would appear to apply. To the impartial observer, retention of adjustability would seem desirable with, perhaps, provision for locking the adjustment features, if this restriction were found necessary.

PRECISION

Theoretically—and perhaps actually—the threaded-screw adjustments of the University

¹ Assistant Executive Director, Committee on Prosthetics Research and Development, National Academy of Sciences—National Research Council, 2101 Constitution Ave., N.W., Washington, D. C. 20418.

² Persons attending the workshop were: Herbert Elftman, Sidney Fishman, as *co-chairmen*; Edward Haak, James Poulson, of the Georgia Warm Springs Foundation; Robert C. Juvinall, James W. Rae, Jr., Edwin M. Smith, of the University of Michigan; G. Hartmann, Nancy Verdon (Appoldt), of New York University; Alice Garrett, Patrick Marer, Betty Yerxa, of Rancho Los Amigos Hospital; Thorkild Engen, of Texas Institute of Rehabilitation and Research; Linda Parker, Randolph Witt, of Texas Rehabilitation Center; Hans A. Mauch, Colin A. McLaurin, Eugene F. Murphy, as engineering consultants; Hector W. Kay, James R. Kingham, A. Bennett Wilson, Jr., of the staff of the Committee on Prosthetics Research and Development. (Mr. Wilson also served as an engineering consultant.)

of Michigan model provide the means for securing more precise adjustments than any of the other units.

There appears to be no question that the provision of an efficient system of balances and biases is critical to the patient's performance and increases in importance with the extent of disability.

There is, however, considerable question concerning the degree of precision achieved or required in these units. Since motion of the forearm in the trough shifts the center of gravity of the forearm in relation to its axis of rotation, as do objects of different weights held in the hand, optimal adjustment would seem to be dynamic rather than static. Moreover, desired adjustments are in relation to a particular configuration of trough and rocker-arm assembly, for example, and this configuration itself may not represent the optimal design. It is noteworthy, though, that all the systems reviewed appeared to be very useful devices, despite these lacks.

EXTENT of USE

Texas Rehabilitation Center apparently applies linkage feeders primarily or solely for use with lapboards. Most of the other institutions plan more extensive use, particularly that involving activities at tables or desks, with a strong bias toward vocational rehabilitation or an approximation of normalcy. This difference in approach obviously influences feeder design and application, particularly with respect to the "reach" provided and provisions for securing adequate trough height to avoid disturbing objects on the table or desk. Total linkage length, the use of drop rather than straight swivel arms, and curved rather than straight distal links, may all be affected by these considerations.

On this question of limited vs. extended feeder usage, the latter approach (maximum function and use) seems preferable unless the goals are unrealizable.

LINK LENGTHS AND RATIOS

In mechanical terms, the maximum feeder reach is the sum of the lengths of the proximal and distal links, while the minimum reach is the difference between the two lengths. Kine-

matically, the two links should be of equal length.

A considerable variety of link lengths and ratios was evident in the five feeders reviewed, each apparently representing a compromise between kinematic and practical considerations, that is, the need to reduce the length of the proximal links to permit passage through doorways without interference by the projecting joint between the proximal and distal link. All compromises apparently worked satisfactorily. However, the maximum length for the proximal link commensurate with noninterference would appear desirable to reduce the stress on bearings.

BEARINGS AND FRICTION

Four of the feeders reviewed incorporated ball bearings to reduce joint friction while only one (Texas Institute for Rehabilitation and Research) used needle bearings. However, since these latter were said to be strong and durable and result in smaller joints, they may well be the bearings of choice.

There was some difference of opinion concerning the need for antifriction bearings at the rocker-arm assembly (for trough function). Some conferees deemed a small amount of friction (for dampening) desirable here (for some patients); others disagreed. An obvious solution to meet both contingencies would be the incorporation of antifriction bearings, with nylon washers available for insertion if friction were desired.

DISTAL LINKS

Straight, angled, and curved distal links were represented in the feeders reviewed. Functionally (reduced interference between distal link and trough) and aesthetically, the curved links appeared to be superior.

TROUGH PIVOTS AND FOREARM POSITION

Despite the variety of rocker-arm assembly designs and trough-pivot positions (offset, below the trough, and forked to each side of the trough), the function of all designs appeared to be reasonably satisfactory. Independent engineering opinion tended to favor a forked pivot supporting the trough halfway through the thickness of the forearm rather than below it.

Forearm motion (sliding) within the trough was considered. The value of the typical elbow disk (dial) in stabilizing the forearm was questioned by the engineering consultants at the workshop. A strap that pivots on an axis passing through the anatomical axis of the elbow (as in the University of Michigan design) was considered to be more satisfactory. Velcro was suggested as a possible means for retaining the forearm in the trough.

COSMESIS

Feeders are rather conspicuous, mechanical, utilitarian devices. Hence the stress placed on cosmetic considerations by the conferees was all the more noteworthy. Two factors are apparently involved: *first*, the appearance of the feeder itself, that is, graceful lines, lack of obtrusiveness, etc.; *second*, the simulation of normalcy in use, for example, sitting at the table to eat a meal rather than using a lap-board.

AN APPROPRIATE NAME

So-called linkage or ball-bearing feeders are obviously more than this name connotes. A less awkward term that would more appropriately define the characteristics and function of the device would be very desirable. Numerous suggestions were made by the conferees, including the term "balanced forearm orthosis" developed by Dr. Robert L. Bennett at the Georgia Warm Springs Foundation. However, none of the suggestions aroused any enthusiasm.

POTENTIAL USERS

An attempt was made by the workshop participants to estimate the number of persons who would derive benefit from the use of a feeder.

It was mentioned that a large but unspecified number of postpoliomyelitis patients would require such devices for the remainder of their lives.

As far as new cases were concerned, the five centers represented at the workshop fitted a total of approximately 150 cases per year. It was estimated that an equal number of patients who might benefit from feeders were not being fitted because of lack of publicity concerning

their value or lack of knowledge concerning applications. The conferees were also of the opinion that although new poliomyelitis patients are rare, survivors of automobile, diving, trampoline, and other accidents resulting in high spinal-cord injuries are increasing. In general, these patients require more sophisticated feeders than those developed originally for victims of poliomyelitis.

NEED FOR FURTHER RESEARCH

All the feeders reviewed appeared to be of fairly adequate design, and all appeared to be fairly useful devices. Presumably, each device could be improved by incorporating features in other designs, or by taking cognizance of suggestions advanced during the workshop. However, further research to develop a new design—a "super feeder"—does not seem indicated at the present time.

NEED FOR EDUCATION

If, as postulated at the workshop, numerous patients with high spinal-cord injuries (who could benefit from the use of a feeder) are not being provided with the device, an obvious educational need exists. To meet this need, two elements are involved: *first*, information concerning the existence and usefulness of linkage feeders should be brought to the attention of physicians and institutions treating appropriate patients; *second*, hospital and rehabilitation personnel should be trained in the application and adjustment of the device.

To these ends, it was considered that:

1. Publicity might profitably be given to the NYU review and to the deliberations of the workshop conference.

2. Announcement should be made that commercially made feeders closely resembling the Rancho Los Amigos Hospital model described in the NYU report are available.³

3. Announcement should be made that instructional material dealing with the application and adjustment of feeders has been prepared by the Georgia Warm Springs Foundation (1, 2) and Rancho Los Amigos

³ Jaeco Orthopedic Specialties, Box 616 M-R5, Hot Springs, Ark. 71919; J. A. Preston Corp., 71 5th Ave., New York, N.Y.; Orthopaedic Supplies Co., Inc., 9126 East Firestone Blvd., Bldg. R, Downey, Calif.; Rehabilitation Equipment, Inc., 175 E. 83rd St., New York, N. Y. 10028.

Hospital (4, 5, 6), and that reports on design principles have been published by the University of Michigan (7, 8).

4. Based on available experience, information concerning feeder design principles and applications might well be included in one or more courses offered by the Prosthetics and Orthotics Education Program.

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Nomenclature for Congenital Skeletal Limb Deficiencies, a Revision of the Frantz and O'Rahilly Classification¹

*Report of the Consultants to the Subcommittee on Child Prosthetics
Problems of the Committee on Prosthetics Research and Development:*

Cameron B. Hall, M.D., Los Angeles, Calif.

Claude N. Lambert, M.D., Chicago, Ill.

Rattan O'Rahilly, M.D., St. Louis, Mo.

Chester A. Swinyard, M.D., Ph.D., New York, N.Y.

Prepared by Robert L. Burtch, M.A.,² Research Scientist, Prosthetic and Orthotic Studies, New York University Post-Graduate Medical School, under the supervision of Sidney Fishman, Ph.D., Project Director, and Hector W. Kay, M.Ed.,³ Associate Project Director, Prosthetic and Orthotic Studies, New York University Post-Graduate Medical School.

AT THE request of the Subcommittee on Child Prosthetics Problems of the Committee on Prosthetics Research and Development, Child Prosthetic Studies, New York University, initiated a study of congenital skeletal limb deficiencies during March 1963 (1). The primary purpose of this initial effort was to determine the adequacy of the classification nomenclature for congenital skeletal limb deficiencies proposed by Drs. Charles H. Frantz and Ronan O'Rahilly (4) and of a description-classification form developed by NYU Child Prosthetic Studies. The results of the evaluation (2) indicated that 471 of 577 limbs (85 per

cent) were classifiable within the framework of the Frantz-O'Rahilly system.

In the light of these generally favorable results, the Subcommittee on Child Prosthetics Problems appointed a group of consultants (Drs. Cameron B. Hall, Claude N. Lambert, Ronan O'Rahilly, and Chester A. Swinyard) to consider possible ways and means by which the Frantz-O'Rahilly plan might be modified to provide an even more comprehensive system for classifying limb deficiencies.

In the course of several joint meetings of the consultants and the NYU staff, a revised system was developed. The revised system generally follows the basic principles proposed by Drs. Frantz and O'Rahilly, in that: *first*, it is based on a description of *absent* skeletal parts; *second*, deficiencies are classified under the two basic headings, Terminal and Inter-calary, with subgroups of Transverse and Longitudinal under each of these headings. However, the use of anatomical terms has been extended significantly and is included in the classification of all deficiencies. Thus the use of such clinical descriptive terms as hemimelia, peromelia, ectromelia, phocomelia, dysmelia, etc., has been eliminated. Only two basic de-

¹ This study was conducted under a special grant from the Children's Bureau, Department of Health, Education, and Welfare.

² Since September 1, 1965, Mr. Burtch has been serving as Coordinator of the Physical Medicine and Rehabilitation Service, Maimonides Hospital—Coney Island Division, Ocean and Shore Parkways, Brooklyn, N.Y. 11235.

³ Since April 1, 1965, Mr. Kay has been serving as Assistant Executive Director, Committee on Prosthetics Research and Development, National Academy of Sciences—National Research Council, 2101 Constitution Ave., N.W., Washington, D. C. 20418.

scriptive terms are now proposed: Amelia, or *complete* absence of a free limb, and meromelia, or *partial* absence of a free limb. The latter term is a derivative of the Greek *meros* (part or partial) and *melos* (limb).

The use of the revised nomenclature adheres to procedures set forth in the *Standard Nomenclature of Diseases and Operations* (7). The classification of a given deficiency, therefore, proceeds from the general to the specific, citing absent skeletal elements for definitive identification. For example, Meromelia: Terminal Longitudinal; Metacarpal: I, II, III describes a terminal longitudinal deficiency of the hand involving absence of digital rays I, II, and III. To provide a basis for possible international consideration, the anatomical terminology utilized in this system is consistent with *Nomina Anatomica* (3).

Since x-rays and the resulting classification may be expected to change depending on the degree of maturation (for example, tarsals and carpals), cases where ossification is continuing must be reclassified periodically.

The material related to the revised classification system is presented in five parts:

- I. A definition of the terms and symbols employed.
- II. Two charts (II. a. and II. b.) adapted from articles by Dr. Hall *et al.* (5) and Dr. O'Rahilly (6) to facilitate understanding of the basic principles involved.
- III. A detailed, illustrated description of the classification plan.
- IV. A description-classification form used for recording purposes.
- V. Instructions for use of the description-classification form.

I. TERMS AND SYMBOLS

TERMS

Amelia	<i>Complete</i> absence of a free limb (exclusive of girdle).
Meromelia	<i>Partial</i> absence of a free limb (exclusive of girdle).
Terminal Deficiency	Absence of all skeletal elements distal to the proximal limit of the deficiency, along the designated axis (longitudinal or transverse).
Intercalary Deficiency	Absence of middle part(s) lying between a proximal-distal series of limb components; elements proximal to and distal to the absent part(s) are present.
Transverse	Absence extending across the width of the limb.

Longitudinal	Absence extending parallel with the long axis of the limb (forearm and/or hand, or leg and/or foot), either pre-axial, postaxial, or (as in the hand or foot) central in nature.
Pre-axial	Absence of the portion of the forearm and/or hand, or leg and/or foot on the thumb or the great-toe side of the limb (radial or tibial portion).
Postaxial	Absence of the portion of the forearm and/or hand, or leg and/or foot on the side of the limb opposite the thumb or the great toe (ulnar or fibular portion).
Central	Absence of one or more of the intermediate digital rays (for example, Ray III).
Rudimentary	A remnant of an osseous element. If the remnant is identifiable (for example, the humerus), the term "rudimentary humerus" would be applicable. If the remnant cannot be identified, the symbol "X" (unknown) would be cited (for example, "rudimentary X").
Ray	A digit.

SYMBOLS

I	Intercalary.	?	Questionable
T	Terminal.		identity of element cited (for example, radius ?).
—	Transverse.		
/	Longitudinal.		
Pre-Post	Pre-axial.	X	Unknown (unidentifiable).
	Postaxial.		
		:I, II, III, IV, or V	Digital ray(s) involved, starting from pre-axial to postaxial side of limb.

SKELETAL ELEMENTS

Capital letters are used to identify skeletal elements that are *completely* absent; small (lower case) letters are used to identify skeletal elements that are *partially* absent. If the word identifying the skeletal element is written out, the first letter of the word is capitalized when the element is completely absent (for example, Humeral), and in lower case when only partially absent (for example, humeral).

HU or hu	Humeral.	TI or ti	Tibial.
U or u	Ulnar.	FI or fi	Fibular.
R or r	Radial.	TA or ta	Tarsal.
CA or ca	Carpal,	MT or mt	Metatarsal.

MC or mc	Metacarpal.	PP or pp	Phalanx Proximal.
PH or ph	Phalangeal.	PM or pm	Phalanx Middle.
FE or fe	Femoral,	PD or pd	Phalanx Distal.

Skeletal Segments

P	Proximal third of element cited.
M	Middle third of element cited.
D	Distal third of element cited.

The symbols P, M, and D are used to indicate thirds of the skeletal elements cited, which may be completely or partially absent. Utilization of the three symbols requires the following clarification:

Terminal Transverse (T—) Deficiencies

P	absence of <i>part</i> of the proximal third of the skeletal element cited <i>and everything distal to it</i> .
M	absence of <i>all or part</i> of the middle third of the skeletal element cited <i>and everything distal to it</i> .
D	absence of <i>all or part</i> of the distal third of the skeletal element cited <i>and everything distal to it</i> .

Terminal Longitudinal (T/) Deficiencies

P	absence of <i>part</i> of the proximal third of the skeletal element cited and everything distal to it <i>parallel with the same axis</i> .
M	absence of <i>all or part</i> of the middle third of the skeletal element cited and everything distal to it <i>parallel with the same axis</i> .
D	absence of <i>all or part</i> of the distal third of the skeletal element cited and everything distal to it <i>parallel with the same axis</i> .

Intercalary Transverse (I—) Deficiencies and Longitudinal (I/) Deficiencies

P	absence of <i>all or part</i> of the proximal third of the skeletal element cited.
M	absence of <i>all or part</i> of the middle third of the skeletal element cited.
D	absence of <i>all or part</i> of the distal third of the skeletal element cited

II. a. BASIC SCHEMA FOR CLASSIFICATION OF CONGENITAL SKELETAL LIMB DEFICIENCIES

Figure 1 presents a basic schema for the classification of congenital skeletal limb deficiencies which has been adapted from one originally presented by Dr. Cameron B. Hall *et al.* (5).

II. b. BASIC SCHEMA FOR CLASSIFICATION OF CONGENITAL SKELETAL LIMB DEFICIENCIES

Figure 2 presents a basic schema for the classification of congenital skeletal limb deficiencies which has been adapted from one originally presented by Dr. Ronan O'Rahilly (6).

III. CLASSIFICATION NOMENCLATURE

- A. Terminal Transverse (T—) Deficiencies (Figs. 3 and 4)
Amelia—complete absence of a free limb (exclusive of girdle).
(For example, Amelia: T—; Upper Right.)

