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The Child with Terminal Transverse Partial Hemimelia: A Review of the Literature on Prosthetic Management

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INTRODUCTION

This independent-study honors project dealt with congenital skeletal limb deficiencies. This paper discusses and reviews the literature concerning the prosthetic management of the individual with unilateral terminal transverse partial hemimelia of the upper extremity. Specific topics considered are: a general description of the entity, including etiology and incidence; psychological factors affecting the limb-deficient child and his parents; normal and abnormal biomechanics of the upper extremity; components of the prosthesis (terminal devices, wrist units, elbow hinges, cuffs, harnessing, and sockets); prosthetic prescription and fitting; the trend toward early fitting; preprosthetic therapy; and prosthetic training. One section discusses the information elicited from a survey conducted by letters and questionnaires that were sent to the 28 clinics participating in the Child Prosthetics Research Program, conducted under the auspices of the Subcommittee on Child Prosthetics Problems of the Committee on Prosthetics Research and Development to ascertain the age of the congenitally skeletally limb-deficient child at the time of his initial fitting for a prosthesis. An analysis of the data from the 12 clinics replying is presented, along with the developmental criteria for fitting.

The scope of this paper is limited to the unilateral upper-extremity, below-elbow congenital amputee. Bilateral amputees, cineplasty, surgical conversion, or externally powered prostheses are not considered. The literature review was limited by time to the books and journals published in 1960 or later, with selected earlier articles. Articles published before 1960, as well as those not available at the Albany Medical College Library or through the inter-library loan system, are listed in the "Bibliography." Both reference lists were compiled from *Index Medicus; Amputees, Amputations, and Artificial Limbs* (published by the Committee on Prosthetic-Orthotic Education of the National Academy of Sciences—National Research Council, Washington, D.C.); and the bibliographies of articles I reviewed.

Terminal transverse hemimelia indicates congenital absence of the entire distal part of the limb below the elbow. The term is part of the modified Frantz-O'Rahilly *(10,11,38)* classification nomenclature. Hemimelia is the absence of a large part of a limb, from the Greek *melos* meaning limb and *hemi,* half. *Partial* hemimelia indicates that less than half the limb is missing. The defect we are considering is transverse rather than longitudinal, presenting a short or very short stump similar

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to that of an acquired below-elbow amputation.

The etiology of skeletal limb deficiencies is largely unknown, except for the well-documented teratogenic effects of thalidomide. The thalidomide tragedy has led to an increased interest in, and awareness of, what can be done for the congenital amputee *(45).*

The list of proposed etiological factors includes environmental conditions such as drugs, maternal health and nutrition, genetic factors or predisposition, and chromosomal aberrations *(5,53,82).* Most congenital defects have their origin during the first eight weeks of embryonic life *(53,64).*

Glessner *(48)* indicates that there are two distinct groups of congenital absence of limbs: (1) spontaneous intrauterine amputation after limb formation, caused by focal deficiencies, and (2) limb-bud arrests or agenesis of the terminal part of the limb. Amniotic bands wrapped tightly around part of an extremity may lead to necrosis and eventual intrauterine amputation *(104).* Terminal deficiencies due to limb-bud arrests are by far the most common type of congenital absence *(35,48,70).* The terms *congenital amputation* and *congenital skeletal limb deficiency* are used interchangeably in the literature.

Terminal transverse partial hemimelia is the most common type of congenital limb deficiency. There is unexplained preponderance of left-sided absence (2 or 3 to 1), and females are involved more frequently than males. Studies by Bergholtz *(4),* Davies, Friz, and Clippinger *(23),* Munson and Dolan *(83),* and Gehant *(42)* failed to show the greater incidence in females exhibited in Kay and Fishman's report *(62).*

The measures of prosthetic management in habilitation of a congenital amputee are somewhat different than those employed in the rehabilitation of an "acquired" amputee. The child must learn functional skills that he never possessed, rather than relearning substitute functional activities. The fact that the juvenile amputee is neither skeletally nor emotionally mature is an important consideration in the prosthetic management. The growth and development of the limb-deficient child is essentially the same as that of the normal child; the environmental stimuli to motor development are not decreased significantly by unilateral deficiency. Ideally, prosthetic management should extend from birth through vocational training.

Function of the upper extremity is extremely complex and relatively independent of the contralateral extremity. With unilateral absence, there is an increased use of the remaining extremity, since the ability of a prosthesis to compensate for the loss of an arm is significantly less than is possible in the lower extremities. Below-elbow amputees are least in need of externally powered prostheses *(119,120).* They can effectively use body power to activate the prosthesis and receive the benefits of sensory feedback through the socket and harness. The prosthesis should be considered as an assistive device in bimanual activity. Because absence of one extremity can be easily compensated for, getting the unilateral amputee to use his prosthesis presents a great challenge. Fitting and training should be started as early as possible, before these compensations can develop.

It is generally believed that a team approach is most successful in the management of the limb-deficient child. The foremost members are the mother, who spends the most time with her child and influences him the most *(97,114),* and the child. Other possible members of this interdisciplinary team are the physician, orthopedist, prosthetist, occupational therapist, physical therapist, psychologist, social worker, and biomedical engineer. Each child presents unique problems to be met. Epps and Brennecke *(28)* outlined a sequence of treatment that includes referral, history and medical examination, intake evaluation, preprosthetic physical and occupational therapy, prescription, fabrication, thorough check-out by the team, training, and regular recheck every three or four months.

Factors influencing the cost of the prosthesis are: age at initial fitting, regular maintenance, frequency of harness adjustment, wearing pattern, operating skill, acceptance, and components prescribed *(13)*. Average service for a prosthesis ranges from two to three years, but a child fitted during infancy may require three to five prostheses before school age *(72)*. The additional cost of early fitting is compensated for over the years *(13)*, especially in regard to the benefits of skill and acceptance.

PSYCHOLOGICAL ASPECTS

The importance of parental attitudes towards the child, his disability, and the idea of a prosthesis, and their effect on the eventual acceptance or rejection of a prosthesis, has been emphasized throughout the literature. There is no direct correlation between the degree of the child's deficiency and the mother's perception of the child's abnormality, her feelings toward him and the way she handles him (52). The way in which parents deal with the birth of a limb-deficient child depends to a great degree on how they have coped with previous crises. Replacement of a missing extremity with a well-functioning artificial one is valuable only if the parents can accept the idea of a prosthesis. Often, children have rejected prostheses because the parents, consciously or unconsciously, could not accept the fact that it was necessary *(31,119,120)*.

The way in which the parents are informed of the child's deficiency may influence their later reactions. If he desires to do so, the father should be allowed to inform the mother, in the presence of a physician *(106)*. Mothers can be profoundly influenced by the reactions of the delivery-room staff *(5,115)*. The training of the limb-deficient child can best begin by providing the parents with a detailed, factual, realistic, and sympathetic appraisal of their baby and his prospects for future educational, vocational, and social rehabilitation *(53)*. Unrealistic claims that modern prosthetics and engineering can provide artificial devices as natural-looking and as efficient as the human hand can seriously hinder the habilitation program. The first few hours after the birth of the child are crucial; it is during this period that parents form attitudes and defenses that can have tremendously far-reaching effects.

With the birth of a deformed child, the parents suffer a severe psychological shock, for which they are totally unprepared. Certain emotions have been commonly expressed by parents of congenital amputees: guilt, hopelessness, death wishes, fear, anger, rejection, despair, shame, repulsion, grief, shock, hostility, and abandonment *(5,8,9,20,106)*. The need for prompt, professional assistance is crucial. Parents are extremely sensitive to the reactions and attitudes of others, and they need help to know that they and their child are accepted. In addition to individual counseling by a psychologist, social worker, or other qualified persons, group sessions have been established *(58,100,115)*. Parents benefit from the opportunity to verbalize their feelings and receive support and help in handling their emotions and in developing constructive attitudes. Wallace *(115)* noted the impact of these group-therapy sessions on the fathers, citing fewer absences, less hesitation about expressing their feelings, and awareness that their attitudes affect the child's adjustment and help to mold his self-image.

If, instead of realistic acceptance, strong defense mechanisms are built up by the parents during this early period, they will not be able to communicate with their child when he becomes aware of and questions his deficiency. One indication of the mother's acceptance of the child is the way she handles the baby. Some important factors to look for in observing parental behavior are: avoidance of direct contact with the baby, ritualistic organization and emphasis on cleanliness, barriers to communication, aggression toward professionals, and subconscious refusal to accept the existence of the child's abnormality (5).

The mother will eventually become the child's best therapist, and the early months must provide a basis for her later role. Parents must be aware of the importance of their love in the future rehabilitation of their child. Hall *(53)* and Mongeau and others *(81)* advocate that children become an integral part of the family immediately. Mongeau found that children taken home directly from the hospital after birth have shown greater capacity for adaptation than those who were institutionalized. A strong family basis can be of great help to the child when he may later face repeated hospitalizations for prosthetic training or other reasons. According to Gesell and Amatruda *(43)*, a child's basic behavior traits are fairly well established by the time he is a year old. Some of these traits are hereditary and some are absorbed from the attitudes of the family.

Crisis intervention, as described by Brooks and others (9), is the awareness of impending crises in the development of the limb-deficient child and the intervention by qualified professional personnel to aid in making those transitory periods as easy as possible. One such crisis is that of homecoming. The curiosity and concern of relatives and friends must be faced. The effect of the birth of a limb-deficient child naturally has a great impact on his siblings *(115)*. They too must be aided in adjusting to this stress situation. Other potential crisis periods are prosthetic fitting, entering school, and adolescence *(49)*.

During the child's period of growth and development, he has the same needs for independence and self-sufficiency that normal children have. Dependence and overprotection must be avoided. Discipline must be consistent and realistic, neither extremely permissive nor extremely restrictive. The profound effects of the parents on the child cannot be overemphasized.