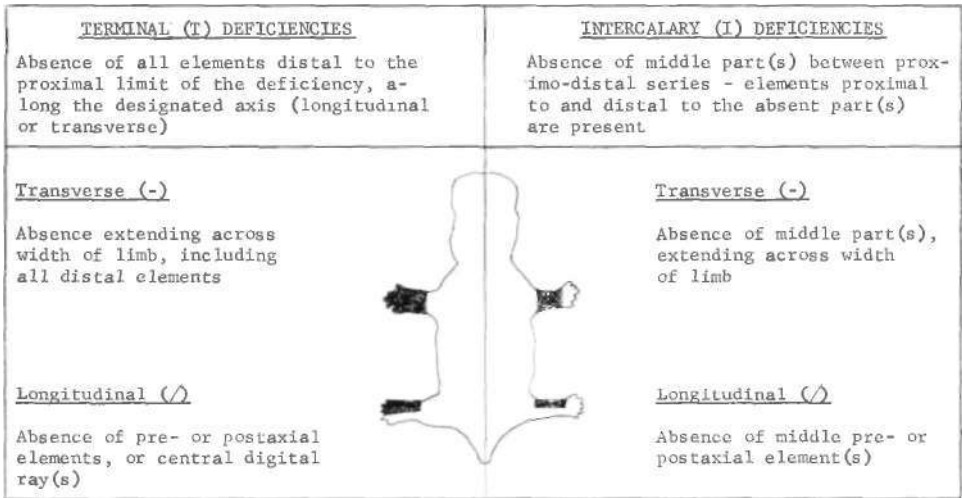


Fig. 1. Basic schema adapted from Dr. Cameron B. Hall *et al.* (5).

MEROMELIA

TERMINAL (1) DEFICIENCIES

Absence of all elements distal to the proximal limit of the deficiency, along the designated axis (longitudinal or transverse)

Absence of middle part(s) between proximo-distal series - elements proximal to and distal to the absent part(s) are present

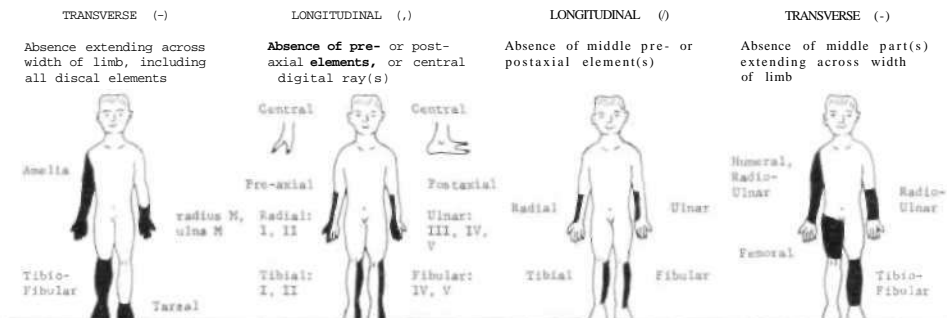


Fig. 2. Basic schema adapted from Dr. Ronan O'Rahilly (6). The term "meromelia," denoting *partial* absence of a free limb, is applicable to all examples in the schema with the exception of the transverse deficiency of the *complete* limb which has been denoted as "amelia."

Meromelia—partial absence of a free limb (exclusive of girdle).

1. Humeral or Femoral (P, M, or D)

Partial absence of the humerus or femur and all distal elements.

(For example, Meromelia: T—; humeral D (distal third above-elbow-type stump).)

2. Radio-Ulnar or Tibio-Fibular

a. Complete absence of the Radius and Ulna or Tibia and Fibula, and all distal elements.

(For example, Meromelia: T—; Radio-Ulnar (elbow-disarticulation-type stump).)

b. Partial absence of the radius and ulna or tibia and fibula, and all distal elements. Use P, M, or D, as appropriate.

(For example, Meromelia: T—; radio-ulnar M (short below-elbow-type stump).)

c. Complete absence of *one* of the forearm or leg elements, and all distal elements.

(For example, Meromelia: T—; Radius (wrist-disarticulation-type stump).)

3. Carpal or Tarsal

Complete absence of all hand or foot elements. (For example, Meromelia: T—; Tarsal (ankle-disarticulation-type stump).)

4. Carpal or Tarsal, Distal

Absence of the distal row of carpals or tarsals, and all other hand or foot elements distal to this level.

(For example, Meromelia: T—; carpal, Distal (mid-carpal-type stump).)

5. Carpal or tarsal, Pre- or Postaxial

Absence of either the pre- or postaxial carpal or tarsal bones, *and all other hand or foot elements*. (For example, Meromelia: T—; carpal, Pre-axial (carpal-metacarpal-type stump).)

6. Metacarpal or Metatarsal

a. Absence of all metacarpals or metatarsals and all hand or foot elements distal to this level. (For example, Meromelia: T—; Metatarsal (tarsal-metatarsal-type stump).)

b. Absence of a portion of metacarpals or metatarsals and all hand or foot elements distal to this level. Use P, M, or D to indicate absent segment (s) of each metacarpal or metatarsal. (For example, Meromelia: T—; metacarpal: I D, II D, III D, IV M, V M (trans-metacarpal-type stump).)

7. Phalangeal

a. Absence of all phalanges from all five digits. (For example, Meromelia: T—; Phalangeal, Upper Right (metacarpo-phalangeal-type stump).)

b. Complete or partial absence of *one or more phalanges from all five digits* (but not all phalanges from all five digits).

(For example, Meromelia: T—; phalangeal, Upper Right: I, II; III PM, IV PM, D; V PD (trans-phalangeal-type stump).)

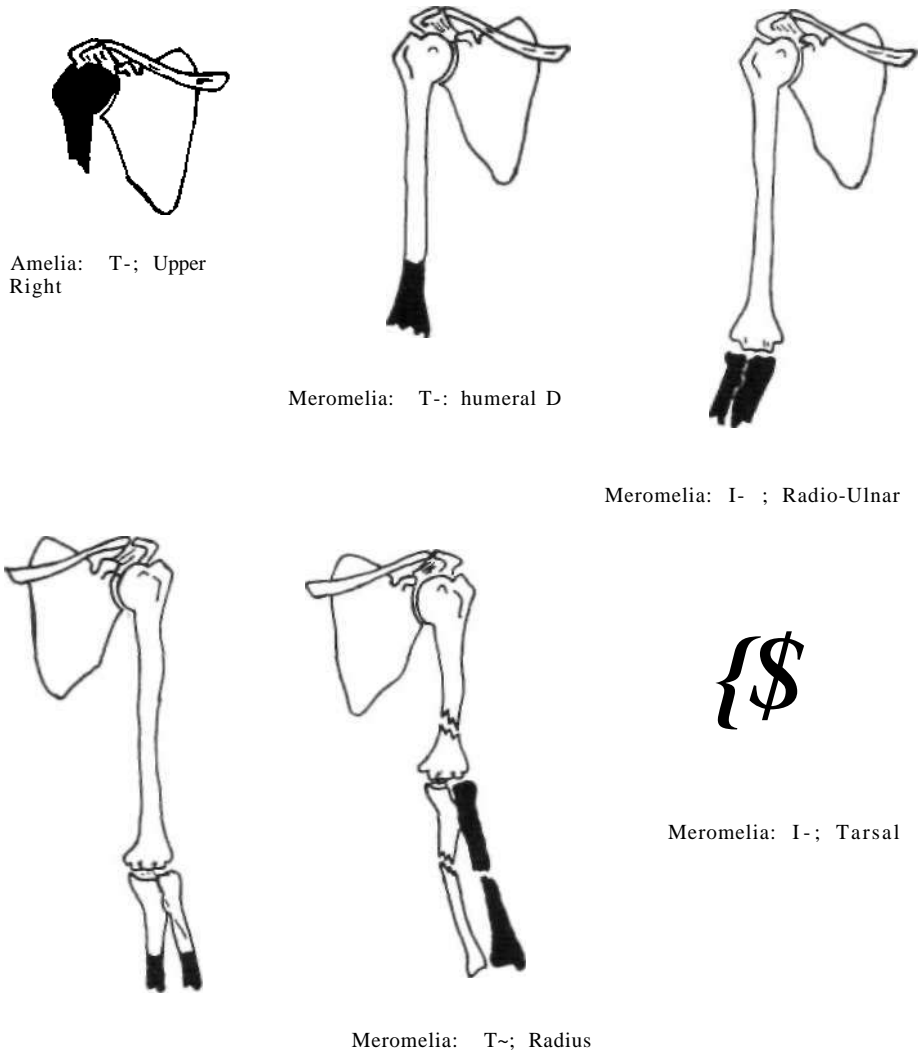
Terminal Longitudinal (T/) Deficiencies (Fig. 5)

1. Major Long Bones

a. Complete absence of one of the forearm or leg elements and of the corresponding portion of the hand or foot. The skeleto-anatomical terms Radial (R), Ulnar (U), Tibial (TI), or Fibular (FI) are used to indicate the absent long bone. In order to provide greater precision, the identifying number of each absent ray is included in the nomenclature.

(For example, Meromelia: T/; Radial: I, II.)

If all but one unidentifiable ray or rudimen-



Amelia: T-; Upper Right

Meromelia: T-: humeral D

Meromelia: I- ; Radio-Ulnar

Meromelia: I-; Tarsal

Meromelia: T~; Radius

Meromelia: T-; radio-ulnar M

Fig. 3. Terminal transverse (T—) deficiencies. The shaded areas in the example sketches represent absent elements or parts thereof.

- tary ray is absent, the symbol "X" (unknown) or term "rudimentary X" is used.
- b. Partial absence of one of the forearm or leg elements and absence of the corresponding portion of the hand or foot. P, M, or D is used to indicate the absent segment (s) of the long bone. Lower case letters are used, and the absent ray(s) is cited.
(For example, Meromelia: T/; fibular M: IV, V.)
2. Carpal or tarsal, Pre- or Postaxial
Absence of *either* the pre- or postaxial carpal or tarsal bones, *and* corresponding digital rays.

- (For example, Meromelia: T/; carpal, Pre-axial: I, IL)
Metacarpal or metatarsal (P, M, or D)
- a. Absence of all phalanges of one to four digits *and* complete or partial absence of their respective metacarpals or metatarsals.
(For example, Meromelia: T/; metacarpal: I, II, III, V.)
- b. In the case of partial absence of a specific metacarpal or metatarsal, P, M, or D is used to indicate the absent segment (s).
(For example, Meromelia: T/; metatarsal: I, II; III D; V M.)

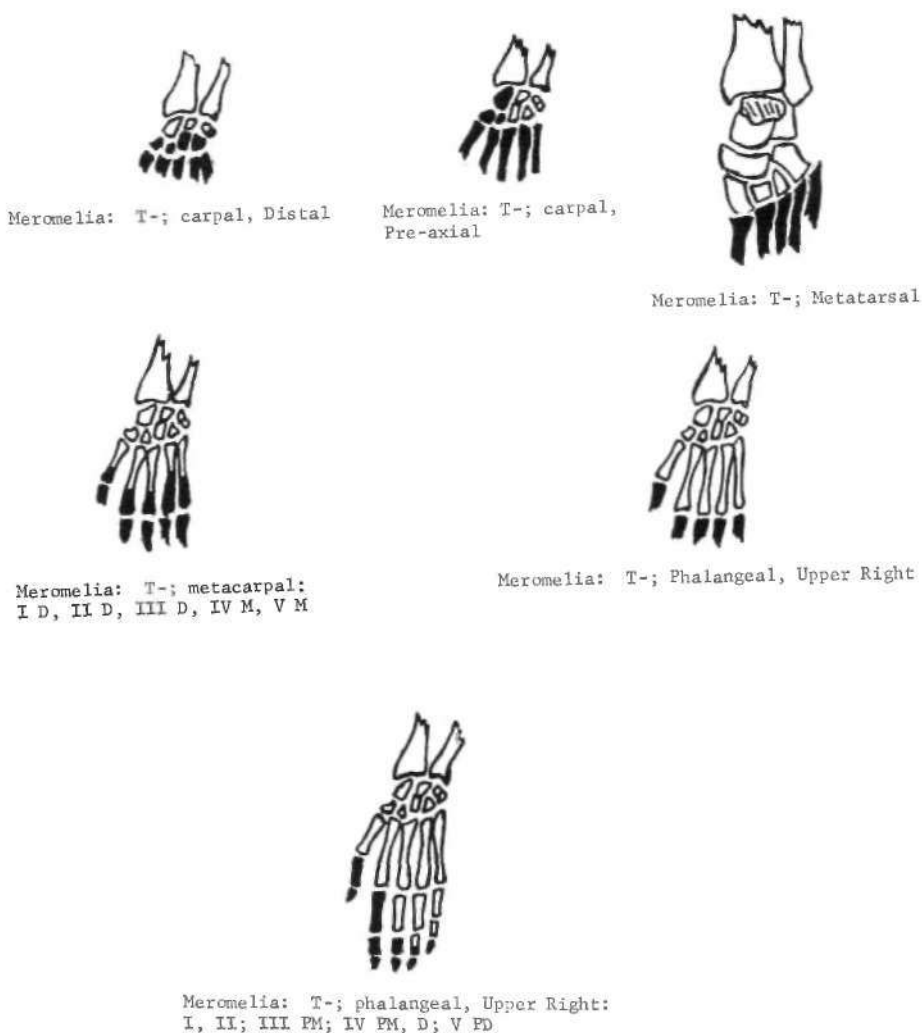


Fig. 4. Terminal transverse (T—) deficiencies (continued). The shaded areas in the example sketches represent absent elements or parts thereof.

4. Phalangeal

Absence of all or part of one or more phalanges from one to four digits.

(For example, Meromelia: T/; phalangeal, Upper Right: I, II, III.)

C. Intercalary Transverse (I —) Deficiencies (Figs. 6 and 7)

A minimum of at least two digital rays (two metacarpals or metatarsals and their associated phalanges) must be present to permit classification as an Intercalary Transverse (I—) deficiency of the major long bones. In such cases, the hand or foot deficiencies (if any) are classified separately. Where there are fewer than two complete digital rays, the deficiency is classified as Terminal Transverse (T—), with a description of the distal digital elements that are absent (for example, "all but one ray absent").

1. Major Long Bones

a. Humeral, Radio-Ulnar; or Femoral, Tibio-Fibular

Complete absence of all three major long bones in the limb with hand or foot elements attached directly to the trunk.

(For example, Meromelia: I—; Humeral, Radio-Ulnar.)

a'. Concomitant hand or foot deficiencies are classified independently of the major long bone deficit.

(For example, Meromelia: I—; Humeral, Radio-Ulnar; plus T/; metacarpal: I, II, V.)

b. Humeral or Femoral

Complete or partial absence of the long bone cited.

(For example, Meromelia: I—; Humeral.)

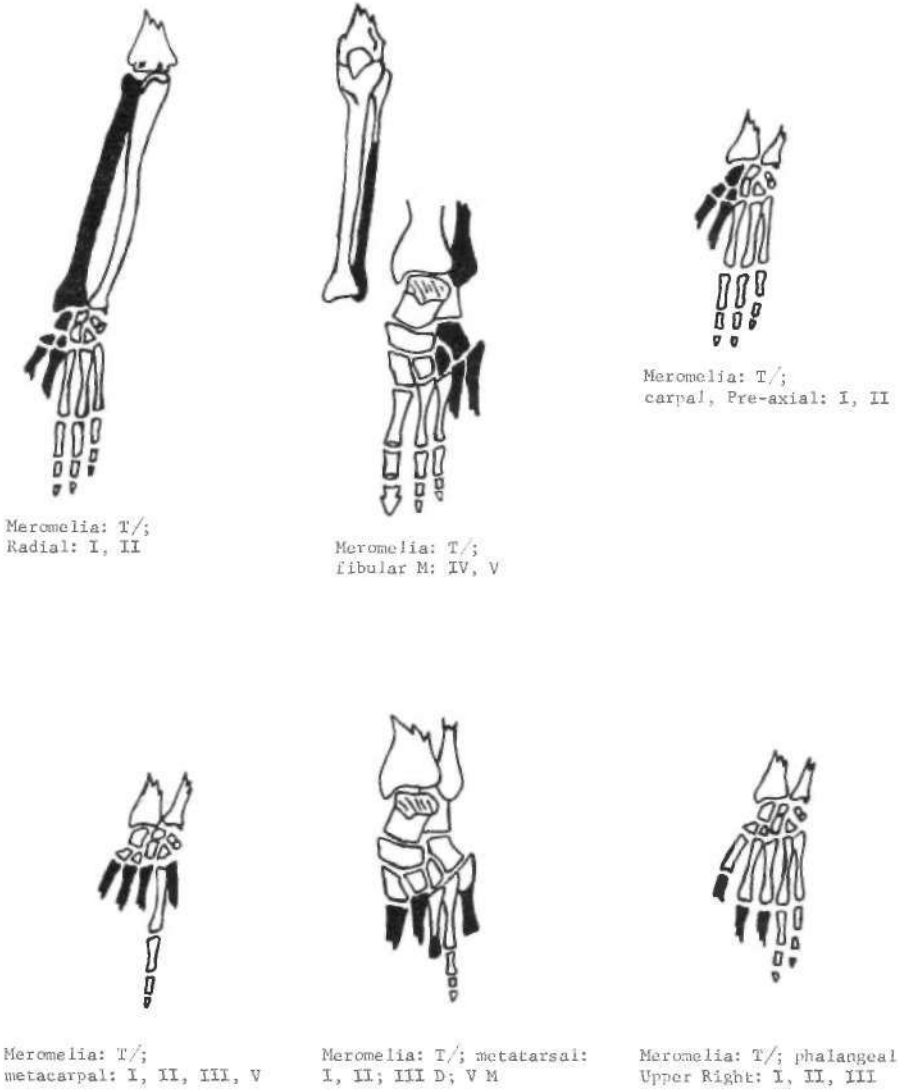


Fig. 5. Terminal longitudinal (T/) deficiencies. The shaded areas in the example sketches represent absent elements or parts thereof.

- b'. If a partial absence exists, P, M, or D is added to indicate the absent segment(s) of the bone cited.
(For example, Meromelia: I—; humeral M. D.)
- c. Radio-Ulnar or Tibio-Fibular
Complete or partial absence of the long bone cited.
(For example, Meromelia: I—; Radio-Ulnar.)
- c'. If a partial absence exists, P, M, or D is used to indicate the absent segment(s) of each bone.
(For example, Meromelia: I—; tibio-fibular P, M.)

- d. Humeral, radio-ulnar; or femoral, tibio-fibular
Partial absence of *all three major long bones* in the upper or lower limb. P, M, or D is used to indicate the absent segment (s) of each long bone.
(For example, Meromelia: I—; humeral D; radio-ulnar M, D.)
- Carpal or Tarsal
Complete absence of the carpal or tarsal bones, with proximal and distal skeletal elements present.
(For example, Meromelia: I—; Carpal.)

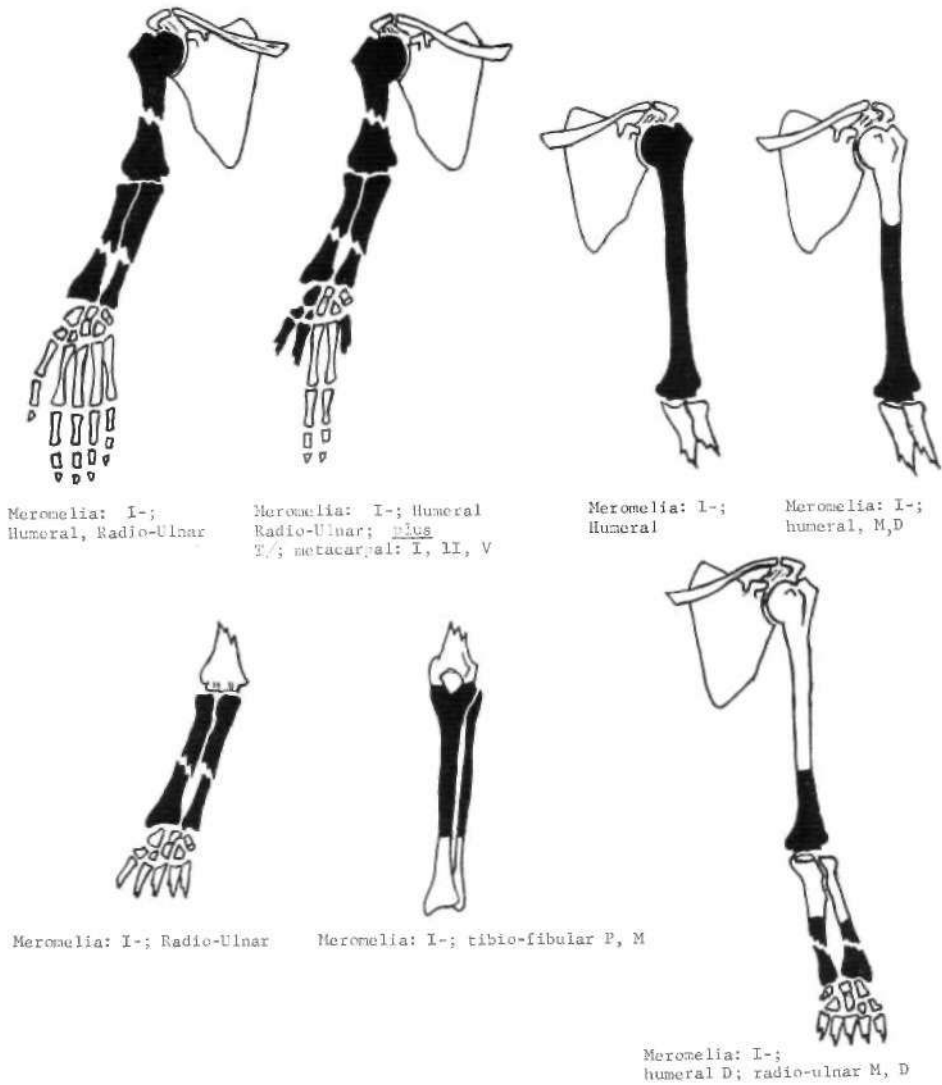


Fig. 6. Intercalary transverse (I—) deficiencies. The shaded areas in the example sketches represent absent elements or parts thereof.

3. Metacarpal or Metatarsal
Complete absence of the metacarpals or metatarsals, with proximal and distal skeletal elements present.
(For example, Meromelia: I—; Metacarpal.)
 4. Phalangeal
Absence of all or part of the proximal and/or middle phalanx from all *five* digits.
(For example, Meromelia: I—; phalangeal, Lower Right: I PP; II PP; III PM; IV PM; V PP.)
- Intercalary Longitudinal (I/) Deficiencies (Fig. 8)
1. Major Long Bones
 - a. Complete absence of one of the forearm (R or

- U) or leg (TI or FI) elements with hand or foot elements intact along the same axis as the deficient long bone.
(For example, Meromelia: I/; Fibular.)
- b. Similar to above except that *only part* of the long bone cited is absent. P, M, or D is used to indicate the absent segment (s).
(For example, Meromelia: I/; radial P, M.)
- Carpal or tarsal, Pre- or Postaxial
Absence of *either* the pre- or postaxial carpal or tarsal bones with all other hand or foot elements present.
(For example, Meromelia: I/; tarsal, Pre-axial.)



Meromelia: I-; Carpal



Meromelia: I-; Metacarpal



Meromelia: I-; phalangeal, Lower Right:
I PP; II PP; III PM; IV PM; V PP

Fig. 7. Intercalary transverse (I—) deficiencies (continued). The shaded areas in the example sketches represent absent elements or parts thereof.

Metacarpal or metatarsal

Absence of *all or part* of one to four metacarpals or metatarsals.

(For example, Meromelia: I/; metatarsal: I, II.)

If only part of a metacarpal or metatarsal is absent, I', M, or D is used to indicate the absent segment(s) of the involved ray.

(For example, Meromelia: I/; metatarsal: I D; II M, D.)

Phalangeal

Absence of *all or part* of the proximal and/or middle phalanx of from one to four digits.

(For example, Meromelia: I/; phalangeal, Upper Left: I PP; II I'M; IV PP.)

IV. DESCRIPTION-CLASSIFICATION FORM

Figure 9 presents the description-classification form developed by NYU Child Prosthetic Studies for recording congenital skeletal limb deficiencies.

V. CLASSIFICATION OF CONGENITAL SKELETAL LIMB DEFICIENCIES

The following instructions were developed by NYU Child Prosthetic Studies to accompany the description-classification form:

1. Fill in the identification items at the top of the page.

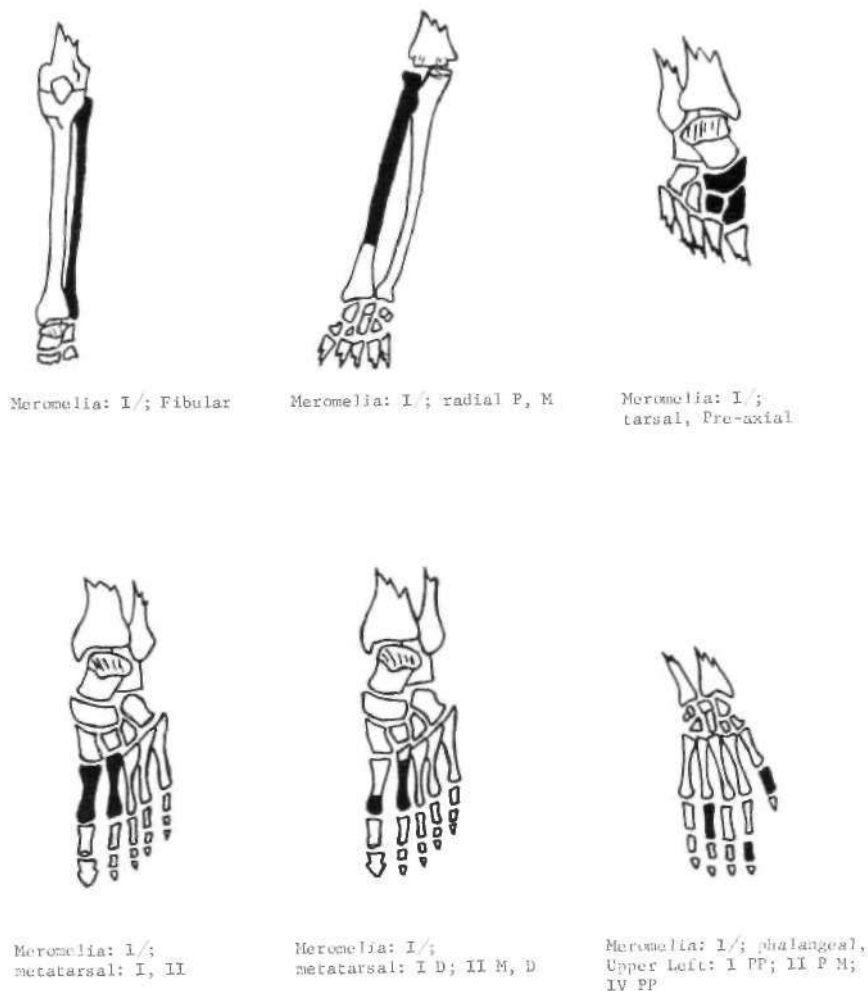


Fig. 8. Intercalary longitudinal (I/) deficiencies. The shaded areas in the example sketches represent absent elements or parts thereof.

2. Indicate in the space provided the presence or history of congenital visceral, soft-tissue or skeletal anomalies other than those of the limbs; that is, cardiac, pulmonary, gastrointestinal (esophageal and/or duodenal atresia, imperforated anus, etc.); genito-urinary, for example, cryptorchidism; cleft palate, hare lip, congenital and/or structural scoliosis, spina bifida, etc.

3. Using a *black* pencil or pen, shade in all *absent* skeletal elements or parts of elements. If an anomaly has been converted to an amputation, describe and classify the *original* anomaly. Care should be taken to retain the approximate length and girth proportions when shading in partial elements. Using a *red* pencil or pen, also indicate on the appropriate limb the approximate *site* and *date* of the surgical conversion(s).

4. In cases where prosthetic restoration is appropriate, indicate the analogous functional level of amputa-

tion for prosthetic purposes (for example, short above-elbow, short below-elbow, long above-knee, etc.) in the space provided. Consult *Upper and Lower Extremity Manual(s)* for functional amputation levels.

5. Indicate next to the appropriate skeletal part on the diagram any of the following conditions that exist. Also, include any unlisted conditions present, as well as any additional information that will enhance the completeness of the description.

Synostosis	Contracture
Hypoplasia	Pseudoarthrosis
Bifurcation	
Valgus	Dislocation
Varus	Subluxation
Syndactylism	Supernumerary digit(s)
Torsion	Soft-tissue nubbin(s)

6. After completing the description of each affected

NEW YORK UNIVERSITY - CHILD PROSTHETIC STUDIES
DESCRIPTION - CLASSIFICATION FORM CONGENITAL SKELETAL LIMB DEFICIENCIES

Clinic _____ Name _____ Sex _____ N-5 No. _____ Date _____
 Race _____ Birth Date _____ Date of X-Rays _____ Place of Birth _____ (City) _____ (County) _____ (State) _____

1. Scapula
2. Clavicle
3. Shoulder Joint
4. Humerus
5. Elbow Joint
6. Ulna
7. Radius
8. Wrist Joint
9. Carpals
10. Metacarpals
11. Phalanges

Functional Amputation Level _____

KEY

1. Scapula
2. Clavicle
3. Shoulder Joint
4. Humerus
5. Elbow Joint
6. Ulna
7. Radius
8. Wrist Joint
9. Carpals
10. Metacarpals
11. Phalanges

Functional Amputation Level _____

ANOMALIES OTHER THAN OF LIMBS

CLASSIFICATION, RIGHT: _____ CLASSIFICATION, LEFT: _____

- 1 - Sacrum
- 2 - Hip bone
- 3 - Hip joint
- 4 - Femur
- 5 - Patella
- 6 - Knee joint
- 7 - Tibia
- 8 - Fibula
- 9 - Ankle joint
- 10 - Tarsals
- 11 - Metatarsals
- 12 - Phalanges

Functional Amputation Level _____

Functional Amputation Level _____

CLASSIFICATION, RIGHT: _____ CLASSIFICATION, LEFT: _____

Fig. 9. Description-classification form for recording congenital skeletal limb deficiencies.

limb, insert in the appropriate space the appropriate classification nomenclature.

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Recent Concepts in the Treatment of the Limb-Deficient Child¹

CAMERON B. HALL, M.D.²

STIMULATED in the United States by the development of 22 child amputee clinics (19) during the past 12 years, and ignited by the catastrophic epidemic of congenitally deformed offspring associated with maternal thalidomide ingestion in Europe and Asia during recent years (5,6,10,11,20,21), the limb-deficient child (2) has captured the interest not only of the physician, embryologist, anatomist, and prosthetist, but also of the organic and physical chemist, radiologist, geneticist, sociologist, statistician, psychologist, and, still waiting in the wings, the expert in forensic medicine. While each field has contributed much, this article will confine itself to the advances found in embryology and teratology, training, prosthetics, and surgery.

EMBRYOLOGY AND TERATOLOGY

It should be recalled that the human embryo displays paired mesodermal ridges paralleling the dorsal ridge at approximately the fourth intrauterine week. By the end of the sixth week ectodermal masses appear at the shoulder and hip areas of these ridges, the so-called *limb buds* (8,9,14) (Fig. 1). In the next two weeks these limb buds develop into upper and lower extremities with human configuration

and microscopically recognizable muscles, tendons, nerves, bones, ligaments, and joints—even to collateral ligaments in the interphalangeal joints of the fingers—and all before

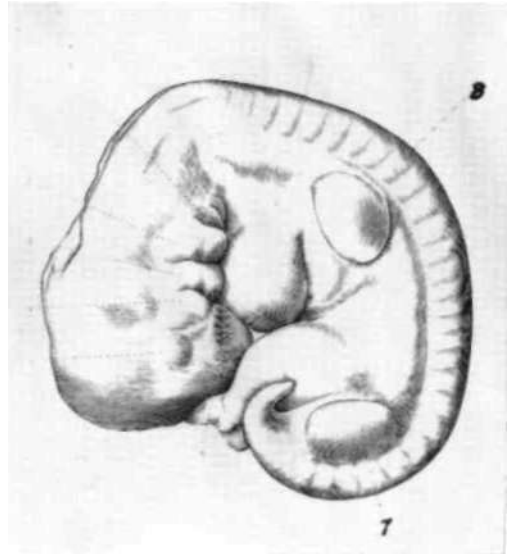


Fig 1. Upper 8 and lower 7 show limb bud development in the six-week human embryo 6.33 mm. in length. From Blechschmidt, E., *The Stages of Human Development Before Birth* (3).