The manner and degree to which the child is influenced by his deficiency is determined before he reaches conscious awareness of his condition. If he has been provided with a sense of security, acceptance, and love, he will have a strong basis from which he can develop a positive self-image and achieve independence. The limb-deficient child faces the same problems and sequence in emotional and social development as normal children, but each crisis is likely to be of greater intensity and magnitude *(5,73,102)*. The child who has received encouragement and support from his family will expect the same type of relationship from outsiders and will approach social contacts spontaneously, rather than attempting to avoid them. The child will attain a balance between the dominance of his parents' influence and the satisfaction he gains from his independence *(9)*. He should be encouraged to enter into social relationships with a minimum of special attention.

Taylor *(108)* has discussed at length the psychological needs of handicapped children. In addition to the fundamental needs of love and acceptance, she cites the needs for adventure and exploration, rebellion to release pent-up frustration, limitation of freedom, friends and social experience, privacy, achievement as a basis of self-esteem, and the need for awareness of the child as a person. These needs are the same as those operating in all nonhandicapped individuals.

Gouin-Decarie *(52)* recognized that a pertinent problem in studying the psychology of a limb-deficient child relates to his conception of space, which is closely associated with the formation of the body image. She found that these children made use of a visual, rather than a tactile, image in recognizing familiar objects. Several authors have discussed the concept of body image, or schema, in child amputees *(16,47,55,57,65)*. All have indicated the absence of marked distortion of body image in most of these individuals. Alteration of body image is, however, a significant problem in noncongenital amputees. Centers and Centers *(16)* analyzed the results of a draw-a-person test administered to congenital amputees. The majority of amputees represented themselves realistically, either leaving out the missing limb or including the prosthesis. They concluded that, while body images differed in a matter-of-fact way, they did not differ markedly in signs of greater conflict, anxiety, or defensiveness. The study did not support the authors' hypothesis that amputee children will have more conflict and defensiveness about their bodies than will nonamputee children.

The body image is critical in relation to the acceptance or rejection of a prosthesis. Congenital amputees experience the same processes in the formation of body image as normal children. The earlier the child is trained to wear a prosthesis, the easier it will become a part of his body image *(47).* One factor in the ready incorporation of the prosthesis is that modern prostheses are functionally adequate for many of the activities engaged in by young children *{16).* A prosthetic device is never really useful until it is integrated into the body schema. Acceptance and rejection of the prosthesis is more extensively considered in the section on early fitting.

The question of the possibility of the phenomenon of phantom sensation in congenital amputees is an interesting one. A discussion of the theories concerning the cause of this phenomenon is beyond the scope of this paper. Hoover *(57),* Lambert *(70),* and Simmel *(96)* believe that neither phantom-limb sensation nor pain exists in this group of individuals. Lambert bases his belief on the principle that nerve endings going to the distal limb have never developed. Simmel attributes the impossibility of phantom sensation to the fact that the absent part has never been represented in the body schema. In their census of the juvenile-amputee population, Kay and Fishman *(62)* reported three instances of phantoms in congenital amputees, but these could not be substantiated by further interrogation. Weinstein and Sersen *(117)* reported phantoms in 5 out of 30 children with congenital deficiencies. If the presence of a phantom reflects the "need" of the child to experience a missing part, it should have functional properties. The phantoms reported in this study were usually shrunken, telescoped parts with gaps and missing appendages.

Certain other psychological aspects can best be discussed as they relate to the chronological age groups of the congenital amputee. The significant divisions are: preschool, entry into school, latency, and adolescence.

In the preschool category, a period of negativism and resistance occurs around two years of age. This is a normal reaction; the child is trying to establish his personality and achieve a little independence *(9).* This period of negativism often conflicts with prosthetic-training procedures, especially terminal-device activation.

Entry into school is an important milestone for any child. He moves from the security of his home environment into a competitive social society. The limb-deficient child needs a reliable basis for dealing with this new group of people. This is provided by his parents and family during the early childhood years. In his group experience, the child will test and validate ways of dealing with people outside his family *(5).* Adjustment is facilitated if the teacher and class are prepared and informed in advance. Healthy curiosity is the most frequent reaction of classmates, and a factual explanation of the prosthesis and its use should lead to acceptance by the classmates and increased self-confidence of the limb-deficient child. Wilson *(119,120)* expresses the belief that it is preferable for the limb-deficient child to attend regular school. Unnecessary special consideration should be avoided. The handicapped child may experience feelings of social devaluation, which any member of a minority group feels *(5,65).* Centers and Centers *(17)* discuss the results of a social-discrimination questionnaire. The hypothesis that peer-group children express more covert rejecting attitudes toward amputees than toward nonamputee children was supported. They attribute this finding to the fact that one of the most significant variables operating in social interaction is personal appearance. Centers and Centers conducted their study almost ten years ago. It would be interesting to retest this hypothesis in light of recent social trends toward greater acceptance of minority groups and increased emphasis on individual merit as opposed to sterotyped generalizations.

The preadolescent latency period is relatively calm, with no major crisis periods. The normal child experiences many conflicts during adolescence, many of which are associated with appearance. These conflicts are all compounded in the limb-deficient child. During this period, a cosmetic hand is often prescribed for the adolescent amputee to replace the functional hook for social occasions. Vocational guidance becomes increasingly important during this period of adolescence.

NORMAL AND ABNORMAL BIOMECHANICS

The arm enables the hand to be placed in position for skilled functional activities. The most commonly recognized forms of prehension include tip, palmar, three-jawed-chuck, lateral, hook grasp, cylindrical grasp, and spherical grasp. Palmar prehension employing opposition of the thumb predominates in picking up objects and holding them for use. Long tendons with muscles at a distance permit the great variety of motion characteristic of the human hand. In addition to skill, the hand frequently functions in support postures. Sensation is another major function of the hand. The hand is richly supplied with sensory-nerve endings mediating touch, temperature, pain, and position. Large areas of the cerebral cortex represent the complex sensory and motor function of the hand. Boivin *(6)* advocates investigation into the prehension patterns and sequences commonly used in activities of daily living. Stabilization of the wrist in various positions aids prehension. For example, the wrist assumes an angle of 145° when very strong prehension is required (703). Finley, Wirta, and Cody *(30)* studied the synergic action of muscles of the upper extremity resulting in a better understanding of the relationship between central and peripheral control of movement. The three major components of the response phenomenon that they noted were: cognitive, ballistic-type physical displacement, and apparent sensing to compare, confirm, or adjust to assure successful accomplishment of the desired act. The information regarding time sequences is useful as reference material in studying pathomechanics.

Finger and hand movement, wrist flexion and extension, and varying degrees of pronation and supination are lacking in the congenital below-elbow amputee. Prosthetic replacement of the wrist and hand is poor, only crude prehension and positioning are possible, and there is no substitution for the lack of sensory feedback. Maximum utilization of the residual biomechanics is essential in prosthetic replacement *(107)*. The biggest challenge is to design an upper-extremity prosthesis that (1) can be powered by and controlled with little effort, (2) can perform through the almost spherical range of a normal arm, (3) has a terminal device that can achieve prehension, (4) will respond to sensation, and (5) is cosmetically acceptable *(82)*. Upper-extremity prosthetics are significantly deficient in all of these areas. Because of the fixed prehension pattern of the terminal device and the fixed wrist, nearly all fine orientation movements must be made at levels higher than the forearm by compensatory motions of the elbow, hand, and shoulder *(103)*. Prosthetic controls permit only the simplest motions decomposed into their basic elements and executed slowly, in series, one at a time.

Stoner *(103)* notes that no prosthesis accomplishes any of the wrist-flexion movements. The reasons for this neglect of wrist replacement are: (1) usually no controls from the harness are available to furnish the power, (2) wrist motions are used in fine movement of the hand and are not essential to bring the hand into the major spheres of action about the body, and (3) loss of wrist flexion can be compensated for grossly by other arm motions. Preposition flexion devices are available and are useful for activity close to the body.

Pronation and supination are functions of forearm length. Wrist joints allow passive positioning for the most advantageous angle of terminal-device operation. With shorter forearm stumps, the mechanical advantage of flexion is decreased, in addition to the loss of pronation and supination.

Joint motions in congenital amputees are often bizarre (5). Kruger and Breyan *(67)* report that, in an X-ray evaluation of 16 extremities with terminal transverse partial hemimelia, 13 showed dislocation of the head of the radius. Of these, 77% showed dislocation before prescription of the initial prosthesis. It is therefore concluded that the phenomenon is inherent in the disability itself. The dislocation is asymptomatic. The authors offer two possible explanations for the phenomenon: deficiency of the ligamentous structures, or unopposed action of the biceps brachialis muscle. They consider the latter explanation the more likely. In short stumps, the pronator teres muscle is absent, and the biceps in flexing and supinating meets no opposition, thereby dislocating the radial head.

HARNESSING

Harnessing techniques for upper-extremity prostheses must be based on biomechanical analyses of the remaining movements. Successful use of the prosthesis requires a harness that allows the most efficient use of those movements that are available. The socket limits some of the residual motion of the stump itself, and the harness limits the motion of the sound extremity to some extent. The harness should distribute the weight of the prosthesis evenly over a wide area and be functional in as many positions of normal use as possible. It should transmit power with a minimum of interference and be operable by relatively inconspicuous body motions. Power is provided by the stump itself (elbow flexion) or by the relative motion between two body parts (glenohumeral flexion and/or scapular abduction). Control-cable systems transmit this power from the amputee's body to the prosthesis. The suspension system may use a figure-of-eight, figure-of-nine, or shoulder-saddle chest-strap type of harness. The most common suspension is a figure-of-eight harness with a Northwestern ring-type cross *(40).* The Northwestern ring allows adjustment of individual harness straps. The figure-of-nine harness is often used for power transmission with Miinster-type sockets, which do not require a great deal of additional suspension. The chest strap is useful in spreading the load in heavy work *(119,120)* and maintaining the prosthesis in the proper position in the presence of baby fat. The harness provides some degree of feedback from the environment. O'Shea *(86)* has described a shoulder-saddle chest-strap harness with the primary advantage of increased comfort. Hile *(56)* described the adaptation and reinforcement of a brassiere to replace the chest-strap harness when breast development occurred.