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² Assistant Clinical Professor of Surgery, Orthopaedic Department, and Research Orthopaedist, Child Amputee Prosthetics Project, Rehabilitation Center, University of California, Los Angeles, Calif. 90024.

the embryo is more than 25 mm. in length (Fig. 2). The first 56 days of life are devoted to *differentiation* of organs and tissue systems, and the remainder of the 270 days are occupied primarily with growth and development of these tissues. There is increasing evidence that the great bulk of congenital anomalies apparent at birth have occurred during the first eight weeks before the embryo is one inch in crown-



Fig. 2. Development of upper and lower extremities in the eight-week human embryo. Noteworthy is the remarkable growth and differentiation since the limb buds of only two weeks earlier. Patterns of muscles and nerves are comparable to those of an adult. Crown-to-rump length is only 25 mm. From Bardeen, *American Journal of Anatomy*, Vol. 1, 1902.

to-rump length and often before the mother herself is convinced that she is pregnant.

Streeter (18) has defined 22 horizons appearing in the human embryo during the first six weeks. He describes the thickened ectoderm of the upper ridge as Horizon XII, the *Anlage* of the limb buds, appearing at approximately the fourth week along with the paired somites of the dorsal ridge. The somites contribute to the development of vertebral bodies and ribs but probably not, contrary to previous concepts, to the development of limbs themselves. Saunders (15,16,17) has shown that excision of somites results in no alteration of the adjacent limb in the experimental embryo. The ectodermal ridge, however, appears to be the inductor of limb growth. Its removal by microsurgery in the embryos of experimental animals results in the failure of limb development. The transplantation and reorientation of the ecto-

dermal caps of the limb bud will give rise to predicted anomalies. Removal of half the cap results in a limb longitudinally deficient in the area governed by the removed portion. Saunders, Zwilling (22,23), and others have produced twinning, mirror images, and upper-extremity/lower-extremity transplants by such microsurgical methods. The interrelationship of ectoderm and mesoderm is of much interest; one appears to control the growth and differentiation of the other with a distinct specificity of their site of origin. The thickened terminal portion of the limb bud ectoderm is well recognized and is capable of directing and orienting extremity growth.

Blechsmidt's studies (3) of the ectoderm-mesoderm relationship point out the role of cell death or retardation on the concave portion of the limb coupled with cell multiplication on the convex portion as the controlling factor in limb curvature and rotation. Cell death plays a prominent role in the contouring and sculpturing of the embryonic limb to its eventual human form. The latter is evident and specific at the end of the eighth intrauterine week. Selective cellular regression allows separation of mesodermal masses into the parallel skeletal rays of hands and feet, produces the cavitation of joints and articular spaces in the proper locations, and governs the development of body cavities wherever these are located (Fig. 3). Disturbance of either the mechanism of cell reproduction or selective cellular death can be seen as a cause of congenital deformities. The lack of appropriate cell death between femur and tibia will result in a permanently fused knee. The lack of cell death in the interdigital spaces will result in mittenlike syndactylized hands.

The maintenance or guiding factor governing any or all of these phenomena is as yet undiscovered. Heretofore the cell has been the principal object of study; but lately investigation of the ground substance, the vast intercellular ocean, suggests that the controlling agents may reside in this area of embryonic tissue. Pinner has shown by staining methods that the mesenchymal ground substance is high in mucopolysaccharides, particularly in the region of neural tube closure and in the

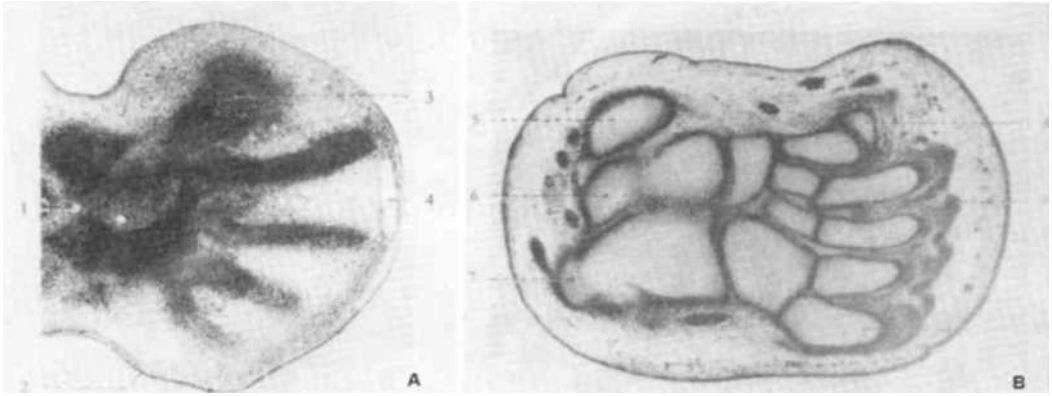


Fig. 3. Selective cellular regression. A, Early cellular regression allowing mesoderm separation into metatarsal rays (14-mm. embryo); B, continued cellular regression producing articular spaces and individual skeletal elements of foot (29-mm. embryo). From Blechschmidt, K., *The Stages of Human Development Before Birth* (3).

basement membrane between the mesoderm and ectoderm of the developing limb bud. Among the substances proven to inhibit mucopolysaccharide biosynthesis are many known teratogenic agents. The embryonic age at which the anomaly production occurs may be as varied as the number of agents which can produce them with regularity in the laboratory animal. Some 70 agents, insults, or mechanisms are known methods that may produce statistically significant deformities. The timing of administration within the fetal growth period seems as important as the nature of the agent itself. The complex pattern of cellular growth and cellular death may be interrupted at any point, producing a characteristic anomaly.

Zwilling points out that deformities may result from: *first*, an interference with *progressive events* of either the primary limb bud establishment or the elaboration of secondary limb patterns; *second*, interference with the *regressive* phase of selective cell death; *third*, interference with the *growth and development* of elements once established; and, *fourth*, interference with the as yet little known molecular control of induction and regression. Molecular control appears to be an enzyme-coenzyme relationship that may be the basis for the first three categories.

The role of thalidomide (Fig. 4) is not yet understood. Its mechanism of action suggests that it may be a counterfeit agent interjecting itself into a vital process but preventing the

successful completion of that physiological process. It appears to have been a definite factor in the recent wave of congenital deformities among maternal populations using the medication during early weeks of pregnancy. Carefully documented case histories as well as thoroughly checked epidemiological studies not only reveal close relationship between the day of starting the drug and the type of anomaly observed at birth, but also have shown the rise in incidence of certain infant deformities within a geographical area to be in direct relationship to the amount of thalidomide supplied to the wholesale drug agents of that particular locale. The critical maternal ingestion period appears to have been between the 27th and 30th day of pregnancy; the most severely deformed children seem to have resulted from medication taken between the 27th and 30th day after conception.

In addition to the environmentally induced deformity, anomalies may also result from chromosomal aberration within the infant itself as well as from genetic potentialities of the parents. Patterns of deformity on an hereditary basis are well recognized. To the parents of deformed children the genetic possibilities are of marked importance: "If we have another baby will it be deformed? If this deformed baby grows up and marries, will it have deformed offspring?" The complexity of eugenic counselling is beyond the scope of this paper, but, in general, the answer to either



Fig. 4. Three-year-old boy whose mother took thalidomide during early pregnancy. He exhibits typical facial and ear deformities plus bilateral upper-extremity amelia with rudimentary single digits. Successful application of externally powered prostheses will give major benefits. Such patients should be trained in the use of their feet in all aspects of daily activities. This patient has won an award at a painting exhibition, competing against older normal children.

question would be "no risk" with environmentally induced deformities (drugs, viruses, X-ray exposure, etc.). With chromosomal aberration the risk is probably small. With a congenital malformation due to dominant or recessive genes in both parents the chances of another deformed offspring are strong, and the chances of this child passing the deformity to his children are also strong. It behooves the clinician to ascertain the basic cause of his patient's difficulty in order to provide parents with this vital information.

Whatever the etiology, deformities can be classified after the method of O'Rahilly (13)

into two basic types—*terminal* where no part exists distal to or in line with the deficient portion, and *intercalary* where there is an intersegmental loss with portions proximal to and distal to remaining grossly intact. Within both of these classifications, the deficiencies may be *transverse*, encompassing the entire girth of the limb; or they may be *paraxial*, occurring as a longitudinal deficiency in grossly the pre- or postaxial elements with the uninvolved portion remaining grossly intact. While no universally accepted explanation of these deformity types has yet been made, the experimental findings of Saunders and Zwilling as previously noted can be considered as a possible explanation of human deformities.

The dermatome distribution of spinal nerves in the fetus reveals a pre- and postaxial distribution of known regularity. By using a diagram of these patterns primarily for the purpose of orientation, the two basic deficiency types, *terminal* and *intercalary*, can be assigned one to each side of the diagram, and the two subtypes, *paraxial* and *transverse*, can be assigned one to an upper and the other to a lower limb (7). With this simple arrangement the skeletal deficiencies of O'Rahilly's classification can be related very closely to the findings of the experimental embryologists and teratologists. The Frantz-O'Rahilly (4) method of classifying clinical entities has proven very useful in the cataloguing and division for treatment of child patients with these congenital deficiencies. This is based on the roentgenographic appearance of the extremities observable within a day or two after birth.

TRAINING (Fig. 5)

Training of the limb-deficient child actually starts within a few hours of birth when the parents are provided with a detailed, factual, realistic, and above all, sympathetic appraisal of their baby and its prospects for future educational, vocational, and social rehabilitation (12). The psychic trauma to the parents should not be underestimated, and a well-founded program can do much to alleviate their burden. The child should become a part of the family immediately. Later, prolonged hospitalization may prove necessary for surgical and prosthetic treatment. The first few months within the



Fig. 5. Training by a competent therapist ensures successful use of a well-fitted prosthesis.

protective love of an informed family appears to be of great value in the care of these patients. The mother will ultimately become the child's best therapist, and the early months of intimate association will provide a basis for her later role as teacher. The mother must be given systematic instruction that is checked and supervised at regular intervals.

Physical and occupational therapy should be started as soon as the youngster begins to take part in his environment. The prone position will strengthen the back as the youngster lifts his head in curiosity. Clothing should be altered so that foreshortened extremities have full freedom to touch and grasp. In the armless child the legs should be completely uncovered so that the baby can watch and play with his feet. These will develop into his future "hands" and toys should be placed for foot activities. Even the weakest and most rudimentary digits arising from malformed shoulders should be stimulated and strengthened for eventual prosthesis control. The ability to grasp and touch must be learned; lack of opportunity to

do this will result in atrophy and disuse of valuable extremities. Children with both upper and lower amelias must be encouraged to feel with their mouth and lips and to hold objects between their chin and shoulders. Flexibility of the legs and feet should be encouraged in the armless. Surgical procedures should aim to increase function, and those that limit the ability of the feet to reach the face should be avoided. Hip flexibility must be much above the normal, but once obtained, it can provide these patients with an independence in dressing and undressing as well as in handling their own toilet care. Walking will be somewhat delayed in the child with foreshortened upper extremities. The ability to pull himself up, to balance when erect, and to cushion himself when falling will be absent. His head should be protected with a sponge-rubber-ring helmet (Fig. 6). He should be deliberately taught to fall and rise without injury.



Fig. 6. Leather-and-sponge-rubber bicycle helmet protects the toddler-age patient with bilateral arm deficiencies against head injuries.

How does one decide that an arm prosthesis is necessary? Probably a child who can eat and play with his deformed hands will not require a prosthesis. The hands should be capable of apposition across the front of the body, even with the expansion of the thorax in growth. Youngsters with amelias or short phocomelias will require artificial limbs, and fitting starts when the child has obtained good sitting balance. Children whose lower-extremity deformity prohibits stabilization in sitting should be provided with appropriate stabilized trunk support for upright posture. The arm prostheses are fitted initially for *passive* operation (Fig. 7)—joints, terminal devices, etc., are operated by the parents, or by the child's remaining good hand in the unilateral amputee. Gross arm movement bringing both hands together in a clapping motion will serve to hold a ball or doll and is actually the first *active* motion of the amputee. This is basically a shrugging or coapting movement of the shoulders. When this is mastered, active control of

one of the terminal devices, usually on the dominant side first, can be added. In the amputee fitted passively at six or eight months, this can be accomplished at the sixteenth to the twenty-fourth month depending on the ability of the child and the nature of his deformity. The control of the elbow lock can be added at three years. In the pneumatically powered devices developed in Germany (Fig. 8), the clever amputee has learned good control of elbow flexion and extension, forearm pronation and supination, and terminal-device grasp and release—all under the control of amelic shoulders or phocomelic fingers—by five years of age. The use of external power, either from portable carbon-dioxide-filled tanks or from electrical batteries, is a realistic solution to the complete lack of upper extremities. At the UCLA Child Amputee Prosthetics Project, it has been possible to provide functioning upper extremities for these patients with harnesses and cables, but the energy expense to the patient is tremendous and is often not available until

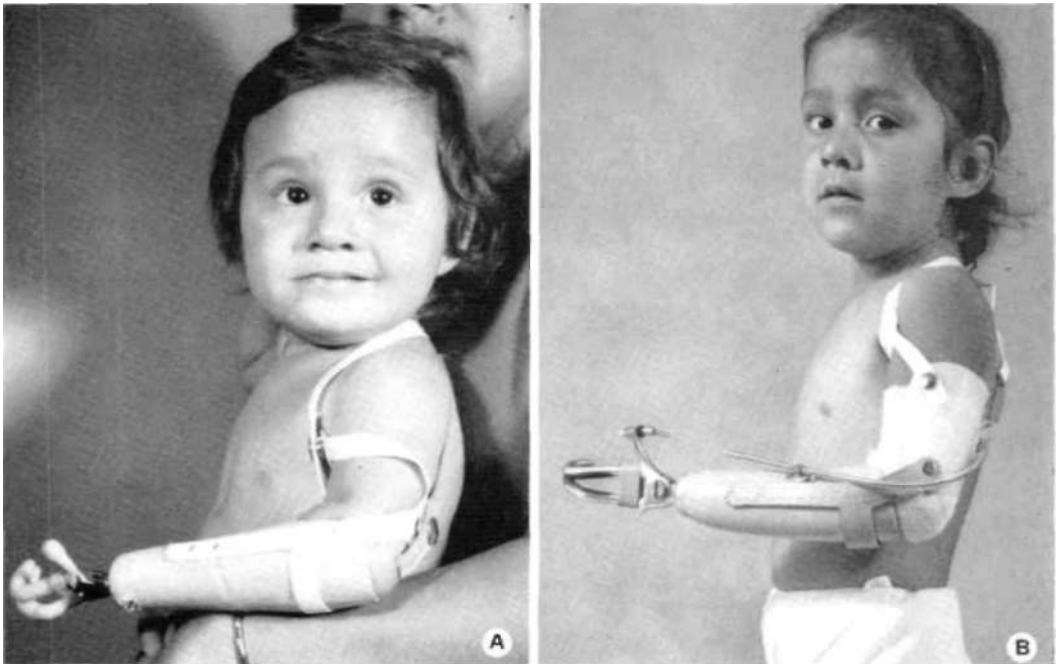


Fig. 7. Upper-extremity prostheses for young patients. A, Passively operated below-elbow prosthesis can be fitted when the child acquires good sitting balance at the age of nine to ten months; B, activation of the terminal device by means of a figure-eight Dacron harness and Bowden cable is possible at 18 months, with good use of the prosthesis in the activities of daily living.

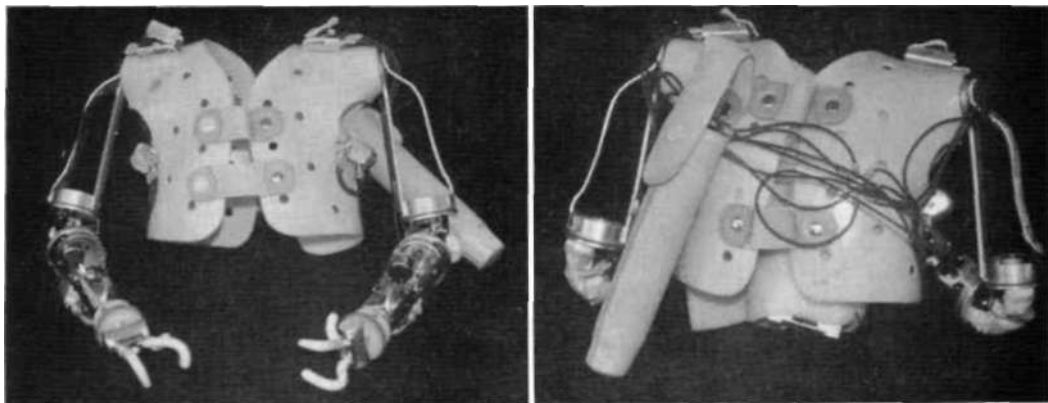


Fig. 8. Anterior and posterior views of pneumatically powered bilateral shoulder-disarticulation prosthesis as constructed under the direction of Dr. Ernst Marquardt, of the University of Heidelberg.

the child is approximately seven or eight years of age.