Requirements for suspension and harnessing vary from individual to individual, and skillful use of the available power sources is essential to good prosthetic use. Rapid rate of growth and limited power are critical factors in designing harnesses for congenital amputees *(5).* Frequent adjustment by the prosthetist assures optimum harness and prosthetic function.

COMPONENTS OF THE PROSTHESIS

TERMINAL DEVICES

Two major considerations in the design of a prosthesis for a child are the continual neuromuscular and skeletal changes due to growth and the child's limited sources for power and control. Linear growth is more rapid than circumferential growth. The prosthesis can be fabricated to allow for later adjustments for growth, thus extending the functional life of the device. The components must be sturdy enough to withstand vigorous use, yet must be light enough to be controlled by the child. Some of the problems involved in the prosthetic replacement of human body parts are control, feedback, reliability, size, and appearance *(84).* Upper-extremity prostheses for children are essentially scaled-down models of adult types. However, Hall *(53)* and Wilson *(121)* note that recent advances in children's prosthetics include improved design and function of terminal devices, lightweight plastic sockets and shells, and more efficient harnessing methods. There are a large number of mechanical components available that can be combined to best meet the needs of the individual child. Split mechanical hooks stress the restoration of function at the expense of abnormal appearance, while artificial hands with cosmetic gloves attempt to combine modest levels of function with near-normal static appearance. Both hooks and artificial hands should be given the same care as the normal hand; since sensation is absent, they are more prone to damage.

There are two mechanisms of terminal-device operation: voluntary opening and voluntary closing. In the voluntary-opening type, tension on the control cable opens against a variable spring force, while in the voluntary-closing type, control-cable tension closes against the spring force. Hooks and hands are available with either mechanism. Voluntary opening is the simplest form of prehension mechanism: the prehension force is provided by special heavy rubber bands. Among the disadvantages of this type are the inability to handle delicate or heavy objects, and the fact that this mechanism is opposite to the prehension of the normal hand. An advantage of the voluntary-closing terminal device is that it more accurately simulates normal prehension, and pressure can more easily be graded to the object to be grasped. Formerly, manually controlled locks were employed, but now automatic locking is available. The fact that, to release the lock, the cable pull must be greater than the pull that closes the terminal device may be a disadvantage. Neither mechanism has been proved superior in a wide range of activities *(119, 120),* but research to improve both types for juvenile amputees is continuing.

Ritter and Sammons *(91)* have elaborated on the advantages of voluntary-closing devices for children's prostheses. The fact that normal prehension is simulated is especially relevant in bilateral grasping. Performing different hand patterns simultaneously, as is necessary with voluntary-opening devices, is particularly difficult for the preschool child to learn, since he is still developing refinement of prehension. A description of the Army Prosthetics Research Laboratories (APRL) voluntary-closing hand, which provides palmar prehension of the three-jaw-chuck type, has been presented by Stoner *(103).* Teska and Swinyard *(109)* have described a test to evaluate its functional capacity, versatility, and durability. Research is also being conducted concerning the Robins-Aid voluntary-opening hand *(88).*

The concept of cosmesis, or the appearance of the prosthesis, is difficult to define, but is very important. It is a very individualized concept, having varying importance for different people. Function, cosmesis, and acceptance are almost inextricably allied *(18).* The area of compromise between function and cosmesis is a delicate and crucial one. Those professionals vitally concerned with function must be careful not to look down on the parents who may seem to be overly concerned with cosmesis. Several new plastics have been reported *(18)* that, while not identical to the color and texture of the human skin, do convey an idea of softness and warmth. These new terminal-device designs represent an attempt to combine improved function with an aesthetically satisfactory appearance, but without trying to imitate representationally the characteristics of the missing part.

It was formerly common practice to provide the congenital amputee with a plastic mitt or wafer as the initial terminal device. Dean *(25),* Lineberger *(72),* and Watkins and Ford *(116)* have presented arguments supporting this practice. Among the major reasons given are: cosmetic appeal, flexibility, support without slipping in creeping, avoidance of injury to the child himself or others during play, and other factors supporting early fitting in general.

The infant passive hook is now considered the better choice as an initial terminal device. Some of the reasons for its preferred function are listed by Blakeslee (5): (1) it provides for gross palmar prehension and body-support activities with skill equal to the mitt, (2) it allows the infant to hook over objects for support in pulling to a standing position, (3) it provides a holder for small objects that are placed in it, (4) it helps the infant to develop bilateral prehensile awareness, being recognized as a device to hold objects, and (5) parents who were willing to accept a prosthesis for their child readily accepted the passive hook. Shaperman *(95)* reported the results of an evaluation of the passive mitt and the passive hook with similar results. She also noted improved skill and increased speed of learning when the control cable was added to the passive hook. Initially, the hook presented a slightly greater safety hazard, but the injuries that did occur were minor. Shaperman noted that the hook was one ounce heavier than the mitt, but it appeared to be well within the limits of the infant's ability to lift and manipulate it easily.

Hooks are available in a variety of sizes, shapes, and weights. The Dorrance 12P or 10P hook are commonly provided for the unilateral juvenile amputee. They are canted and plastic-covered. Proponents of prescribing hooks cite the advantages of greater prehensile function, with greater visibility and facility available. Numerous authors *(5,26,40,72,76,105,119,120)* have expressed a preference for the use of the hook rather than the hand. Edelstein maintains that the cosmetic appeal of a skillfully used hook is greater than that of a cadaverous-looking glove. The idea that the hook can only be accepted as a tool, and that therefore it is hard to see the need for a more cosmetic socket, has been expressed by Boivin (7).

Research toward improved hook design and function is being carried out. The literature reveals progress reports in the development of the Sumida hook *(87,112, 113)*, the Northwestern University Center control hook *(87)*, the Steeper split hook no. 65 *(101)*, and other more recent advances in prosthetics *(21)*.

Carroll *(14)* conducted a study to analyze the prehension force needed by child amputees. The test items were related to function and varied with the age of the child. Most items tested static prehension only; the individual could either hold the object, or it slipped out of the hook because of insufficient prehension force. Dynamic prehension, or the child's ability to control the prehension force, was tested by the ability to hold a paper cup with water in it. The results of this study showed that more children were fitted adequately in regard to the size of the terminal device than in relation to the prehension force. None of the children were found to be wearing an excessive number of rubber bands. With the exception of the toddler group, the prehension force was found to be inadequate for performance of one or more of the test items. One result of this study was a set of suggested pinch forces for below-elbow amputees:

Age (years)	*Pounds of force*
2-4	2.25
3-9	3.5
5-9	4
8-17	5
15-20	6

Greater consideration needs to be given to the adequacy of prehension forces for the functional activities of congenital amputees.

Cosmetic hands are often prescribed when the juvenile amputee reaches adolescence. Interlocking wrist-unit mechanisms are available that permit the use of a hook for functional activities and a more cosmetic hand for social occasions. These hands usually provide a modified three-jaw-chuck prehension between movable index and middle fingers and a thumb that can lock in position. Hands available for children include the Dorrance no. 2 hand *(50)* and the APRL-Sierra child-size no. 1 hand *(32,34,109).* One disadvantage that must be considered is the greater weight of the hand as compared to the hook. The APRL-Sierra no. 1 hand weighs 170 grams, while the Dorrance 10x hook weighs 60 grams *(111).* This is especially important, considering that this additional weight has the mechanical advantage of a long forearm lever and the congenital amputee does not possess a great deal of muscle power.

The APRL-Sierra no. 1 hand was developed to meet the need for a functional and cosmetically acceptable hand for juvenile amputees. It is a voluntary-opening mechanism with a hand shell of cast aluminum, articulated index and middle fingers, a two-position thumb, and nonarticulated but flexible ring and little fingers *(32).* In this field study, only 7 of 77 children rejected the hand completely. The remaining participants fell into four groups: those that used the hand exclusively, those that used the hand predominantly, those that used both equally, and those that used the hook predominantly. The authors suggest that the age of the child is a major factor regarding hook or hand preference. Younger children may experience difficulty with hand weight and opening forces, may be more careless in their use of the hand, and may be less subject to social pressures toward cosmesis. Sex appeared to be an even greater consideration than age. Girls of all ages appear to be potentially the best candidates for the Sierra-APRL no. 1 hand, while younger boys would seem least likely to accept the device. Fishman and Kay *(34)* performed a study to delineate the relative usefulness of the hook and the hand. The results were at variance with previous clinical impressions, which indicate that a hand is a significantly less functional terminal device than a hook. In an extensive evaluation of the Dorrance no. 2 hand in 72 bimanual activities, Gorton *(50)* found that no definite trends emerged to indicate that the hook was measurably more functional than the hand or that the hand was significantly more functional. The test employed by Fishman and Kay analyzed general and specific patterns of grasp by means of functional activities. The rating scale for performance of activities was somewhat subjective, but the detailed analysis of the results was excellent. From this study, the authors concluded that: (1) the APRL-Sierra no. 1 hand was heavier and, in most cases, more difficult to operate than the previously used hook, but these were not serious drawbacks for the majority of subjects; and (2) the hand provided somewhat less pinch force than most of the hooks and a less precise grasp. While the majority of children reported that they could perform more activities better with the hook, they also were able to specify a number of activities that were performed better with the hand, such as picking up a pencil, grasping paper, and holding silverware for eating.

Constant research and re-evaluation of prostheses is essential *(77,80).* Boivin *(6)* has written an excellent article criticizing present artificial-hand design. He maintains that an inherent belief exists that the refinement of the normal hand cannot presently be reproduced, leading to the assumption that it can never be reproduced. He cites the apparent lack of coordination and integration in biomedical engineering research, and proposes that a reason for this is that the goal is providing normal hand function, but that this is being attempted without sufficient consideration for the actual anatomical and physiological functions of the hand according to the kinesiological data presently available. One example is the fact that artificial hands flex only at the metacarpophalangeal joint, while the flexor digitorum profundus, the most active finger flexor, flexes at the interphalangeal joints as well. Boivin presents two suggestions for modification of artificial-hand design: first, that the normal transverse arch be reproduced in artificial hands, adding to cosmesis and function; and second, that artificial hands be made smaller and covered with a soft subcutaneous tissuelike material under the glove. Besides improved cosmesis, this would improve grasp by allowing better molding of the fingers over the object to be grasped. This second approach is presently being used by the Otto Bock Orthopedic Industry, Incorporated, in their new modular arm. The catalogues illustrate an above-elbow arm, but it is quite possible to employ this system for below-elbow amputees by fabricating the socket, attaching the proper length tube and the terminal device. This "System Arm" can be used for every level of upper-extremity amputation except wrist disarticulation and extremely long below-elbow amputations. Child-size systems are available. (This information was received from personal communication with Otto Bock Orthopedic Industry, Incorporated.)