The training of a child fitted with a prosthesis is a time-consuming but highly rewarding procedure. It is started under the careful supervision of a trained therapist, and the mother is taught as well as the patient. Training then proceeds at home with clinic visits at regular intervals for solution of difficulties and addition of new maneuvers or activities. The functional level of a normal child of the same age should be the basis of achievement goals. A three-year-old with prostheses should not be expected to tie his own shoes when the normal youngster accomplishes this only after diligent instruction at the age of five or six!

The development of foot activities in the armless child should continue all through his life. Prostheses, however good, can never entirely replace well-trained feet. In the bath and in the bed, prostheses are of little help. One patient is a lovely twenty-eight-year-old mother of two active children who drives, keeps house, dresses the children and herself, and fixes her own hair in the current fashion. She is a bilateral upper-extremity amelic and has never worn prostheses, stating that she "can't be bothered." In truth it is considered that she would benefit from artificial arms under many circumstances, but her life has been full without them.

PROSTHETICS

Recent advances in the field of children's prosthetics include improved design and func-

tion of terminal devices (not just "scaled-down" adult hooks), wrist and elbow joints, lightweight plastic sockets and shells, and more efficient harnessing methods. The externally powered, carbon-dioxide devices of Heidelberg, as well as the electrically powered devices of Chicago, are an immense step in the treatment of the bilateral upper short phocomelic and amelic patient. The initial research and development of self-propelled wheeled vehicles for the lower-extremity amputee proceed both in America and Europe (Fig. 9).

The application of prosthesis to the congenital or traumatic child amputee has reached a stage of acceptance in the United States so as to be almost routine. No longer must the child "wait 'til he grows up, then he can get a wooden arm." Earlier and earlier fittings result in complete patient and family acceptance of and benefit from the prosthesis. All patients are fitted with arms at six months of age and with legs at about nine months. The prostheses become as much a part of the youngster as his undergarments and are removed only when the latter are not normally worn—in the bath or in bed. Alterations and refitting accommodate changes inherent in growth and increased activity levels. The capabilities of such patients over their unfitted similarly handicapped counterparts are obvious.

The fitting of the bilateral upper amelic or phocomelic patient has been a very difficult problem. The tremendous rise in the incidence of such patients associated with thalidomide has been seen in many areas. In Schleswig-



Fig. 9. Battery-powered electrical cart. Speed, direction, and seat height selection are controlled by the amputee by means of joystick arrangement. The cart was developed and constructed at the Child Amputee Prosthetics Project, University of California, Los Angeles.

Holstein *three* phocomelias in 266,599 live births were recorded in the 1949-56 period. In September 1961 the rate of *five* phocomelias *per one thousand* births was recorded. Prosthetic restoration of such patients under the classic methods was completely inadequate. Extremities with sufficient length, power, and excursion of movements simply were not available for the successful stabilization and operation of the routine child prosthesis. In Heidelberg, however, a pneumatically powered prosthesis for the adult had been developed. Through clever engineering, painstaking manufacture, and imaginative application, this device was scaled to the infant and is now fitted at about six to eight months of age. The utilization of shoulder motion or phocomelic digit control allows performance of the activities of daily living and play commensurate with the child's age.

Such patients are initially fitted with bilateral shoulder and thorax sockets and taught controlled shoulder motion that brings the prosthetic hands into apposition in a clapping motion. This apposition of the terminal devices in front of the child allows the holding of large balls, dolls, and other toys at a very early age. Release is accomplished by a reversal of shoulder action. These controlled motions produce internal and external rotation of the humeral segments, which in themselves provide the apposition and separation of the hand elements. As maturation and dexterity develop, pneumatic controls for the opening and closing of the terminal hook, for pronating and supinating the forearm, and for the flexion and extension of the elbow can be added in amputees as young as four years. Clever placement of the control valve for phocomelic digit operation or shoulder motion in the amelic, allows a "normal" neuromuscular pattern to develop. For example, the bilateral phocomelic five-year-old opens and closes the hook on his ipsilateral side by digit function; he controls pronation and supination of the forearm—actually wrist rotation—by contralateral digit operation; and he operates flexion and extension of his elbow by ipsilateral operation of a strategically placed valve by the nudge of his chin. The control motions are readily understood by the child; and to see a completely armless six-year-old eat a full meal without assistance, using prostheses that have the gross form of upper extremities and appear very natural beneath clothing, is indeed most gratifying. The problem of carbon-dioxide supply, the maintenance of intricate valves, and the adjustments for growth are readily apparent difficulties. They can be overcome in most instances, however, and the benefits to the patient are obvious.

SURGERY

Orthopaedic surgery in the limb-deficient child includes most of the procedures associated with normal children of the same age, but the frequent association of other organ system anomalies—cardiac, pulmonary, gastrointestinal—requires the close cooperation of experienced pediatricians and anesthesiologists. Routine techniques for monitoring the vital signs of anesthetized patients may become

quite a problem in this group. How does one obtain the blood pressure in an amputee whose limbs end above the elbows and knees? How does one provide parenteral fluids to a quadrilateral phocomelic patient? What are the effects of the all-encompassing surgical drapes on the body temperature of a patient who is deficient in one-half of his normal radiating skin surfaces? How does one secure postoperative dressings and casts on grossly foreshortened extremities? None of these problems are insurmountable, but they do add a complicating factor to what might at first appear as a routine surgical exercise.

In general, one should be overly cautious in the "corrective" surgery of limb deficiencies. Too often the result is an "improved" X-ray picture and a functionally impaired patient. The osteotomies and fusions to realign bizarre malpositions in the upper extremity are a case in point. The arm may appear much straighter after the deviated hand is fused to the single

bone forearm, but the fibrous ankylosis of the elbow, almost always present in these cases, prevents the postoperative patient from reaching his face with his newly aligned hand. He has gained little and lost much. The fusion of unstable knees in an upper-extremity amelic patient may provide a stable gait, but the youngster cannot reach his mouth with his toes—a catastrophe to this type of patient. Ill-conceived amputations of what at first may appear as useless and grotesque appendages frequently remove elements that could mature into useful limbs capable of stabilizing a prosthesis or providing control operations to a power system.

Conversion is a term employed to describe the amputation of an extremity so deformed as to be cosmetically and functionally incapable of developing into a useful member. The limb is *converted* to a satisfactory stump (1). While one should delay ablative surgery in most instances, the life history of certain deformities

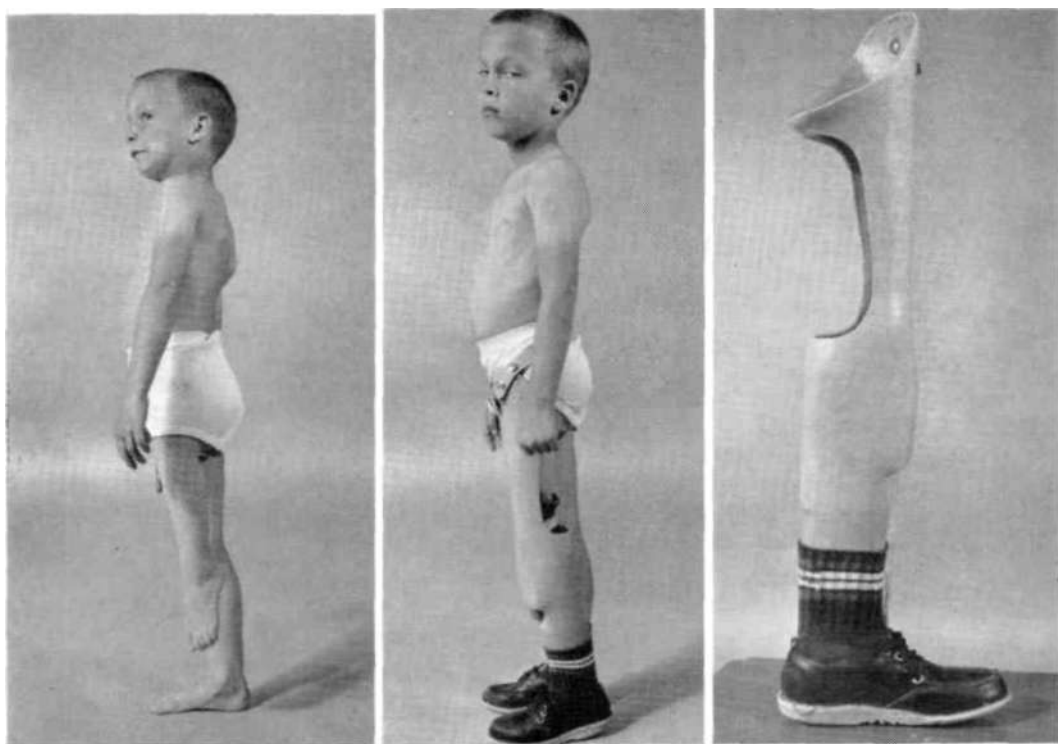


Fig. 10. Views of phocomelia of left lower extremity with pylon-type, end-bearing plastic socket that provides fair cosmesis in long trousers but poor gait characteristics.

is now so well documented that early amputation at the proper level becomes the procedure of choice. Paraxial hemimelias of the lower extremity are common examples. In addition to the complete or partial absence of the tibia or fibula, the remaining bone is shortened, bowed, and rotated; the ankle joint is dislocated; and the foot lies in a plantarflexed attitude of severe valgus or varus. Diligent plaster-of-Paris cast correction, soft tissue surgical releases, and occasional arthrodesis may provide a plantigrade weight-bearing foot. As the child matures, increasing inequality of leg length occurs; additional shoe lifts or braces are added; and by his mid-teens, the patient is walking on a four- to six-inch platform. Or, one might have elected to hold the foot in marked equinus, allowing the tiptoe position to compensate for the decreased leg length.

The bulky prosthesis is then molded about the plantarflexed foot. Such procedures may serve well in the male, whose trousers mask the irregular contour of the prosthesis (Fig. 10). In the female, however, such a prosthesis is impossible to hide or disguise. Functionally, gait patterns are disturbed; and fitting and alignment are complicated. The early conversion of this anomaly by disarticulation of the ankle provides an excellent weight-bearing stump of the Syme type when "barefoot," and the application of a prosthesis provides a cosmetically contoured and finished artificial leg with excellent gait characteristics (Fig. 11). At maturity these stumps have shortened to the conventional below-knee level and are fitted as such.

The congenital reduction in leg length may be so severe that the total length of the af-

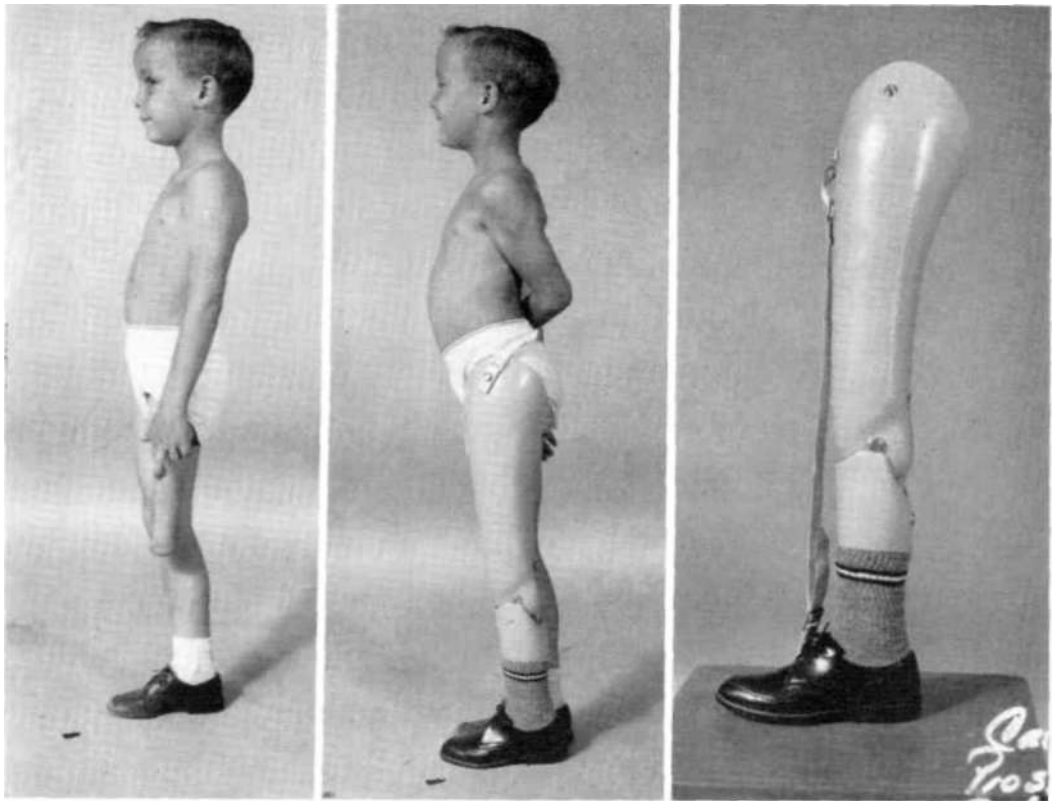


Fig. 11. Same patient who appears in Figure 10 is shown with his prosthesis after a Syme's amputation at the left ankle. End-bearing prosthesis now has knee joint with improved gait characteristics. Unequal future growth will reduce the relative length of the left stump and provide the mature amputee with a stump equal to a long above-knee amputation.

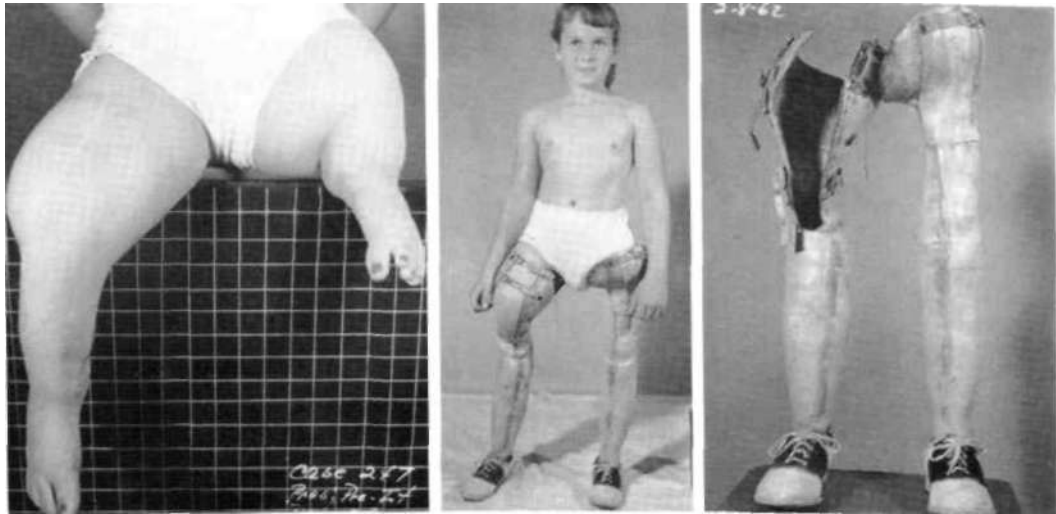


Fig. 12. Views of bilateral phcomelic patient with intact knee and ankle joint on right, fitted with bilateral pylon-type prostheses giving a waddling gait and poor sitting characteristics.



Fig. 13. Same patient shown in Figure 12 after arthrodesis of knee in full extension and Syme's amputation at ankle to provide a stable right thigh stump easily fitted with a standard suction socket. The left phocomelic extremity has been fitted with a modified above-knee socket. Appearance and gait patterns are much improved.

fectured femur and tibia combined may only approximate that of the normal femur. A common multistage procedure, yielding good results at UCLA, consists of an arthrodesis of the knee in full extension, followed, after complete healing, by disarticulation at the ankle joint. A stable, weight-bearing stump of normal "thigh bone" length is provided, and the patient is fitted as a routine above-knee amputee. The gain in function and appearance is very pleasing to the patient and surgeon alike (Figs. 12 and 13).

Fusions in such cases are often performed prior to the closure of epiphyseal plates about the involved joint. Epiphyses fuse readily to their juxta-articular counterpart after excision of joint structures, and their growth contribu-

tion to extremity length continues in spite of operative removal of their articular portions and their transfixion by intramedullary pins used for postoperative stabilization. Arthrodeses in other areas are utilized for stabilizing elements congenitally deficient in supporting ligaments, tendons, and muscles. Transplantation of single remaining bones in paraxial deficiencies of the forearm and leg, with fusions to proximal and distal elements, may provide longer and stronger extremities for use with or without prostheses.

Bizarre abnormalities of the hand may be corrected surgically with much gain in function. The removal of rudimentary elements may provide much increased prehension capability in the remaining structures. *Syndac-*

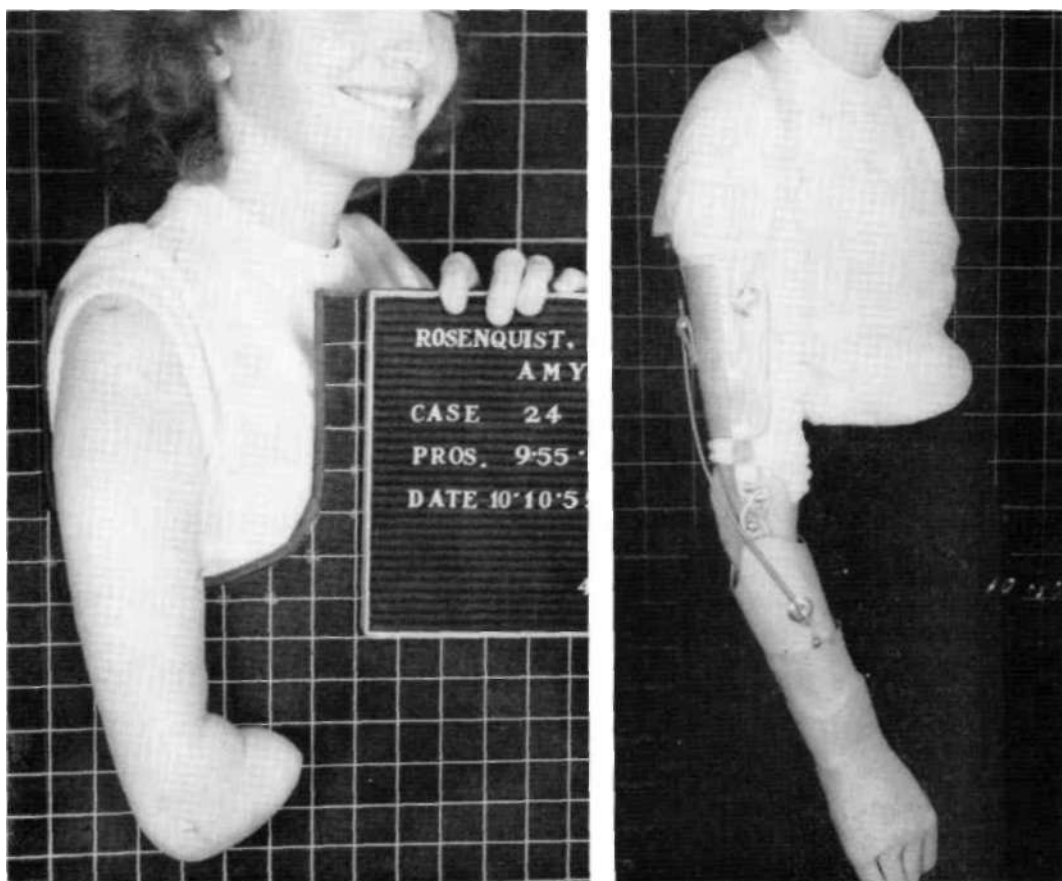


Fig. 14. Attractive early teen-age female with very short below-elbow congenital amputation fitted with step-up hinge and figure-eight harness. The patient was an excellent wearer but objected to the bulk of the prosthesis and the poor appearance of the shoulder harness. She requested a cineplasty to allow the wearing of strapless dresses.

tylism is a common finding, and the surgical separation of digits is very rewarding. Soft-tissue fusions of terminal phalangeal elements are not rare. Small skin bridges may be painlessly divided by the application of necrotizing surgical silk ligatures. Healing keeps pace with the necrosis, and fingers separated in this fashion often have undetectable scars. Full-length syndactylism will require careful plastic reconstruction at the proper age, using full- and split-thickness flaps and grafts to provide satisfactory noncontracting web space construction as described by Bunnell and others.

Biceps lineplasties have been performed with good results in these patients (Figs. 14, 15, and 16). Below-elbow terminal hemimelias are the commonest major congenital amputation in the UCLA child amputee clinic case load. While there is always hypoplasia of humeral musculature, biceps and brachialis development is sufficient to produce excellent

force and excursion of the cineplasty tunnel as well as stump movement. The removal of the annoying and cumbersome shoulder harness, coupled with the increased power and flexibility of the prosthesis, has made this an excellent procedure in the properly selected case. It is possible that it should be recommended more often for teen-age patients.

The most common single surgical procedure in the UCLA child amputee clinic is stump revision for *terminal skeletal overgrowth* (Fig. 17). For the most part, this annoying phenomenon occurs in the above-elbow and the below-knee stumps—no cases in the congenital forearm or femoral amputees have been observed at the UCLA child amputee clinic, although they have occurred in all locations in the acquired amputee. While previous authors have stated that terminal overgrowth does not occur in the congenital type, it has been found to be so common at the L'CLA child amputee clinic that the parents of these patients are warned at

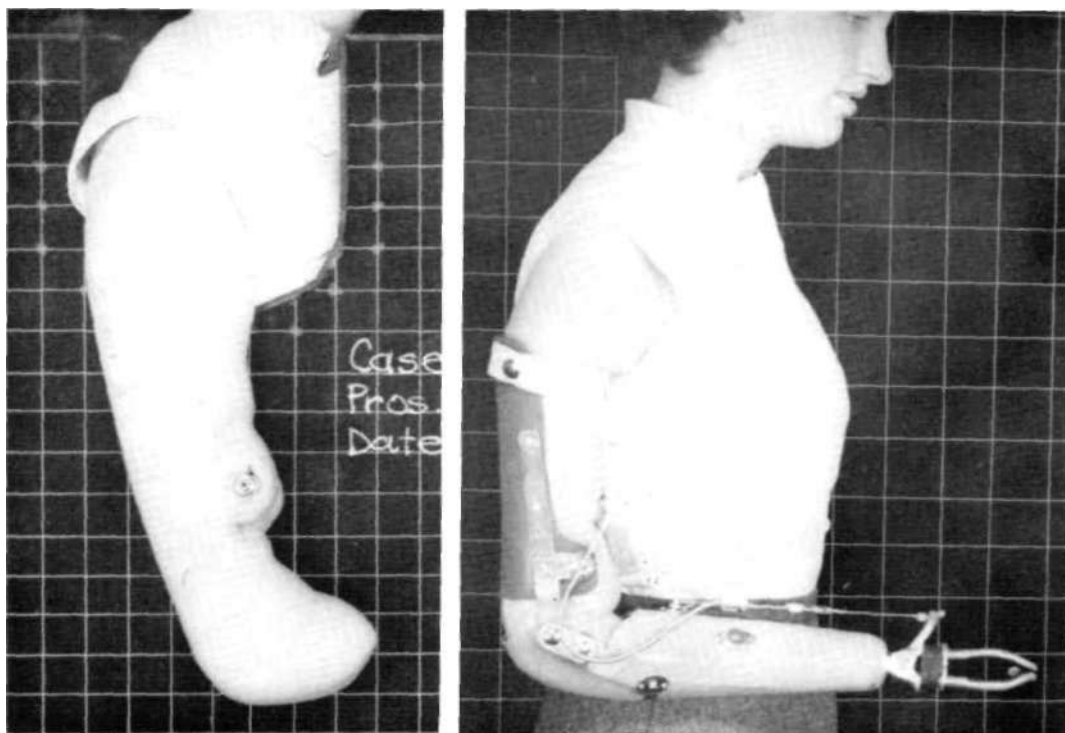


Fig. 15. Same patient shown in Figure 14 after a biceps cineplasty had been performed. The figure-eight harness has been discarded. Hand or hook can be attached interchangeably to the split-socket prosthesis.

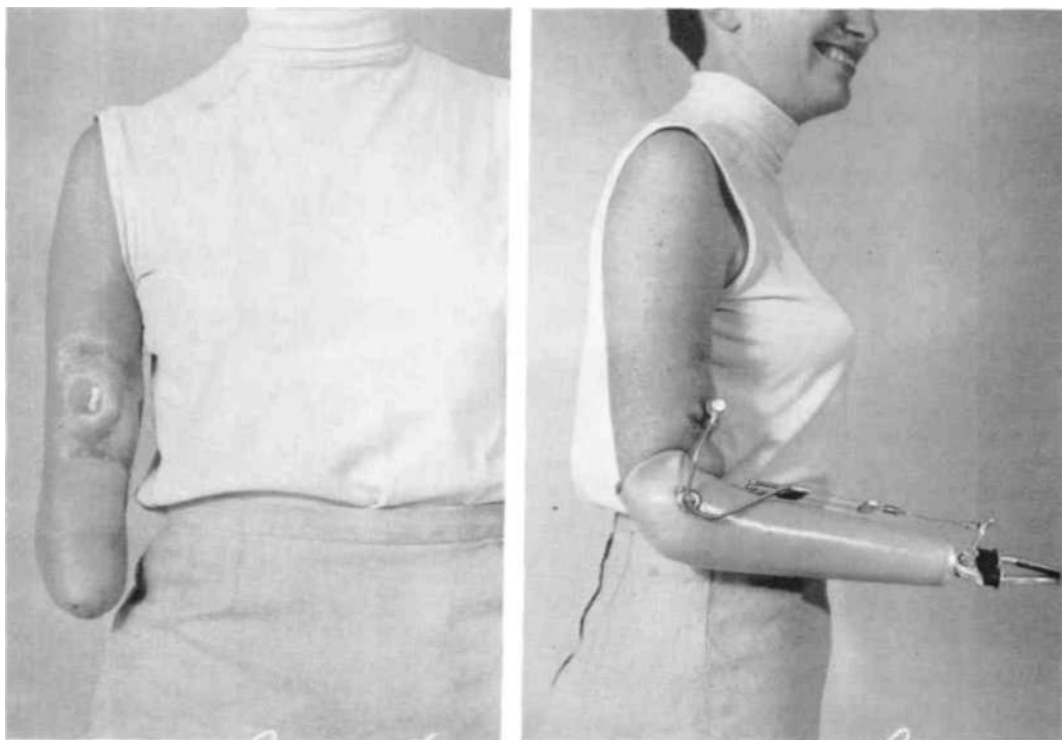


Fig. 16. Same patient shown in Figures 14 and 15 fitted with a Munster-type socket. Cineplasty tunnel is in excellent condition. The patient is a full-time wearer and is delighted with the reduced weight and complexity of the prosthesis as well as with increased proprioception and the stability of the fitting.

their initial clinic visit. Subsequent protrusion of the underlying bone into the terminal stump comes as no surprise, and parents are instructed that one to five surgical revisions may be necessary before the child reaches full growth and the difficulty ceases. Various techniques in the treatment of the bone end have been attempted—including osteoperiosteal plugs, bars, flaps, etc.—to decrease the growth potential of the severed bone end, without success. The transected cortical shaft has been compared to the one side of a long-bone fracture—the terminal appositional subperiosteal and endosteal bone growth is quite similar to the process seen in fracture healing. Why it should produce a sharp, soft-tissue-penetrating, terminal spike is not understood. A bursal sac is almost always present. The routine revision consists of a transverse terminal incision into the sac, removal of the protruding spike with all of its soft tissue covering two to three centi-

meters proximal to the tip, and excision of the proximal bursal sac wall. Complete excision of the entire bursa often complicates distal healing, and since the bursa forms again—whether removed or not—the distal wall is left undisturbed. Healing is usually prompt, and prostheses may be refitted in four to six weeks after surgery.

SUMMARY

In summary, continued research in the fields of embryology, teratology, and genetics has indicated that congenital abnormalities are not always "inherited" but may be environmentally induced, may be caused by chromosomal aberrations, or may result from genetic backgrounds. In a high percentage of cases, the defect has occurred by the end of the eighth intrauterine week in human embryos. The exact mechanism of action of teratogenic agents is not completely understood; but,

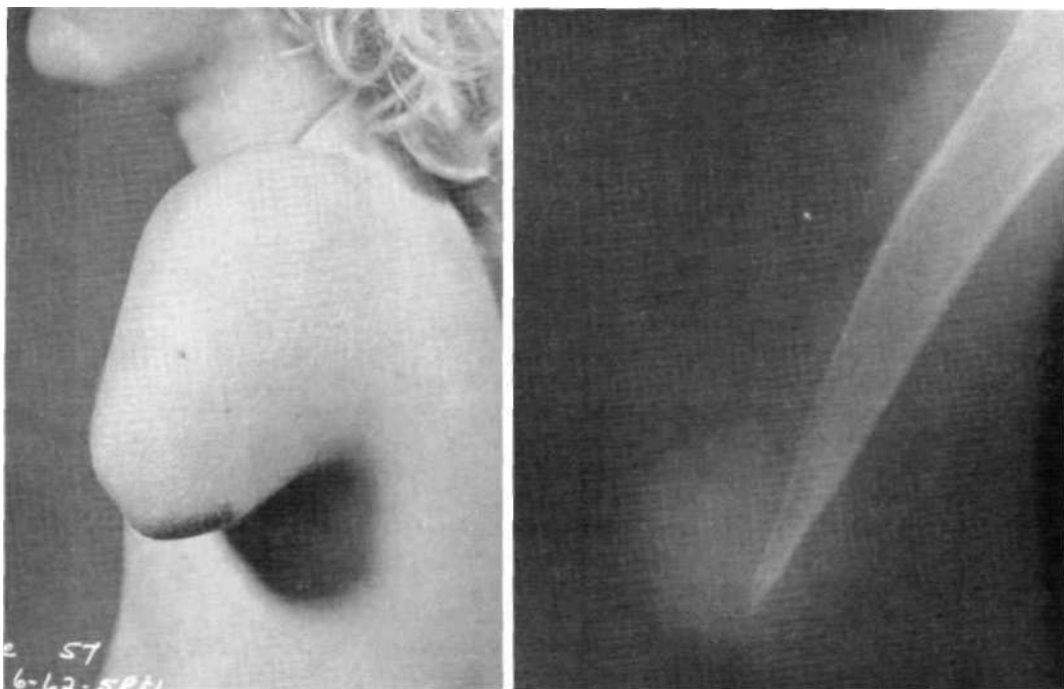


Fig. 17. Congenital above-elbow amputee with recurrent episodes of terminal bone overgrowth and stump perforation. X-ray reveals sharp spur formed by terminal appositional new bone formation. Frequent surgical intervention is required in humeral and tibial amputations of this type; revision is seldom necessary in forearm and femoral amputations.

experimentally, the embryos of laboratory animals can be insulted by a number of agents producing predictable deformities. The time of the insult appears as important as the nature of the agent itself.

Based on roentgenographic findings in the newborn, congenital deformities can be classified according to the methods of O'Rahilly and Frantz, allowing programs and patterns of rehabilitation on an organized basis.

The early training of limb-deficient children allows them to capitalize on existing extremities and simplifies eventual prosthetic restitution.

Advance within the prosthetics field results in the present practical use of externally powered devices in the child amputee and predicts continued developmental success in the future.

In general, surgery should be deferred until maturation produces the maximum potential in the involved limb. The life history of certain deformities, however, allows conversion to

functional amputation stumps at an early age; and the subsequent early fit with prosthetic devices greatly enhances the patients' habilitation.

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A New Surgical-Prosthetic Approach to the Syme's Amputation, a Preliminary Report

AUGUSTO SARMIENTO, M.D.,¹
RAYMOND E. GILMER, JR., M.D.,²
AND ALAN FINNIESTON, C.P.³

The advantage of the end-bearing ankle-disarticulation amputation has been well recognized since Syme published his classic article in 1843 (2). Disadvantages and complications of this level of amputation have led some surgeons to favor amputation at a higher level. Failure of adherence of the heel pad to the distal tibia, resulting in a flabby, loose stump, prevents many amputees from ambulating without a prosthesis (Fig. 1) (1). Break-down of the stump is a frequent occurrence. The appearance of the conventional Syme prosthesis is objectionable to many amputees, particularly females, because of its bulbous end. Within recent years, the introduction of the plastic Syme prosthesis in which a portion of the weight of the amputee is borne by the patellar tendon has resulted in greater acceptance of this level of amputation (J). However, the conventional plastic Syme prosthesis still retains a wider distal end and a window for the accommodation of the bulbous stump, significant disadvantages in appearance and structure.

To overcome the objectionable features of the Syme's amputation, there has been developed at Jackson Memorial Hospital, University of Miami School of Medicine, a new surgical-prosthetic approach to this amputation which maintains the end-bearing quality of the stump and improves upon the appearance of the prosthesis.

¹ Associate Professor of Orthopaedic Surgery, School of Medicine, University of Miami, Jackson Memorial Hospital, Miami, Fla. 33136.