WRIST UNITS, ELBOW HINGES, AND SOCKETS

Wrist units perform the dual function of attaching the terminal device to the prosthetic forearm and providing terminal-device rotation for manual prepositioning. There are manual-friction, manual-lock, and active-rotation units. Manual-friction is the most commonly used type. A rubber washer and a metal washer are compressed as the terminal device is screwed into place. Behavior of the unit is unpredictable because of the uneven compression and the easy accumulation of dirt, but it has the advantages of simplicity and easy maintenance. Manual-lock units allow rotation and locking of the terminal device by separate steps through the use of cylindrical inserts that have index teeth around their circumference *(92).* The inserts are threaded to fit the terminal-device stud. Active-rotation devices use stump rotation to produce rotation of the terminal device and are able to amplify residual stump rotation *(92).*

Wrist-flexion units that provide partial replacement for lost palmar and dorsal flexion of the wrist are available. By adding the extra degree of freedom, they can minimize the need for compensatory motions at higher levels. These units are presently only suitable for light duty *(103).* Clarke, Kral, and Shaperman *(19)* evaluated wrist-flexion units for children. The advantages of the addition of a wrist-flexion unit to an upper-extremity prosthesis include: (1) the ability to bring the arms close to the body for self-care activities, (2) the ability to bring the arms together in the midline for bimanual activities, and (3) less need for body exertion and bending to accomplish these activities. The authors found that one angle of flexion or flexion and radial deviation is sufficient for all activities. Wrist flexion of 25° or less is comfortable and useful, and there is no advantage above 25°. They advocate that the conventional wrist unit be laminated into the forearm unit in a flexed position, after careful evaluation to determine the most advantageous angle. This overcomes the disadvantages of wrist-flexion units for children, such as added weight of the terminal device, an additional component to preposition, and mechanical unreliability. It would seem that the need for dorsiflexion at the wrist for functional activities should be further evaluated, since this study only considered variable degrees of palmar flexion.

Flexion of below-elbow prostheses is provided by hinges of various types; the main classes are "rigid," "semirigid," and "flexible." They can be made of metal, leather, or metal cable. Some elbow hinges are polycentric and have a step-up ratio to provide a greater range of motion for a short below-elbow amputation. This is useful if adequate power is available, since flexion strength is lost through this mechanism. When both power and range are insufficient, it is possible to utilize the stump power to activate a locking hinge. Flexion of the forearm is then provided by humeral flexion.

Most below-elbow prostheses require an upper-arm cuff made of leather to help to stabilize the connection between the amputee and the prosthesis necessary to adequate control *(75).* The most common types are the very light triceps pad and the open cuff. These would be the most useful for congenital amputees; the heavy-duty closed cuff would not usually be necessary.

The socket is the foundation of all upper-extremity prostheses. The standard socket designs are used for juvenile amputees, but they may fit poorly because of the large amount of soft tissues in the child and the lack of well-developed bony prominences. It is through the socket that power and control are transmitted from the stump to the prosthesis and some degree of feedback is received. Double-wall construction allows a stump-fitted inner wall with an outer wall designed for structural uniformity and cosmesis. Retention of pronation and supination in short and very short below-elbow amputees is usually not a consideration, since pronation and supination are factors of forearm length. Another important matter is stability in flexion. In short and very short stumps, a single-axis hinge helps to provide this stability.

Among the types of sockets available are single-socket, split-socket, preflexed socket, and Munster-socket designs. Single sockets are often lacking in the necessary flexion stability for congenital amputees. Because of limited range of motion, a short or very short stump may require a split socket with a step-up hinge. One degree of stump movement gives 2° or 3° of prosthesis movement, thereby increasing the range of motion, but two or three times normal force is needed to accomplish this. VanDerwerker and Rosenberger *(111)* described the mechanism and installation of a flexor assist for use with the step-up split socket. Pellicore *(89)* noted the unfavorable cosmesis of the split socket, which was later largely replaced by the use of a preflexed forearm. This improved the cosmesis somewhat and increased the functional forearm power, but the range of motion was limited to 100°-110° instead of the normal 135°.

A great deal of the recent literature is devoted to a description and discussion of the Munster-type socket. The technique, involving intimate encapsulation of the stump, was developed by Dr. O. Hepp and Dr. G. G. Kuhn of Munster, Germany, and introduced into the United States in 1958. Short below-elbow stumps present a small attachment area, poor leverage, and a decreased useful range of motion. Some of the characteristics of the Miinster technique that help to overcome these deficiencies are: (1) the elbow is set in a preflexed position yielding the most useful range of motion, usually about 35 deg., (2) a channel is provided at the antecubital space for the biceps tendon to avoid interference between the socket and biceps tendon during flexion, and (3) the posterior aspect of the socket is fitted high around the olecranon and the epicondyles, taking advantage of these bony prominences to provide attachment and stability to the socket *(33,63).* These characteristics eliminate the need for split sockets with step-up hinges, giving improved prosthetic control and feedback, and often eliminate the need for a harness for suspension purposes. Younger congenital amputees may require more harnessing to maintain the prosthesis in place.

Epps and Hile *(29)* described the fabrication techniques and evaluated the Miinster prosthesis. Among the favorable points they found were: simplified harnessing, light weight, no perspiration problem, and excellent stability under axial-load testing. They also noted the elbow hyperextension characteristic of the individual with terminal transverse partial hemimelia. They concluded that the Munster-type prosthesis is the fitting choice for the child with a unilateral short or very short below-elbow amputation. In their investigation of the applicability of Munster-type fittings, Fishman and Kay *(33)* found that all of the subjects were definitely in favor of this type of prosthesis. The decrease in flexion range had no appreciable effect on prosthetic function for unilateral amputees. (Some modifications, such as lowering the anterior trim line and provision of a wrist-flexion device, may be necessary for the bilateral amputee.) Among the advantages cited are the facts that the stump does not slip out while performing overhead activities, and that less energy is required in operation of the prosthesis. They suggest that this type of fitting is functionally advantageous for amputees with very short to medium below-elbow stumps. Two factors limit the applicability of this technique for stumps of longer lengths: (1) the pronation and supination in these stumps cannot be harnessed with a Munster prosthesis, and (2) the proximal socket opening at a sharp angle to the shaft presents increasing difficulty in donning and doffing the prosthesis as stump length increases.

Gazeley, Ey, and Sampson *(41)* reviewed four cases of fitting children with Munster sockets and concluded that the technique is not satisfactory for bilateral amputees, because of the limited flexion. Except for that, they were very pleased with its use. Gorton *(51),* Kay and Fishman *(62),* and Pellicore *(89)* have all cited the usefulness of the Munster-type prostheses in fitting short and very short below-elbow stumps. Gorton found the positive factors to be: increased stability and socket retention, socket comfort with minimal stump motion within the socket, harness comfort with the elimination of the triceps pad and front support strap, and improved cosmesis due to the minimization of the harnessing system. The negative features listed were: decreased range of motion (limited to about 70°), limited elbow flexion, and harness discomfort due to the control strap riding low across the back. The other authors discovered similar findings. With the limited range of motion, it is necessary to make this the most functional range. Partial flexion is necessary to keep the prosthesis on the stump. Complete extension is not as essential to functional activity as an adequate flexion range.

The use of sockets that do not completely enclose the stump is more extensive in Germany than in the United States. With this type of prosthetic fitting, the end of the stump remains free for gripping and touching. According to Fletcher *(35, 36)* and an article in the *British Medical Journal (2),* in congenital limb deficiency the end of the limb has a tactile sensation equivalent to that of a normal fingertip, even when the distal two-thirds of the forearm is missing. He attributes the prosthetic rejection by many children to the fact that standard prostheses rob them of this important sense of touch. He feels that fitting such an individual with an artificial limb is, in effect, performing a physiological amputation. Kuhn *(68)* and Jentschura, Marquardt, and Rudel *(61)* have described an open-end socket that enables the patient to use the sensory surface of his stump as well as the terminal device. The socket is provided with a friction joint on the dorsum of the prosthesis so that the terminal device can be bent away from the end of the stump. The economic advantage of an increased "life span" of the prosthesis, as well as the functional advantages of the open socket, have been presented by Jaramillo and Lehneis *(60).* The preservation of tactile sensation is an important consideration in upper-extremity prosthetic design. Increased research on open sockets is indicated, since they seem to provide a critical advantage over the standard prostheses, especially for the bilateral amputee.

PROSTHETIC PRESCRIPTION AND FITTING

The prescription of a prosthesis for a congenital amputee, as for any amputee, is best achieved by a team approach. The child's functional needs and developmental status must be ascertained in order to provide the optimum combination of components. Actual fabrication is followed by a final check-out of the compatibility of the amputee and the prosthesis.

The physician, prosthetist, and physical and occupational therapists are the main members of the prosthetic-clinic team *(100).* The physician, in writing the prescription, must combine his knowledge of the individual with the results of evaluations performed by other members of the team. The prosthetist advises about possible solutions to the case, measures the patient, fabricates the prosthesis and harness, and evaluates the functional results of fitting. The physical and occupational therapists evaluate motor development, range of motion, and muscle strength, advise the physician and prosthetist of available body power for control, suggest possible solutions to fitting problems, and perform the final checkout evaluation.

As a functional replacement for the missing limb, the prosthesis must be a simple, lightweight device that will enable the child to perform certain tasks, but not necessarily all tasks. Stamp, Mahon, and Morgan *(99)* found that, with the unilateral below-elbow amputee, the use of a prosthesis improves the function of the opposite, normal extremity. The combination of a normal extremity and a prosthesis is much more functionally efficient than is the combination of a normal extremity and a stump.

The functional needs of the child must be determined in order to provide a prosthesis that will fill these needs. Self-care needs are an important part of the functional evaluation. Observing the compensatory patterns that the child has naturally developed for holding or reaching yield an indication of his specific functional needs. One approach to functional evaluation (5) has been to observe which parts are missing and to formulate a prescription on the theory that these are the parts that need to be replaced prosthetically. This theory assumes that, once these are provided, the child will meet all of his activity needs. It is important that the total effect of the prosthesis is a significant gain in function. The advantages and disadvantages for each individual must be carefully considered.

It is necessary in the early examination to determine the developmental status of the child *(74).* This evaluation bears a significant relationship to the timing and type of prosthetic fitting. In much of the literature, the achievement of a secure sitting balance is designated as an important criterion to upper-extremity prosthetic fitting. (The criteria for fitting are discussed more completely in the section on the trend toward early fitting.) An important part of the evaluation is the observation of the infant's prehension patterns. The infant's ability to control and relate his various arm, hand, and body movements predicts his pattern of prosthesis operation and use (5). The development of compensatory prehension patterns is one of the positive indications for fitting the child with a cable-operated hook. The child's interest, attention span, and coordination must also be determined. All of this information aids in prescribing a prosthesis and planning a training program.

In addition to this evaluation of neuromuscular development, the therapist must also determine muscle strength and range of motion. The prosthetist needs to know which structures are present and which are absent, and what sources of power are available. Muscle defects may accompany skeletal defects, as pectoral agenesis occasionally accompanies below-elbow deficiency (5). Some of the abnormalities of neuromuscular-system function to notice are: involuntary motion, deviations in the speed of motion, resistance to passive movement, atrophy, fatigue, and static or dynamic postural deviations *(27).* Functional muscle testing as described by Daniels, Williams, and Worthingham *(22)* provides valuable information. Range-of-motion tests are useful in noting any contractures or other factors limiting the range and in determining the scapular movement available to operate the devices prescribed. Sequential testing and accurate recording are necessary in functional, motor-developmental, muscle-strength, and range-of-motion evaluations.

Exact body measurements, both longitudinal and circumferential, are often made by the prosthetist at the time of fitting. In the unilateral amputee, the epicondyle-to-thumb length is important as a sizing reference for the total length of the finished prosthesis.

The choice of the components for the prosthesis is based on a thorough knowledge of the functional needs and the potentials of the individual. It was formerly accepted practice to prescribe a passive mitt, but this practice has been replaced by the use of a passive, plastic-covered hook. The hook gives the child the opportunity to incorporate the concept of a prehensile device from the start. The manual-friction wrist unit is often useful for congenital amputees. At first it can be positioned by the parents, and later by the child himself. Sockets that permit rotation are not usually indicated in short below-elbow stumps, since residual pronation and supination is minimal. The Miinster-type socket, or modifications of it, as well as conventional below-elbow double-walled laminated sockets, seem to be successful in fitting the individual with terminal transverse partial hemimelia. Harnessing and suspension are highly individualized and can make the difference between successful and unsuccessful prosthetic prescription. Some of the greatest problems in prescribing and fitting the congenital amputee arise from his rapid, uneven rate of growth, the presence of baby fat, the lack of well-defined bony prominences, and the almost constant mobility of all young children. It must be emphasized that good prescription of prosthetic components must be based on a thorough knowledge of the individual. The prosthesis should allow him to function at his highest level in his environment. For the congenital amputee, this may mean providing him with the opportunity to assume a normal pattern of development of bimanual activity. In unilateral amputees, the prosthesis functions as a helper, not as the dominant hand.

Fabrication and interim fittings are performed by the prosthetist. After careful initial measurements, a plaster cast of the stump is made. This is used to make a mold of the stump. A full description of the techniques for fabricating the prosthesis is beyond the scope of this paper; however, a step-by-step account of fabrication is given in the *Manual of Upper Extremity Prosthetics (92).*

There is no universally acceptable check-out procedure for the child amputee. The standardized adult forms are not useful, because child prosthetics is a relatively new field in which improvements in techniques are constantly being made (5). Additional contraindications to a standardized form are the varied ages and developmental levels of the children, philosophies of case management and prescription which may vary from clinic to clinic, and the fact that so many modifications of the prostheses for congenital amputees are needed. The standard check-out forms must be adapted if they are to be used for child amputees. The clinic team must evaluate the fit and function. The prosthetist's primary interest is the mechanical aspects, the therapist's is the child's functional benefit. The physician must coordinate the efforts of all of the paramedical personnel. Blakeslee (5) has presented some of the important considerations regarding check-out for the juvenile amputee.

Prosthesis fit

1. Is the prosthesis cosmetically acceptable? Is it well made, and does the workmanship follow all of the specifications of the prescription?
2. Is the prosthesis of the proper length, and is the socket fit satisfactory? Do bony prominences have sufficient space? Do the component controls appear to be within reach of the amputee?
3. In the upper-extremity prosthesis, is the harness adjusted properly and is it comfortable?
4. When the prosthesis is removed, are there any excessive pressure points in the socket area?

Functional considerations

All components must be checked to make certain they are in good working order, and must be adjusted for efficient operation by the child and/or adult. Some of the primary functional considerations are:

1. Is the prosthesis properly aligned?
2. If it is an upper-extremity device, is the control system appropriate for this child? Will he be able to control the arm and operate the controls in the desired range of motion? Is the terminal device in good condition and does it operate smoothly? Does the harness appear to be correctly positioned and in balance?

3. Can the prosthesis be applied with ease? Is the amputee comfortable in the standing, sitting, and walking positions and while performing functional activities?

These check-out procedures emphasize the points to consider in preprosthetic evaluations, prescription of components, and fabrication. The prosthesis must be made to fit the needs of the child; the child should not be expected to adapt to the prosthesis.

THE TREND TOWARD EARLY FITTING

A great deal has been written concerning the advantages of early fitting, and a variety of developmental criteria for fitting have been described. This section deals with the advantages of early prosthetic fitting for the upper-extremity juvenile amputee, a brief discussion of normal motor development, and a discussion of fitting at various ages. The age levels can be roughly grouped as follows: before school age, nine to twelve months, six to eight months, four to six months, and three months or younger. This grouping is the distribution that occurred naturally in the literature. The concept of prosthetic acceptance or rejection is also discussed in this section.

The philosophy of early fitting is the dominant theme of much of the literature. The difference exists in the definition of the term *early.* Before this concept was accepted, prescription of an artificial limb was not advised until the patient reached the middle or late teens *(116),* in order to avoid the expense of purchasing a device that soon would be outgrown. More recently, the child was fitted just prior to school age *(26, 119),* but still after the child had become oriented to one-handed function. Frantz *(37)* has presented a brief history of the management of the juvenile amputee during the past twenty years.

Mongeau and others *(81)* recommend that the habilitation of congenitally deformed children be initiated at an early age. Many other authors have proposed reasons for early fitting. Friedmann *(40)* lists the following advantages: (1) to stimulate bilateral function, (2) to help the child and parents to accept the prosthesis for function or cosmesis, (3) to incorporate the prosthesis into the child's body image, (4) to improve balance, (5) to get the child accustomed to the normal length of the limb, (6) to prevent scoliosis and other skeletal abnormalities due to asymmetry, (7) to make the child aware of prehensile function, and (8) to promote eye/hand control. In addition to the advantage of greater acceptance, Blakeslee *(5)* cites the fact that early fitting leads to a more normal development of the residual parts and diminishes atrophy caused by disuse and hypogenesis. The prosthesis encourages physical activity, which increases growth and strength. The avoidance of substitute patterns of grasp, such as holding objects in the axilla or elbow-bend and working in an awkward or energy-consuming position, was noted as an advantage by Blakeslee *(5),* Brooks and others *(8),* Gillis *(44),* and Klopsteg, and Wilson et al. *(65).* More of the movement patterns of the upper extremity are acquired than in the lower extremity, thus increasing the importance of early fitting. Gillis maintains that the movement patterns necessary to control the prosthesis are most perfectly developed at the same time as those for the natural limb. The possibilities of atrophy through disuse and the development of contractures are greater with later prosthetic fitting *(25, 79).* As the result of a study conducted at the Rehabilitation Institute of Montreal, Gingras and others *(46)* found that in a majority of cases there was hypotrophy of the deficient limb. They found an average difference of one centimeter between the lengths of the humeri. The hypotrophy was attributed to disuse because it had been observed that patients who had early prosthetic training were enabled to put their muscles to greater use and therefore they showed less limb-length inequality. An additional advantage of early fitting mentioned by

Edelstein *(26)* is that it aids the limb-deficient child in crawling. Children learn to use the upper-extremity prosthesis as well as, if not better than, adults *(65).* The advantages of skill in prosthetic use resulting from early fitting have been cited by Brooks and others *(8),* Dean *(25),* and Mayo *(79).* Some of the favorable results of early prosthetic fitting for the unilateral below-elbow amputee presented by Brooks and Shaperman (7) include: (1) full-time wearing of the prosthesis, (2) skillful operation of the prosthesis, (3) natural and spontaneous patterns using the prosthesis and including it in normal activities, (4) good habits of prosthesis maintenance, and (5) good acceptance of the prosthesis by the child, family, and community.

In reviewing the literature, the author noted that earlier fitting was advocated more often for children with bilateral and multiple limb deficiencies than for those with unilateral deficiencies. One possible explanation for this may be the comparatively greater need for sensory input for development and function by the former group. The supposition of earlier fitting was substantiated in a census study by Kay and Fishman *(62).* They suggested that this may be related to the greater need by multiple limb-deficient individuals for prosthetic assistance.