² Chief Resident, Orthopaedic Surgery, Jackson Memorial Hospital, Miami, Fla. 33136.

³ Arthur Finnieston, Inc., 1901 N.W. 17th Ave., Miami, Fla. 33125.

SURGERY

The Syme's amputation has been modified to reduce the circumference of the stump by rongeur away the metaphyseal flare of the

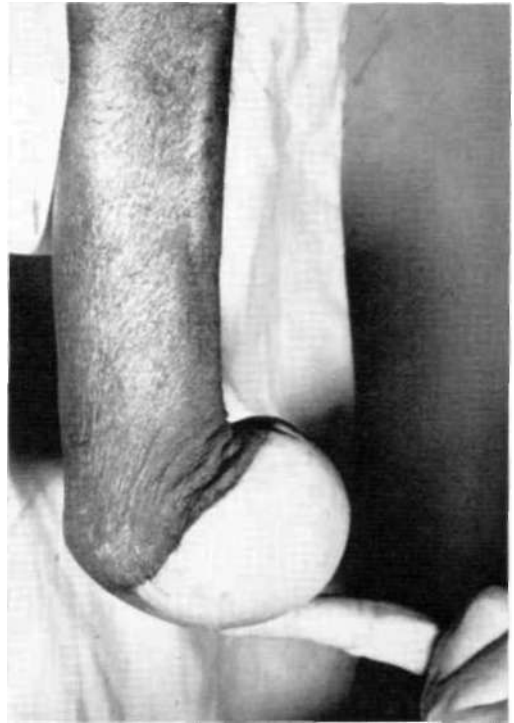


Fig. 1. Poor Syme's stump demonstrating a loose and bulbous distal end.

distal tibia and beveling the distal fibula, making the distal bony stump only slightly wider than the diaphyseal portion of the leg (Fig. 2). The eventual stump circumference is reduced by approximately one-third without



Fig. 2. Roentgenograms of the modified Syme's stump demonstrating the beveled metaphyseal flare.

interfering with the end-bearing quality of the stump (Fig. 3). There is no alteration of the length of the tibia. A skin incision is used, producing a long posterior flap containing the lied pad a- the eventual weight-bearing surface. The skin is closed loosely with interrupted wire sutures widely spaced to permit spontaneous drainage, thereby eliminating the need for external drains. A single layer of nonabsorbent surgical dressing is applied to the suture line, and over this one layer of stockinette is applied. A skintight, firmly wrapped plaster cast is applied to the stump and extended proximally so that components of a patellar-tendon-bearing (PTB) prosthesis can be incorporated into the plaster cast (Fig. 4),

POSTOPERATIVE CARE

The stump cast applied at surgery is allowed to remain on until looseness is apparent because of shrinkage of the stump, usually two to three weeks. As soon postoperatively as the patient's condition permits, a SACH foot, is attached to the stump cast, and protected



Fig. 3. Modified Syme's stump with its distal end only slightly wider than the thinnest diaphyseal diameter.

ambulation is allowed and encouraged, usually within the first postoperative week. The degree of weight-bearing on the temporary prosthesis is determined by the patient's ability to ambulate and the absence of discomfort. The cast is changed at frequent intervals until maximum stump shrinkage is obtained.

PROSTHETIC FITTING

The conventional Syme prosthesis is constructed in such a manner that a removable window in the narrow portion of the socket is necessary to allow introduction of the stump into the prosthesis. With the modified operative technique that reduces the bulkiness of the

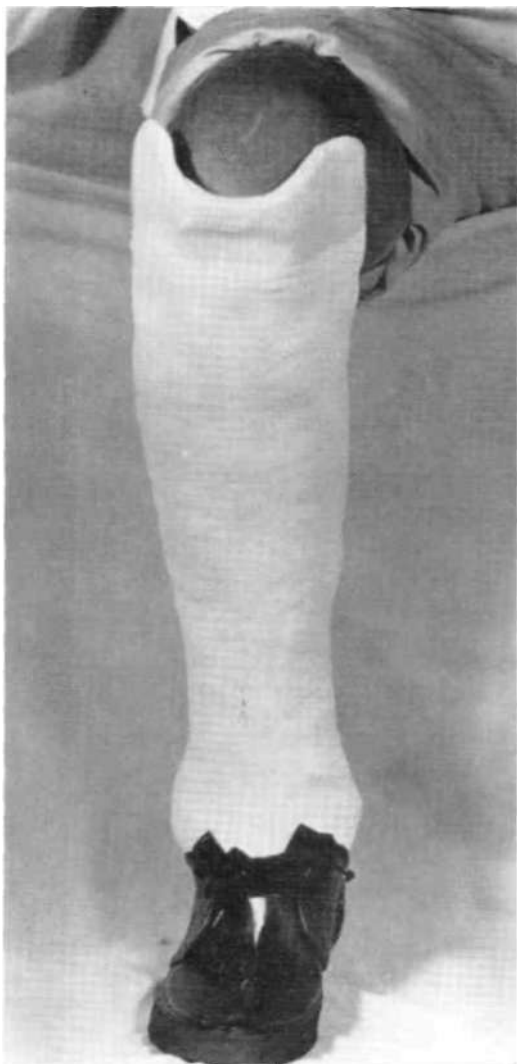


Fig. 4. Temporary plaster prosthesis applied in the operating room immediately after surgery.

distal end of the stump, the requirement for the window has been eliminated (Figs. 5 and 6). A double-walled, windowless prosthesis has been developed. The inner wall is expandable over its narrowest portion at the junction of the middle and distal one-thirds of the shaft. This allows the slightly larger distal end of the stump to glide into the terminal portion of the socket. Upon passage (if the distal end of the stump through the expandable portion of the socket, retraction of the expandable-wall prevents piston action between the stump and

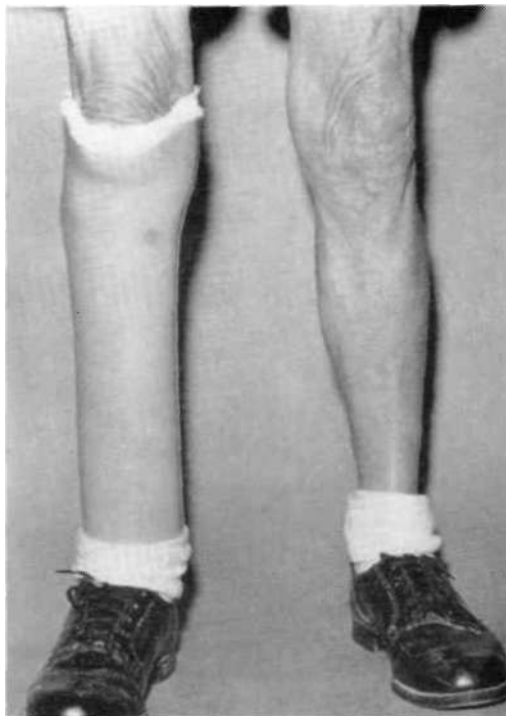


Fig 5. Anterior view of the modified Syme prosthesis. Note the absence of the conventional window and bulky ankle.

the socket. Thus the need for a supracondylar cuff is eliminated. As in the case of the conventional PTB prosthesis, total contact between the inner wall and the stump is indispensable for the prevention of edema and stump breakdown.

CLINICAL EXPERIENCE

At Jackson Memorial Hospital, University of Miami School of Medicine, the modified Syme's amputation has been performed on seven patients whose ages range from 37 to 72. All the patients were diabetics. Five patients were successfully amputated at the Syme's level; two required amputation at a higher level because of stump gangrene. Three patients have been successfully fitted with expandable-socket prostheses. One patient was lost, to follow-up prior to prosthetic fitting, and the most recent patient at the time of writing (March 1966) is still ambulatory with a temporary prosthesis.



Fig. 6. Same patient shown in Figure 5. Lateral view of the modified Syme prosthesis. Note the PTB components, the proximal portion of the prosthesis, and the absence of supracondylar cuff.

DISCUSSION

Other factors being equal, the ambulatory ability of the lower-extremity amputee is directly related to the length of the stump. The longer the lever arm below the knee, the greater the proprioceptive and kinesthetic feedback to the central nervous system, resulting in greater voluntary muscular control and coordination, and a better gait. The advantage of the end-bearing quality as provided in the Syme's amputation further enhances the desirable features of the long below-knee stump.

It is believed that, in patients with peripheral vascular disease, the presence or absence of pulses or absence of bleeding from the major vessels should not be the determining factors for the level of amputation. Collateral circulation that gradually develops during the course

of the disease is often sufficient to maintain viability of the stump. The presence of skin bleeding should determine the level of amputation.

Obliteration of collateral circulation by edema may be the major cause of breakdown of the stump in cases of precarious circulation. The application of a rigid plaster-of-Paris dressing immediately after surgery probably prevents excessive edema and, therefore, enhances survival of these stumps.

The time-honored belief that long below-knee stumps break down because of poor blood supply in the distal portion of the leg is open to question. Lack of total contact between the stump and the socket is the most likely factor responsible for distal edema and breakdown of the stump. Experience with 62 cases of immediate postoperative prosthetic fitting of below-knee amputees has further strengthened the opinion that the presence of pulses or circulation, or both, through the major vessels is not essential for the survival of long amputation stumps. Two of the reported cases who demonstrated absence of blood flow in the major vessels below the superficial femoral artery, as shown on preoperative arteriograms, were successfully amputated at the Syme's level. The physiological impact of early ambulation and the decrease or absence of stump and phantom pain may also have played significant roles in the success of this method for management of the Syme's amputation.

SUMMARY

A new surgical-prosthetic approach to the Syme's amputation has been described.

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Northwestern University Suspension Casting Technique for Hemipelvectomy and Hip Disarticulation

FRED HAMPTON, C.P.¹

INTENDED as an addendum to the article entitled .1 *Hemipelvectomy Prosthesis* which appeared in the Spring 1964 issue of *Artificial Limbs (I)*, this article describes a technique for casting hemipelvectomy or hip-disarticulation "stumps," utilizing a suspension casting

3. Definitive markings can be drawn for relief of bony prominences, scar tissue, etc.
4. Firm wrapping will result in a smooth cast.
5. Positive support is provided for the lateral aspect of the stump.

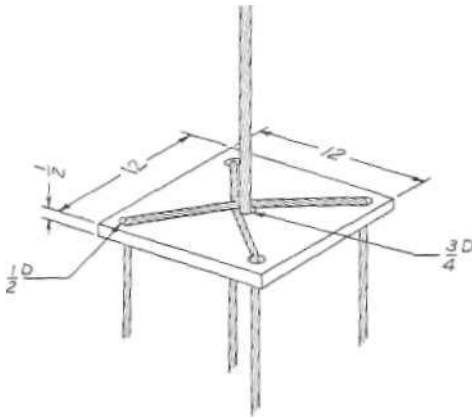


Fig. 1. Spreader constructed from a 12-in. square of 1/2-in. plywood. A 3/4-in. hole is drilled through the center for attachment of the support rope, and a 1/2-in. hole is drilled in each corner for the suspension ropes.

technique. The Northwestern University casting technique differs from others in that the weight is borne over the entire area of the "stump" and lower rib cage rather than just at the distal area.

Advantages to this procedure are:

1. The amputee is supported in a comfortable stance position during the entire casting procedure.
2. Tissues are firmed, allowing an accurate outline of the socket to be drawn on the supporting stockinette.

¹ Assistant Project Director, Northwestern University Prosthetics Research Center, 401 East Ohio St., Chicago, Ill. 60611.



Fig. 2. Inner stockinette held in place by two pieces of 1-in. webbing over the shoulders.

Equipment required includes:

1. Some type of vertical hoist that will permit vertical height adjustment.
2. A spreader strong enough to support the amputee's weight (Fig. 1).

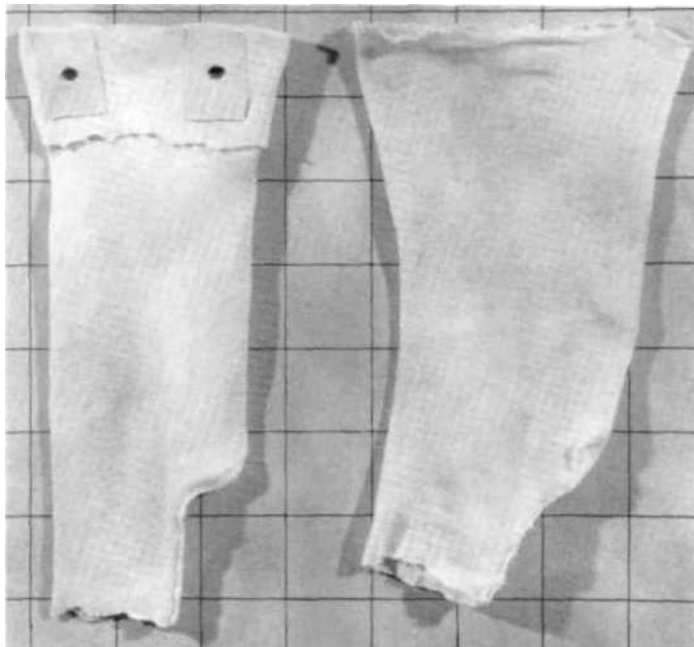


Fig. 3. Two pieces of 6- or 8-in. stockinette used in casting. Suspension sock on left is made of nylon stockinette and has four equidistant points for attachment around the proximal periphery. Because of stresses under weight-bearing conditions, these areas are reinforced by turning down the edge of the stockinette and sewing on a piece of 1-1/2-in. webbing 3 in. in length at the location of each attachment hole.



Fig. 4. Attaching suspension ropes from the spreader to the reinforced holes in the suspension sock.

3. Ropes to suspend the stockinette from the spreader.

The spreader used at the Northwestern University Prosthetics Research Center allows four points of attachment to the stockinette and prevents the ropes from interfering with the amputee's face. It is constructed from a 12-in. square of 1/2-in. plywood. A 3/4-in. hole is drilled through the center for the attachment of the hoist rope, and a 1/2-in. hole is drilled in each corner for the suspension ropes. The suspension ropes are cut long enough to permit each to pass diagonally across the spreader and through the corner holes.

Two pieces of 6- or 8-in. stockinette are required. They must be long enough to cover the body from the level of the nipple line proximally to the level of the upper third of the thigh of the sound leg. The portion that contacts the sound thigh is cut to assure a snug fit and thus provide an anchor point for the stockinette.

The first piece of stockinette is used as a protective covering for the body from the

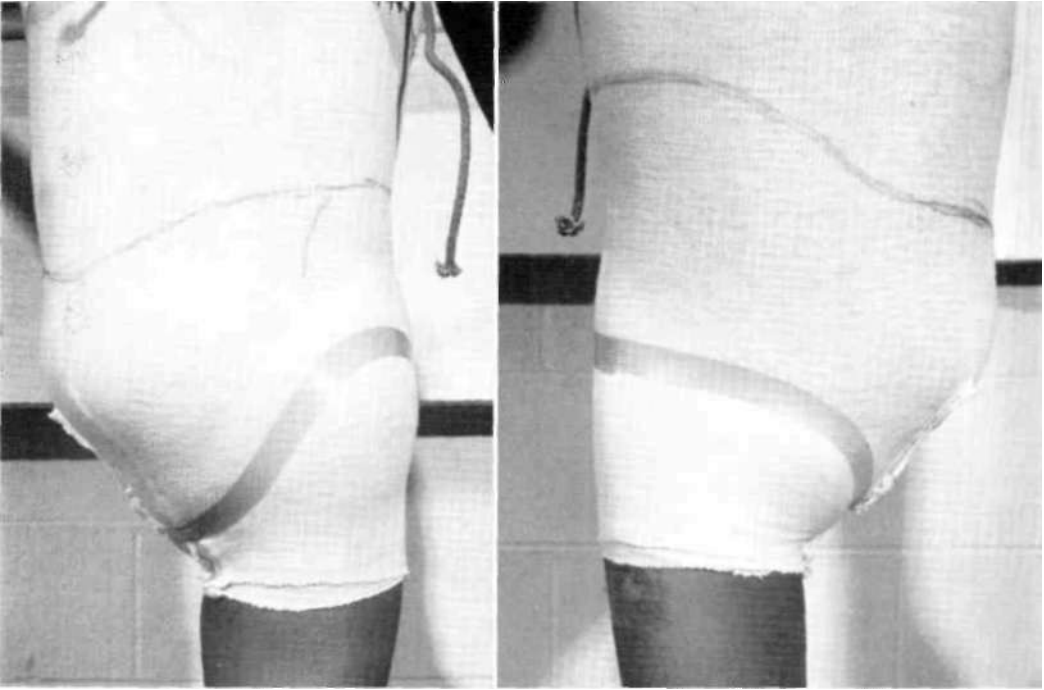


Fig. 5. Starting at the trochanter on the sound side, a strip of pressure-sensitive tape is applied to pass posteriorly over the flare of the gluteal muscles to the sacrum, then distally under the ramus to the anterior aspect of the stump. Anteriorly, the tape is applied across the inguinal crease to the trochanter. In effect, the tape provides the distal outline of the socket.