The developmental norms of Gesell and Amatruda *(43)* form the basis of much developmental evaluation. They are especially relevant to the unilateral congenital amputee. For instance, he may first be aware of his missing limb at about three months of age, when he attempts two-handed grasp. Vitali *(114)* cautions that a limb-deficient child should not be expected to achieve standards of developmental performance before others in his age group.

In an analysis of data collected over a two-year period ending on June 30, 1967, Davies, Friz, and Clippinger *(24)* noted that a relatively high percentage (32%) of congenital amputees were not fitted until after their eleventh birthday. Since the current philosophy is to fit congenital amputees at a very early age, it would be interesting to know the reason for this delay. The authors could not determine whether the fault lay with the amputee clinics or with parents who were reluctant to take their children to clinics or ignorant of the prosthetic opportunities available to them.

In discussing the advantages of early fitting, there is variability in the definition of *early.* Brooks and Shaperman *(8),* Kay and Fishman *(62),* and Watkins and Ford *(116)* support the idea of fitting the unilateral below-elbow amputee before school age, at the latest. Of those authors advocating fitting when sitting balance has been achieved, some are referring to independent sitting without support (about ten months of age) and others to sitting with support (about six months). In either case, this leaves the upper extremities free in a functional position. The group of proponents includes Aitken *(1),* Brooks and others *(8),* Caine and Reeder *(12),* Catto and MacNaughtan *(15),* Jansen *(59),* Shaperman *(95),* and Wilson *(119).*

Several authors indicate a preference for fitting at six to eight months of age. Among these are Blakeslee (5), Gillis *(44),* Hall *(53),* Kempner *(64),* Lineberger *(72),* and Vitali *(114).* Lineberger and Gillis have cited the benefit of having a prosthesis to aid in crawling and pulling to a standing position.

Encouraging bilateral movement patterns and establishing familiarity with and tolerance for the limb are advantages of prosthetic fitting between four and six months of age. This is considered the best age for fitting by Edelstein *(26),* MacNaughtan *(76),* Martin *(78),* and Mayo *(79).*

Lambert and others *(71)* maintain that the congenital amputee should be fitted with a prosthesis as soon as he needs it. For the unilateral upper-extremity amputee, this may be as early as three months. According to Gingras and others *(46),* fitting this early is based not only on considerations of function, but also on the idea of helping the child incorporate the presence of an artificial arm into his body image and to accept it better. Tolerance and adaptation to the prosthesis as well as aid in developing sitting balance has been stressed by Nichols and others *(85).*

Prosthetic acceptance or rejection is a very complex concept. It is an accepted psychological principle that an individual is better able to achieve adequate adjustment to a total loss of function than to a partial one, yet prosthetic devices restore partial function. The relationship of the amputee to his prosthesis is that of man to machine. It is an intimate and long-term contact between a human being and a mechanical device. The gadget tolerance of the individual is of great importance, especially as the child grows older and develops greater skill in using the prosthesis. Both the visual consideration of cosmesis and the auditory factors of a mechanical device, such as the sound of a terminal device closing on an object, play major roles in the formation of the individual's attitude toward his prosthesis. If the prosthesis is regarded as a tool that makes him less different and gives him a better opportunity for integration into his peer group, then the child is more likely to wear and use his prosthesis. If he believes that the prosthesis accentuates the difference between himself and others, it is likely that he will reject it *(17).*

Throughout the literature, it has been emphasized that children usually accept a prosthesis without too much difficulty *(9,72,105,119).* It helps if the individual can gain immediate satisfaction from its use, rather than feeling that it is a deterrent to his activity. A child can be helped to appreciate the usefulness of the prosthesis by providing him with toys and chores that require two hands. Both a full-time wearing pattern and the ability to talk freely and openly about the prosthesis are good indicators of acceptance.

Several authors have emphasized the positive relationship between early fitting and good prosthetic acceptance. A patient most easily accepts a prosthesis if he obtains it before becoming accustomed to one-handed activity *(66).* Kempner *(64),* Mongeau and others *(81),* and Wilson *(119)* believe that early fittings lead to complete patient and family acceptance. In evaluations by Brooks and Shaperman (7), children with short below-elbow stumps fitted before two years of age received the best scores for "acceptance." Gingras and others *(46)* found that rejection is a common occurrence if prosthetic fitting takes place after adolescence, while Blakeslee (5) found excellent acceptance and utilization if the child was fitted before four years of age, and increased rejection after that age.

Congenital amputees experience the same structuring process in regard to body image as do normal children. If a child is presented with a prosthesis during the critical stage when his body image is forming,, he will incorporate the limb into his pattern of activity and self-image *(47,69).* Centers and Centers *(16)* note that modern prostheses are functionally adequate for many of the activities engaged in by children. This may be a factor *in* the incorporation of the prostheses into their body images. Personality factors are directly related to acceptance of a prosthesis.

In the case of the congenital amputee, his parents' attitudes affect his personality and his acceptance or rejection of a prosthesis. Parental influence cannot be overemphasized. It is within the family structure that all of the child's attitudes are developed. A clear view of parental influence is presented by Brooks and Shaperman (7) in their discussion of a group of children who had rejected their prostheses. The group was characterized by a lack of parental support and guidance in the child's general behavior. There was a great deal of emphasis on the child's accomplishments without the prosthesis. These parents expected less of their children than their potential, openly expressed dislike for the appearance of the prosthesis, and had a limited ability to communicate feelings and problems. One review *(85)* indicated that the better-educated middle-class families are most likely to help their children accept prosthetic appliances.

All of these considerations regarding acceptance and rejection are interrelated.

QUESTIONNAIRE SURVEY CONCERNING AGE AT INITIAL FITTING

The questionnaire survey sought to document a trend toward earlier initial fitting of upper-extremity prostheses in the congenital amputee. As the most frequently occurring limb deficiency, unilateral terminal transverse partial hemimelia was selected as the focus of consideration. An extensive review of the literature had seemed to indicate a trend toward earlier fitting. While children were formerly fitted just prior to school age or even during the middle or late teens, the achievement of independent sitting balance is now a widely accepted criterion for prosthetic prescription. According to Gesell and Amatruda's studies of motor development *(43)*, the norm for the achievement of this maturational level is nine months (36 weeks).

It was the belief of the author that (1) even earlier fittings are being performed in significant numbers, (2) a passive hook is most frequently prescribed, and (3) the development of the Miinster-type socket has played a role in the trend toward earlier fitting.

Questionnaires were mailed to the 28 clinics participating in the Child Prosthetics Research Program, a cooperative endeavor conducted under the auspices of the Subcommittee on Child Prosthetics Problems of the Committee on Prosthetics Research and Development. The information requested was of three types: age at time of initial fitting, type of socket and terminal device most frequently prescribed, and basic developmental levels considered essential for fitting the prosthesis.

The sample consisted of 40 new patients with upper-extremity terminal transverse partial hemimelia who were initially fitted between March 1, 1969, and approximately March 1, 1971. The frequency of fittings is indicated in table 1.

TABLE 1. AGE AT INITIAL FITTING UPPER-EXTREMITY TERMINAL TRANSVERSE PARTIAL HEMIMELIA, 40 PATIENTS IN 9 CLINICS

Approx. Age (mo)	No. of Patients	%
0–3	3	7.5
3–6	5	12.5
6–9	7	17.5
9–12	11	27.5
Over 12	14	35.0

One clinic whose data arrived too late to be included in the chart reported fitting more than 200 cases. A relatively small number (between 15 and 20) were fitted between the ages of 6 and 9 months, and a much larger number (50 or 60) were fitted after the age of 12 months. Two other clinics indicated that the information needed to complete the questionnaire was not readily available. (One of these stated that all of their children were fitted after the age of 12 months.)

In requesting the data, no upper limit was set on the last interval (later than 12 months). For this reason, no statistical analysis of the central tendency (mean or median) was possible. The return on this survey was 43%, the low response level being partly attributable to the fact that no date was designated for the return of the questionnaire.

The frequency distribution indicated that 65% of the children were fitted under one year of age. Using nine months as the age for reaching the developmental level of independent sitting, the data indicates that 37.5% were fitted before that age. It is also interesting to note that 20% of the sample was fitted before six months and 7.5% before three months. This information indicates a trend toward fitting earlier than the widely accepted criterion of independent sitting balance. The very important concept of parental attitudes and other intangible factors were not considered, nor was the age when the child was first seen at the clinic taken into account in this study. If it were, perhaps an even stronger trend toward earlier fitting would be noticed.

Regarding the type of terminal device, seven clinics prescribed a Dorrance 10P or 12P passive hook most frequently. One fitted a nonfunctioning hand (mitten) initially and changed to a hook at about two years of age. The other clinic listed both the passive hook and the passive hand in their response. Five of the clinics prescribed a conventional double-walled plastic-laminate socket most frequently, and four clinics most often prescribed a Munster or modified Miinster socket.

An interesting outcome of this survey was the compilation of the developmental criteria for fitting employed by the various clinics. In the following chart, the list of criteria is paired with the developmental norms described by Gesell and Amatruda *(43).*

Developmental Criteria	*G & A Norms (mo)*
Beginning to prop on elbows	3
Readiness for bimanual activity	4
Head control	5
Object transfer	7
Beginning sitting	8
Independent sitting balance	9
Controlled voluntary grasp and release	9-12

One clinic responded that they did not adhere to any developmental criteria, but felt that as soon as the child was three or four months old, a prosthesis could be fabricated with adequate socket fit. It was their belief that the earlier the socket was fitted, the better.

The data collected on this sample did not establish a relationship between the development of the Munster-type socket and the trend toward earlier fitting.

It is hoped that persons responsible for prescribing prostheses might consider the criteria proposed by other clinics for fitting of prostheses for congenital upper-limb amputees. The advantages that prompted the change from pre-school-age fitting to fitting at the developmental level of independent sitting continue to exert an influence toward still earlier fitting. The greatest advantage claimed is that of acceptance of the prosthesis. Logically, if the artificial limb is provided before a one-handed activity pattern is developed, changes for acceptance are increased. It would further seem logical that, when the capacity for two-handed grasp in the mid-line develops (at approximately four months), a prosthetic limb should be there to oppose the normal limb. The proximal stability necessary for control is developed previously in the on-elbows position. Many factors interact to affect the age of initial fitting. The age at which the limb-deficient child is referred to the clinic is certainly a significant one. Parental attitudes are closely associated with this consideration. The development of prosthetic parts specifically designed for children is important, as is the increase in knowledge in the entire field of prosthetic management of the juvenile amputee. Dissemination of this knowledge to the related health fields, especially to those individuals in contact with the mother of the newborn child with limb deficiencies, may promote earlier referral to the appropriate prosthetic team.

It is believed that the trend toward earlier fitting is advantageous. A difference in the practice of various clinics has been noted. A polarity exists with a tendency for some clinics to fit predominantly at a very early age range and others only later. Three of the clinics indicated fitting only after 12 months. It would be useful for all the clinics that participate in the management of congenital amputees to carefully evaluate their criteria for prosthetic fitting and training.

PREPROSTHETIC THERAPY

Preprosthetic care should begin as early as possible. Hall *(53)* believes that physical and occupational therapy should be started as soon as the child begins to take part in his environment. A highly individualized treatment program to correct the deficiencies in range of motion, posture, and muscle strength is an important goal of preprosthetic therapy. The evaluations described earlier as prerequisites to prescription are also a part of the preprosthetic therapy program. Jaramillo and Lehneis *{60)* suggest that the child's poor attention span or negativism may be due to the lack of preprosthetic training by means of a good exercise program, rather than to poor family cooperation.

Several authors have emphasized the important role the mother plays as the therapist *{5,15,60,114).* She can be the best therapist for her child, since she spends more time with him than anyone else. She must understand the purposes of the therapy program and carry out the program at home. A good home program will facilitate prosthetic training. A well-informed mother can help to prevent contractures and postural deviations and to correct existing problems. It is a significant psychological asset for the mother to be an active member of the prosthetic team. An additional consideration that is the mother's responsibility in the early stages of habilitation is stump hygiene. The stump should be washed, rinsed, and dried thoroughly and inspected daily for any minor irritation or abrasion. The limb-deficient child perspires more than normal because of reduced body area (5). He should be dressed in light, unrestrictive clothing for cooling and to allow freedom of movement.

Limitations of range of motion do not occur as often in the upper extremity, and when they do occur, they do not as markedly affect its use *{5,15).* The best treatment is prevention. This can be accomplished by instructing the parents in positioning and active exercises to prevent contractures and build strength and endurance. Extreme caution should be used in stretching any joints in the congenital limb-deficient child. The elbow is especially vulnerable, and passive stretching is contraindicated. (The tendency for radial-head dislocation has already been discussed.) The best techniques for increasing range of motion are those that achieve relaxation of the shortened group by heavy resistance to the antagonist muscle group. The PNF techniques of repeated contractions, slow reversal, slow reversal—hold, rhythmic stabilization, hold—relax, or slow reversal—hold—relax, as described by Knott and Voss would be appropriate. Since the young child is more flexible in his muscular structure, it is easier to reverse the adaptive shortening of the muscles than it would be in adults. Blakeslee (5) also notes the use of passive stretching, casts, and braces for the correction of flexion contractures.

The delay in the early neuromuscular development of children with congenital skeletal limb deficiencies has been noted by Blakeslee (5), Hall (53), Jaramillo and Lehneis *{60),* and Steele *{102).* The child may be delayed in the development of head and neck control, rolling over, creeping, and sitting. He may need assistance in achieving developmental tasks. For example, if the child lacks head and neck stability, placing a small pillow under his chest allows development of the trunk and neck extensors. During this early period, assistance may be needed to help strengthen the neck and trunk flexors, extensors, and rotators. Later, it may be necessary to stimulate bimanual activity, especially gross grasp, by providing large objects for the child to hold. The upper-extremity amputee may need help in pulling to a standing position so that he can adequately develop his lower-extremity musculature.

Essential muscle groups are exercised to maintain mobility and increase strength. Specific muscle groups must be strengthened in order to provide sufficient power to operate the prosthesis. Bates and Honet (3) and Montero *{82)* advocate the use of isometric exercises for this purpose. Exercises for neck and back extensors, flexors, and rotators are best accomplished through play activity. Catto and MacNaughtan *{15)* suggest using mirrors to stimulate the desired movement. The sound side should be included in the exercise program. Emphasis on strengthening the shoulder-girdle musculature for elevation, depression, scapular abduction and adduction, and general chest expansion (respiratory exercises) is important, since these muscles are needed to operate the prosthesis *(15,28, 60,82)*. For the below-elbow amputee, strengthening elbow flexion and extension and any available pronation and supination is of prime importance *(5,15)*.

Blakeslee (5) has emphasized the importance of general conditioning. Limb-deficient children tend to have a low energy output. This was observed even in below-elbow amputees who were otherwise normal in appearance and physiognomy. Greater than average endurance and output are required to operate a prosthesis. He also mentions that individual and group sports and other group activities have been successful in increasing energy output and improving general physical condition. Swimming has been found particularly advantageous.

A preprosthetic therapy program provides a good foundation for later training of the child in the use of the prosthesis.

PROSTHETIC TRAINING

Prosthetic training begins when the congenital amputee receives his prosthesis and continues periodically through vocational training. The initial training and orientation with a passive terminal device is essentially the same as that with an active terminal device, so both are considered together in this section.

Training is one of the most difficult and important phases in the management of the congenital amputee. It is essential that the child is enabled to handle his environment rather than adapting the environment to his needs. Training a congenital amputee is very different than training a traumatic juvenile or an adult amputee who once had a functional extremity. The functional level of a normal child of the same age should be the basis of achievement goals *(25,53)*. The program progresses naturally from gross bimanual grasp to skilled functional activity. Factors affecting training are the child's neuromuscular development, attention span, functional requirements, and parental cooperation.

The parents play an important role in the training of the juvenile amputee. The care and function of the prosthesis must be carefully explained to the parents, and they must be very aware of what it can and cannot do. The importance of the parents in prosthetic training has been emphasized by many authors *(5,39,40,76,79,81, 93,116)*.

Unless contraindicated by medical or other reasons, full-time wearing of the prosthesis from the first application should be the aim. According to Blakeslee *(5)*, one advantage to achieving a full-time wearing pattern as early as possible is the avoidance of the habit of removing the prosthesis for little or no reason. Later in childhood, the wearing pattern will be interrupted for repairs and refitting, so a stable pattern is desirable. Infants accept prosthesis-wearing easily, unless there is discomfort or the parents do not allow the prosthesis to be worn all day. MacNaughtan *(76)*, Shaperman *(93)*, Steele *(102)*, and Watkins and Ford *(116)* advise a gradual increase in tolerance leading to full-time wear except for sleeping, bathing, and rough contact sports. This seems to be a more logical approach than to expect immediate full-time wearing after the child has become accustomed to complete freedom of movement. During the period when the child has a passive prosthesis, he should be encouraged to use it as a "helper" in bimanual grasp, crawling, and pulling to a standing position. Toys are an excellent medium for encouraging bimanual activity. The infant amputee who receives his prosthesis during the first year of life shows remarkably early proficiency in gross arm movements; he develops habits of including the arm as a total unit rather than any specific part of the arm such as the hook, tip, or elbow *(5)*. An awareness of the hook's holding function should be developed as early as possible.

In response to the questionnaire survey conducted by the author, the University of California at Los Angeles included a discussion of the criteria for the addition of a cable. Some of the factors proposed as prerequisites for terminal-device activation are: the readiness for bimanual activity, a reasonable attention span (approximately five minutes), the ability to follow two-step directions, tolerance of handling by the therapist, the presence of sufficient neuromuscular development to operate the cable, a full-time prosthesis-wearing pattern, and an awareness of the hook's holding function. At UCLA, the cable is usually added at a developmental age of two or two and one-half years.

Like the variations observed in the age of choice for initial fitting, similar variability occurs in the age at which the terminal device is activated. The usual age seems to be about two years. MacNaughtan *(76)* has expressed the opinion that training should be conducted at the 14-to-20-month age. Depending on the ability of the child and the nature of his deformity, active control can be accomplished at 16 to 24 months, according to Hall *(53)* and Kempner *(64)*. Edelstein *(26)* cites 18 months, and Lambert *(70)* cites 18 to 24 months for the below-elbow amputee. By the age of 21 to 24 months, the child has developed a two-handed functional pattern, and he shows signs of a need to develop a pinch grasp as opposed to purely palmar prehension *(72)*. By two years of age, according to Blakeslee (5), the child is ready for effective terminal-device activation, although this is typically a period of profound negativism. Dean *(25)* and Mayo *(79)* suggest that a single control cable be activated at 24 to 30 months, while Gingras and others *(46)* believe that, if active prosthesis training is begun by age two or three years, control can be achieved by four years of age.

A study by Trefler *(110)* reveals the drawbacks of normally fitting around two years of age. Some of these considerations are that the child is ready for bilateral grasp before that age; he may be difficult to work with at the "terrible twos" stage of hyperactivity and negativism, and he may have already developed compensatory patterns, which are more easily prevented than broken. The advantages of terminal device activation at 15 months of age with a goal of spontaneous terminal-device use are: (1) the child is easy to work with for short periods of time (he has an attention span of one to two minutes), (2) when the cable system is applied to the child's prosthesis, it often helps to eliminate the problem of excessive external rotation of the socket, and (3) the availability of active grasp can enhance the activity pattern of an intelligent child. No disadvantages of early terminal-device activation were discovered. The cable did not restrict the child's movement during play at all.