Fig. 6. Drawing an outline of the socket on the suspension sock to ensure that the plaster wrap will cover the required area.

plaster. It is pulled up over the sound limb and held under firm tension by two pieces of 1-in. webbing over the shoulders (Fig. 2).

The second piece of stockinette is the suspension sock and is made of nylon stockinette. There are four equidistant points of attachment around the proximal periphery. Because high stresses are induced at these points under weight-bearing conditions, these areas must be reinforced. The proximal edge of the stockinette is folded to a depth of 3 in. A piece of 1-1/2-in. webbing 3 in. in length is sewn at the location of each attachment hole. Holes are then cut in the reinforced areas to allow attachment of the suspension ropes (Fig. 3).

The first stockinette is pulled over the amputee and held securely by the shoulder straps. The nylon suspension sock is pulled on and should extend approximately to the nipple line. Before the ropes from the spreader are attached to the suspension sock, the amputee should be standing directly under the line of pull from the hoist. The spreader is lowered until it just clears his head. The suspension



Fig. 7. The bilateral hip-disarticulation amputee, who is on a cart, is wheeled into position beneath the suspension bars.

ropes are then attached through reinforced holes (Fig. 4), and the spreader is adjusted until it is in a horizontal position. Tension is applied by means of the hoist until the weight is evenly distributed between the suspension sock and the sound limb. A scale may be used to ensure that the amputee is bearing half of his weight on the sling. The amputee is weighed prior to suspension; then, with the amputee still on the scale, the sling is adjusted by the hoist until half of the amputee's original weight is indicated on the scale.

It is important that the anchor point on the thigh of the sound limb be well fixed. If the suspension sock tends to slip, the distal portion should be anchored with a piece of 1-in. webbing passed under the foot and firmly secured.

Under tension, the suspension sock will have a tendency to bridge in the area of the ramus from the medial aspect of the sound leg to the lateral aspect of the stump. Starting at the

trochanter on the sound side, a strip of pressure-sensitive tape is applied to pass posteriorly over the flare of the gluteal muscles to the sacrum, then distally under the ramus to the anterior aspect of the stump. The genitals are positioned toward the sound side, and the pressure-sensitive tape is applied just superior to these organs and across the inguinal crease to the trochanter. In effect, this is the distal outline of the socket. If applied in the correct manner, the tape produces a good radius in the area of the ramus (Fig. 5).

Under weight-bearing conditions the stockinette will stretch. It is important that sufficient weight is borne by the suspension sock and that adjustments be made if necessary. A general outline of the socket is drawn to ensure that the plaster wrap will cover the required area (Fig. 6). Necessary reliefs are marked, or patches (felt or Kemblo rubber) are glued over areas to be relieved.

The procedure for wrapping the stump is the same as previously described (2, 2).

BILATERAL HIP DISARTICULATION

Various techniques may be employed in casting a bilateral hip-disarticulation amputee; for example, in the prone position with a split cast. To facilitate the procedure for obtaining an intimate Teplica of the stump under weight-bearing conditions, the Northwestern University Prosthetics Research Center has adapted the suspension casting technique.

As in the suspension casting of a unilateral hip-disarticulation amputee, the suspension sock is made from a piece of nylon stockinette. The four points used for attachment of the suspension ropes or webbing must be reinforced by doubling the proximal portion of the nylon sock and sewing a piece of 1-1/2-in. webbing 3 in. in length at each attachment point. Two pieces of 3/4-in. galvanized pipe and a set of parallel bars are used for support of the suspension sock.

Two pieces of stockinette are used in the casting. Both socks must be of sufficient length

to cover the body to the nipple line. The distal portion of each sock is sewn. The first sock is pulled on the amputee, and tension is applied and maintained by means of 1-in. webbing over the shoulders. The suspension sock is pulled up snugly over the amputee. The support bars are fastened to the parallel bars for stability, but it must be possible to slide the posterior support bar. The parallel bars are raised; and the amputee, who is on a cart, is wheeled into position (Fig. 7).

The front attachments of the nylon suspension sock are secured to the front bar, with the amputee lying down. Following this, the amputee is pivoted into an upright position. The back bar is moved forward on the parallel bars until the nylon suspension sock can be secured at the two posterior attachment points (Fig. 8). The cart is removed, allowing the suspension sock to support the weight of the amputee (Fig. 9). Under these weight-bearing conditions, any areas that require relief are marked, and the lower rib cage is outlined (Fig. 10).

Standard plaster bandage is used with firm tension applied during wrapping. The amputee is instructed to hold in his stomach during wrapping, and further flattening is done in this



Fig. 8. The back suspension bar is moved forward on the parallel bars until the suspension sock can be secured at the two posterior attachment points.



Fig. 9. The cart is removed, allowing the suspension sock to support the weight of the amputee.



Fig. 10. Areas that require relief are marked, and the lower rib cage is outlined. The amputee depicted has had some ribs removed. An ileostomy bag was left on during casting, and its position was marked.

area by the hands of the prosthetist (Fig. 11).

When the cast has hardened, the amputee is positioned to ensure that his shoulders are level. Three alignment lines are drawn. By use of a plumb bob, the anterior line is established, originating from the sternal notch. The posterior line originates from the seventh cervical vertebra. A vertical line is established, originating from the axilla, to represent the flexion angle of the socket. The amputee is then released from the support bars onto the cart.

The cast is cut down the anterior surface with a Stryker cast cutter and spread sufficiently to



Fig. 11. Flattening the wrap cast in the stomach area.

allow removal from the amputee. After the wrap cast has been closed and a separator has been applied, the cast is oriented in a vertical position by reference to the alignment lines. Plaster for the positive model is poured into the cast, and a holding pipe is inserted in a vertical position. The alignment lines from the wrap cast are cut through to the positive model by use of an awl. These lines are used to locate the positions of the hip joints when the socket is fabricated.

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The Navy Prosthetics Research Laboratory Impulsion Valve

CHARLES C. ASBELLE, B.S., C.P.O.¹

PERSPIRATION of the stump while a prosthesis is being worn has always been a problem to a sizable segment of the amputee population. As a rule, amputees perspire at a greater rate than is normal even without the prosthesis. The newer, total-contact sockets as designed and introduced offer no provision for ventilation. Although in the case of some patients who sweat profusely during the initial use of total-contact sockets the problem seems to disappear after a period, there remains a sufficient number of cases in which perspiration presents a real problem.

In an attempt to provide ventilation in sockets, many prosthetists have drilled or punched many small holes in the socket walls, but this has not proven to be very satisfactory. Because of the high concentration of sweat glands in the extremities (as many as 80 per square cm.), it is virtually impossible to provide mechanically a sufficient number of holes in a socket wall to give adequate ventilation and retain the necessary strength.

To overcome this dilemma, porous plastic laminates (1, 2) that permitted breathing were developed. These have proven to be quite satisfactory for upper-extremity prostheses but much less so for lower-extremity sockets where strength is a paramount problem. Except in cases where the prosthesis is subjected to only light loads, when the socket walls are made thick enough to withstand the stresses imposed the socket becomes intolerably bulky. Because porous laminates offer an almost ideal solution, work is continuing on their refinement.

Meanwhile, experiments and clinical experience indicate that the use of an inexpensive impulsion valve developed by the Navy Pros-

thetics Research Laboratory has been helpful to many patients, though not the ultimate solution to their perspiration problems.

The impulsion device (Fig. 1) in its present state is simply a ball-type check valve arranged so that air is drawn into the stump sock during the swing phase of walking, or when the prosthesis is not bearing weight, and the air is expelled through the stump sock when the stump is forced into the socket as in the stance phase of walking. The valve consists of only two parts, the ball and the housing. The ball is made of polyurethane to prevent clicking noises experienced with other materials. Two sizes of the valve accommodate the entire amputee population (Fig. 2). They are available commercially.²

The recommended method of installation for a total-contact below-knee socket with a liner is shown in Figure 3. The valve, of course, can be used without a liner and in any socket when a stump sock is used.

To determine some idea of the effectiveness of the impulsion valve, 41 amputees participated in a controlled experiment conducted by NPRL. Two subjects had above-elbow amputations, two had Syme's amputations, and the remainder were below-knee amputees. Thirty-one felt that perspiration was a problem to them. The subjects walked for 20 minutes in a controlled high-temperature, high-humidity atmosphere with and without the valve. The weight of the stump socks was compared in each instance to determine any reduction in the accumulation of sweat. The average amount of reduction was 39.7 per cent (2).

Later, at New York University, 11 patients, all below-knee amputees wearing patellar-tendon-bearing sockets satisfactorily, were pro-

¹ Head, Research and Development, Navy Prosthetics Research Laboratory, U. S. Naval Hospital, Oakland, Calif. 94614.

² United States Manufacturing Co., 623 S. Central Ave., Glendale, Calif. 91209.

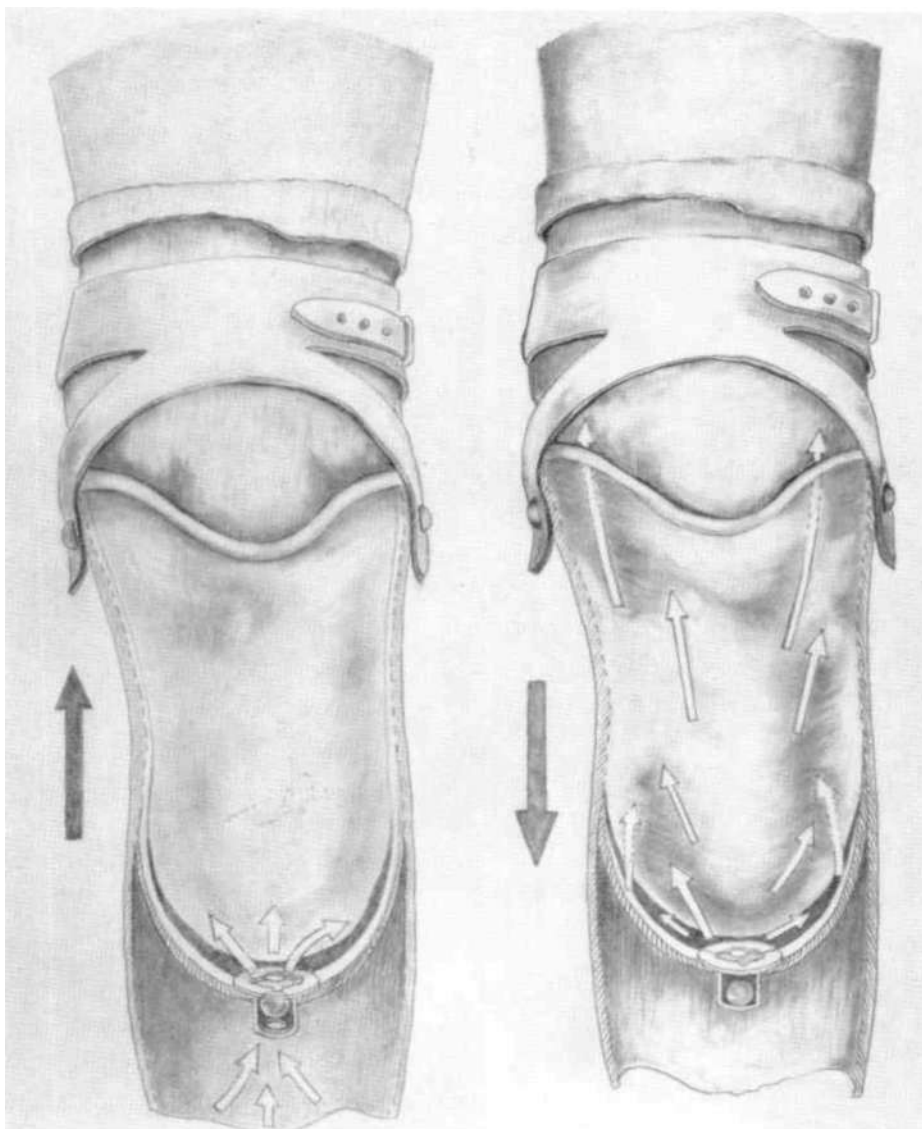


Fig. 1. The function of the Navy Prosthetics Research Laboratory impulsion valve. When the socket is in suspension, air is drawn into socket and stump sock. When socket is bearing weight, air is expelled around proximal periphery of the socket.

vided with impulsion valves. NYU reported as follows: (3)

In the first stage of the study, three subjects withdrew shortly after delivery. One subject withdrew because of a complaint that the valve produced a disagreeable sensation in his stump. He was unable to elaborate any further on this complaint and refused to cooperate in investigating this matter. Therefore this subject's contribution to the study must be viewed with reservation. Two other subjects discontinued

wearing their prostheses for medical reasons not related to the installation of the valve.

The remaining eight amputees in the study reacted positively to the effects of the valve. Seven subjects reported a noticeable improvement in their sweating condition. Four subjects with serious sweating problems said that they noticed a measurable reduction in moisture accumulation in their sockets. The other three subjects whose sweating problems were relatively minor (not troubled with sweat accumulation) reported that

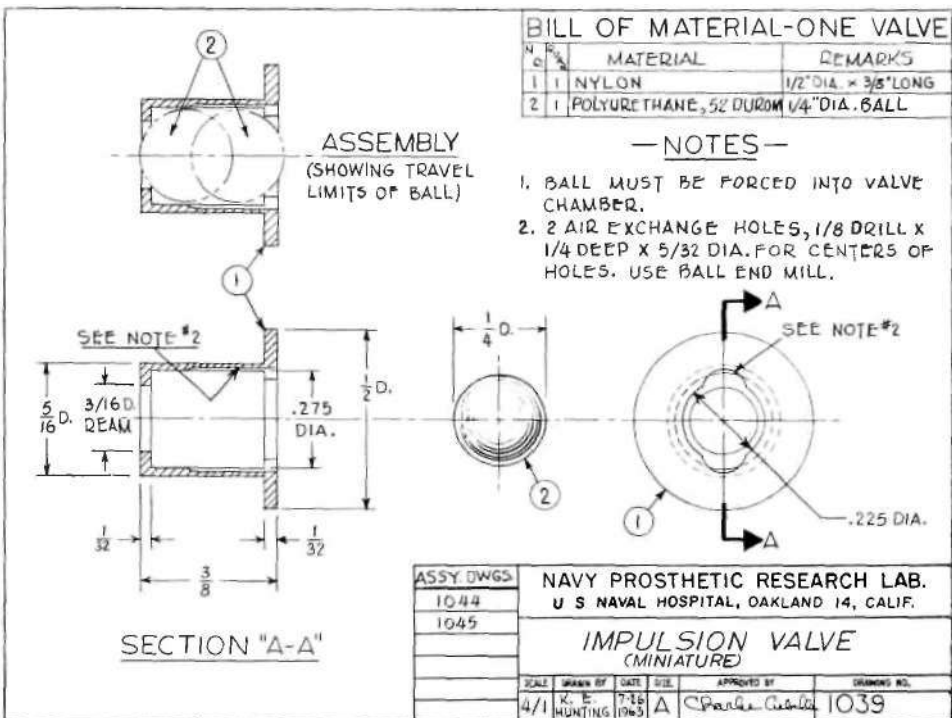


Fig. 2. Details of the two sizes of the NPRL impulsion valve.

INSTALLATION INSTRUCTIONS

Installation in Patellar-Tendon-Bearing (PTB) limb with liner (Fig. 3):

1. Make alignment marks posteriorly on socket and liner to assure replacement in the same position.
2. Remove liner and punch a mark in the bottom of socket (center) and drill a 1/2-in. hole. Countersink is not required because shaped valve flange will not be felt through liner.
3. Ream 1/2-in. hole with 9/16-in. reamer. Remove particles and dust. Trim away ends of any material remaining.
4. Coat the lower surface of valve flange and the matching area around hole in socket with a thin layer of rubber cement. Allow to dry. Press valve into hole from above, being sure that the flange seats firmly against the opposing socket surface. Do not foul inside of valve or ball with the cement.
5. Punch a clean, 3/16-in. hole through liner so that it

falls directly over the valve below. Passage of air through valve and liner must be free.

6. Using alignment marks, replace liner.

7. For legs in which the shin is not perforated, drill a 3/16-in. hole in the ankle region to assure communication of valve intake with outside atmosphere. For foam-filled shins, gouge small air channel for same purpose.

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