Wendt and Shaperman *(118)* conducted an interesting study to determine whether an infant amputee with unilateral below-elbow deficiency who was fitted initially with a prosthesis that included a cable would achieve purposeful control of the terminal device as part of his normal developmental progression without formal training. The results indicated that only a minority of the patients (approximately 25%) did achieve spontaneously the degree of skill usually acquired after formal training. Some patients partially learned skills, and others remained unaware of the function of the hook. It is possible that some children were negatively conditioned by the experience of trying to operate the terminal device and finding that they were unable to do so because of a lack of skill and guidance and concluding that the hook was a poor and unreliable tool. An alternative method of case management that has been suggested is to add the cable when manual hook-opening appears and then to allow natural development of terminal-device control. If the skill does not develop spontaneously, the therapist should intervene with the training program. This emphasizes manual hook-opening as a relevant step toward the eventual development of active opening. It was found that children who do learn terminal-device operation without training develop good skill and use patterns. If they are going to do so independently, they give evidence of this well before two years of age and achieve a well-established pattern by that time. It seems that, if a child is ready to develop the skill for terminal-device operation naturally, he should be allowed to do so.

Prosthetic training once the control cable has been added is composed of two parts: training in the control of the terminal device and later functional training in activities of daily living. The child's ability to operate a hook relates primarily to his maturity *(5,118).* Because of the child's short attention span, brief, frequent training sessions are desirable. Patients may sometimes be required to enter the hospital for the initial training sessions and occasional retraining later. At home, the mother can encourage these brief, frequent practice sessions. The child can best learn the correct control operations and realize the potentials of this prosthesis through play. There is a tendency for the child to continue to use his prosthesis as a passive device even after active control has been added *(72).*

Early training before the control cable is added should establish the concept of the prehensile function of the prosthesis. Manual hook-opening, at first by the parent and later by the child, and placing toys into the hook, should be encouraged. Flexion of the humerus opens the terminal device. The child must be helped to achieve the awareness of the relationship of these two incidents. The concept of stabilizing the sound shoulder in order to operate the terminal device is a difficult one to grasp. Having the child reach toward the terminal device with his sound arm may be helpful, or the therapist may need to stabilize the harness. The technique of immobilization seems to be mastered abruptly and inexplicably (5), but it may take a great deal of time. The important objective is to get the child to open the hook, no matter how awkwardly it is accomplished. It may be necessary to cut down on the number of rubber bands on the hook to enable the child to open it; at this point in training, a large prehension force is not needed. The therapist can help hy offering objects to the child and placing them so that the hook will open when he reaches for them. One of the most difficult things for a child to learn is to pick up objects from a horizontal surface.

The sequence of learning grasp and release with the prosthesis has been described by Blakeslee (5), Richardson and Lund *(90),* Shaperman *(94),* and Wendt and Shaperman *(118).* Although there may be variations in the pattern among individuals, it is agreed that a pattern does exist for learning terminal-device operation. A brief summary of the patterns observed by the above authors is presented here.

Children learn first to actively maintain the hook in an open position and then to initiate hook-opening actively. Early opening is often accomplished by abducting and internally rotating the arm rather than by flexing the shoulder. This closely resembles grasp by the normal infant. The child finds it easier to open the terminal device with the elbow extended than in any other position. There is a tendency for the child to place objects into the hook with the sound hand. The ability to actively close the hook around an object develops before active release. At first, release of objects is accomplished by pulling them out of the hook with the sound hand. The child seems to be unaware that he can open and close the hook for release and that this requires the same motions that were used for grasp. It takes a long time and a great deal of practice for a child to become proficient in the use of the prosthesis. He must learn how far to open the hook to accommodate objects of different sizes and shapes, to position the hook accurately, and to properly time the release of an object. The child must also learn to extend the prosthetic arm and still maintain grasp on an object by releasing his sound shoulder so it no longer acts as the reaction point for control. The younger child cannot be expected to learn these more complex skills.

Training hints have been offered by many therapists. The most frequent suggestion is the use of toys that require bimanual activity *(5,25,76,110).* A lengthy list of toys suitable to each age group and each desired activity can be compiled. It was also mentioned that feeding time has been found to be one of the most successful training periods. Drill activities cannot be neglected, but relating them to functional play activities as soon as possible is desirable. *The Limb-Deficient Child (5)* contains an excellent and extensive section on prosthetic training.

Three prime functions that require prosthetic training are feeding, toilet care, and dressing. Other functional patterns that add to patient independence and satisfaction are: playground, household, and schoolroom activities, sports, musical instruments, card playing, and any other activities commensurate with the child's age. Special assistive devices are available commercially or can be fabricated when necessary *(39).* Vocational training and preparation is a major consideration as the child grows older. For the unilateral amputee, the prosthesis is a helping or assisting device, and the sound arm is the dominant one in all activities. The part of functional training described in this paper is donning and removing the prosthesis. It is not practical to expect the very young amputee to be able to put on his prosthesis independently from the beginning. This is in contrast to the training procedure in adults, which would begin with this skill. Application is accomplished in the same manner as putting on a coat *(5,93,98).* The socket is grasped with the sound arm and the stump is slipped under the inverted-Y strap. If the prosthesis is raised above the head so that the harness hangs down, the sound arm can reach back through the axilla loop, and the harness then can be properly placed. To remove the prosthesis, the child raises both arms over his head and grasps the socket with his sound arm. He can withdraw the stump while pulling up on the socket and then remove the axilla loop. Although a stump sock is usually worn to absorb perspiration, prevent suction, and allow greater comfort in the socket, it is a matter of individual preference. Some children with below-elbow deficiencies prefer not to wear a stump sock *(93).* It is recommended that a T-shirt be worn under the harness to decrease local pressure and irritation, especially in the axilla, and to absorb perspiration.

Successful training will permit the child to function freely and independently in his environment. Additional training may be required when the needs of the individual change.

Follow-up studies of juvenile amputees after long-range treatment from infancy to adulthood have been conducted by Davies, Friz, and Clippinger *(24),* Hamilton *(54),* and Lambert, Hamilton, and Pellicore *(71).* All three indicate the excellent results of long-term prosthetic management as indicated by good social adjustment, excellent prosthetic utilization, high employment rates, and high levels of educational achievement. Increases in these favorable results can be expected as children with congenital limb deformities are referred to prosthetic centers for treatment earlier and earlier.

CONCLUSION

This paper has discussed the prosthetic management of the congenital amputee with upper-extremity terminal transverse partial hemimelia. Psychological aspects, components of the prosthesis, prescription and fitting, the trend toward early fitting, preprosthetic therapy, and prosthetic training have been considered. A review of the literature and a questionnaire survey were completed. Several questions are raised and areas for further research are suggested as a result of this study.

Research concerning the etiology of congenital limb deficiencies is indicated, including the unexplained phenomenon that the highest incidence of these deficiencies involve terminal transverse partial hemimelia of the left upper extremity in females.

Information regarding phantom sensation in the congenital amputee is lacking. Study in this area might help to explain the phenomena of phantom pain and sensation in traumatic amputees.

Reports regarding peer attitudes toward juvenile amputees show some disagreement. Some authors maintain that the attitude exhibited is one of healthy curiosity easily satisfied by an explanation, while a study by Centers and Centers showed more covert rejecting attitudes toward this group of individuals. It would be interesting to retest this hypothesis of social discrimination in the light of recent changes in attitudes toward many minority groups, since this study was conducted nearly ten years ago.

A great deal of research is indicated and is being conducted in the area of prosthetic design. The results of biomechanical and kinesiological studies must be incorporated in the design of components. Analysis of the forces used in prehension and the most frequent types of prehension employed would be beneficial in improving terminal-device design. Further evaluation of the hooks and hands presently available and the voluntary-opening and voluntary-closing mechanisms are needed to determine which is most efficient and to delineate areas for further research. Some work has been done regarding optimum wrist-flexion (palmar) angles for functional activity close to the body. However, no consideration has been made as to the need for dorsiflexion, which is used very frequently in functional activity of the normal hand. The field of plastics offer a great source for improvements in fabrication of prostheses. Durable hooks with improved cosmesis may be a possibility with the new plastic materials available, as it has already aided in light weight and durable socket design and fabrication. The open-ended sockets that permit the use of the sensation at the tip of the stump seem to be an excellent development, especially for the bilateral amputee. Investigation into the advisability of increased use in the United States is indicated.

Some disagreement exists concerning the development of prosthetic tolerance by the juvenile upper-extremity amputee. It is not, however, a significant controversy, since the goal of full-time wear is agreed upon, with differing opinions only concerning the rate at which this goal is reached.

The results of the questionnaire survey indicate a trend toward earlier prosthetic fitting of the congenital amputee. Among the most interesting and valuable of all the information received was the developmental criteria for fitting. This information should be made available to the clinics participating in the Child Prosthetics Research Program, thereby enabling each of them to re-evaluate their criteria in light of this newly accumulated knowledge. Perhaps this can be accomplished through the *Inter-Clinic Information Bulletin.* The survey conducted did not consider the important factors of parental attitudes and age at time of referral to the prosthetic center. Any future study should incorporate these factors. Another study might better be able to establish or negate a relationship between the development of the Munster-type socket and the trend toward early fitting.

Additional information concerning activation of the terminal device is needed. The proposal by Wendt and Shaperman of allowing natural development of the terminal device control once manual opening occurs, then intervening with formal training if control is not established by two years of age, merits consideration.

Prosthetics for congenital amputees is a relatively new area, largely developed since the thalidomide tragedy of a few years ago. It has many areas requiring further research, such as the need for lightweight prostheses that can be operated with the available muscle power and the constant consideration of rapid growth. Research in this specific field of prosthetics for congenital amputees will contribute to and continue to benefit from the ongoing research in prosthetics in general. The goal of this research is improved functional ability for individuals with congenital skeletal limb deficiencies of varying degrees of severity and for all amputees.

ADDENDUM

Three additional responses from the questionnaire survey were received after the statistical analysis had been completed and the article had been prepared. These brought the total return to 53.5%. A summary of the information received is presented here.

The results were generally similar to those previously reported, with a number of individuals fitted at each interval except the first (less than three months).

The developmental criteria presented were: bilateral gross grasp, beginning to sit, independent sitting, and (not previously mentioned) initiation of hand-eye coordination, as with holding a bottle, blocks, and general grasp for objects.

Two of the clinics indicated that they usually fit a first prosthesis at six months of age if the developmental level allows it. Those fitted later in the statistics returned were not referred to the clinics until after that age.

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