Developmental Factors in Infant Upper Extremity Prosthesis Fitting

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The Child Amputee Prosthetics Project (CAPP) at UCLA has been fitting upper extremity prostheses to young child amputees for the past six years. Special attention has been given to those under two years of age—the infants. This Project has realized the necessity of exploring the optimal age for fitting upper extremity prostheses to infants. The motor development and pattern of prosthesis use of thse infants has been followed closely. Ways of fitting and follow-up care for these infants have evolved which make use of clues in his development that determine how and when he should be fitted. Results of this experience continue to be evaluated.[2]

First Attempts at Infant Fitting

In 1955 the available armamentarium and techniques of fitting infants gave no indication that his needs were different from adult needs. The first infants fitted at CAPP had size 10 or larger hook terminal devices with complete control systems. These scaled down adult type arms with large hooks, heavy leather work and harnessing were gross in appearance and unwieldy for use. The infant did not actively operate the terminal device and it was soon apparent that more suitable armamentarium and/or fitting technique was needed. The infant was not just a small adult. His special needs had to be met.

Developmental Considerations

During the first two years of life the neuromuscular control of arms and legs undergoes profound change. Development proceeds in a cephalocaudal (head to toe) direction and the arms develop control and skill, starting from the shoulder and progressing to the hand. At first, normal infants do not use arms and hands with good coordination and they have dffiiculty with fine motions. Shoulder motions during the first year are primarily abductive-adductive. Early reaching motions are poorly directed but the approach toward objects is gradually straightened showing gain in control of distance and angle. Studies have shown that the angle of approach is under the influence of the type of object to be grasped and its placement. Approach receives its direction from the hand going to do the grasp. By the end of the first year the infant can reach for objects with enough arm control to place the hand in good position for grasp.[6] Hand patterns also undergo change in a sequential developmental pattern. By one year of age the infant can use a precise forefinger tip grasp.

The developmental pattern proceeds through a sequence of acts. The occurence of each act in the series is contingent upon those which precede it. Thus it is obvious that considerable learning occurs while performing

the acts which precede the emergence of the ultimate skill. These seemingly-crude early reaching and body movements are important for giving the infant a concept of visual space and of his body and arms within it. When the infant amputee wears a prosthesis during this time, he comes to accept it as "part of himself." He uses the prosthesis with the same arm movement patterns as are natural to his stage of development.

When the tools needed for an act in the developmental pattern are not present, the infant must find some compensatory way to perform it. If the infant amputee has no prosthesis when he goes through the stages of development involving his arms, he compensates by learning to rely on what he has for all his activities. Without a prosthesis the child avoids some bilateral activities or appears awkward in performing them.

Age of Fitting

On the basis of this knowledge and in order to properly evaluate the optimum age for fitting, the CAPP is currently fitting upper extremity prostheses to infants when they achieve independent sitting balance. Developmental studies have shown that this usually occurs at approximately 7 to 9 months of age. A prosthesis is applied at this time because:

1. *Body Control:* An infant has sufficent body control to keep the prosthesis from interfering with his normal activities of rolling and crawling.
2. *Arm Control:* First experiences in the upright position for any infant begin to occur at this time. After achieving upright posture, an infant rapidly extends his play area and begins rapid development in control of arms and hands.
3. *Wearing:* Infants accept wearing prosthesis more easily when fitted at this early age and tend to carry through with a full time wearing pattern in the years that follow.
4. *Arm Patterns:* Experience has shown that infants fitted when they achieve independent sitting balance develop arm patterns which parallel those of the sound arm, and they carry these spontaneous and natural arm patterns over into their later prosthesis use. The child who has developed prosthetic skill performs activities requiring two hands in a fashion common to all persons and does not resort to knees, teeth, or axilla holding.

The Infant Passive Hand or Mitt

The special needs of the infant amputee were considered in the national prosthetics research program. A terminal device which did not require operation by a cable was needed. The device designed was a hand in a simplified abstract form. It was referred to as an infant passive hand or mitt (see Figure 1). It was assumed that by not making the mitt too anthropomorphoid it would be psychologically easier to change to a hook when active grasp was needed. This stylized form also allowed better function than a purely cosmetic hand as it had a cupped shape and deep thumb cleft.

Eighteen infants were fitted at CAPP with various experimental and commercially available models of the mitt. They were well accepted by parents and the infants used them for activities appropriate to their developmental level. The light weight of the mitt and the friction offered by the glove were of advantage to the infant. It was very satisfactory for scooping, lifting, holding large objects bilaterally, and for holding down objects. However there were serious limitations in the function of the mitt.[4, 5]

Limitations of Mitt in Gross Activities

1. Infants needed a more secure hold than the mitt offered when pulling up to a standing position and supporting themselves with such things

as the rails of a crib or play pen. Although initial design criteria specified at least 70 degrees or more of digital flexion in the mitt for this purpose, it did not meet this need.[7]

2. Infants needed a more secure way to hold objects which were placed in the mitt. Pull toy cords, rattles, and balloon strings had to be taped or tied to the mitt. The thumb cleft of the mitt provided a precarious 2 point hold for a limited number of objects.

Limitations of Mitt in Transition to Hook

1. The infants did not develop bilateral prehensile awareness. About the age of 2 infants began to develop compensatory grasp patterns. They held toys and other objects between their knees, in the axilla, or in the bent elbow while manipulating them with the sound hand. To prevent these compensatory patterns from becoming established habits, the child's terminal device was then changed from the mitt to a plastisol coated hook, Dorrance 10P, with cable (see Figure 2). The hook with cable is referred to as an active hook. It is operated by a body motion of the amputee transmitted through the harness and cable.

   An initial period of intensive training in the use of the active hook was given. These children who had changed from mitt to hook learned active hook operation quite slowly. They were slow to realize that their new hook terminal device could hold an object. Even after they had learned to open and close the hook actively, they persisted in holding objects in the elbow, axilla, or between the knees. It required a considerable period of un-learning and re-learning before they would hold objects spontaneously with the active hook.
2. At the time of the transition from mitt to hook, many parents had

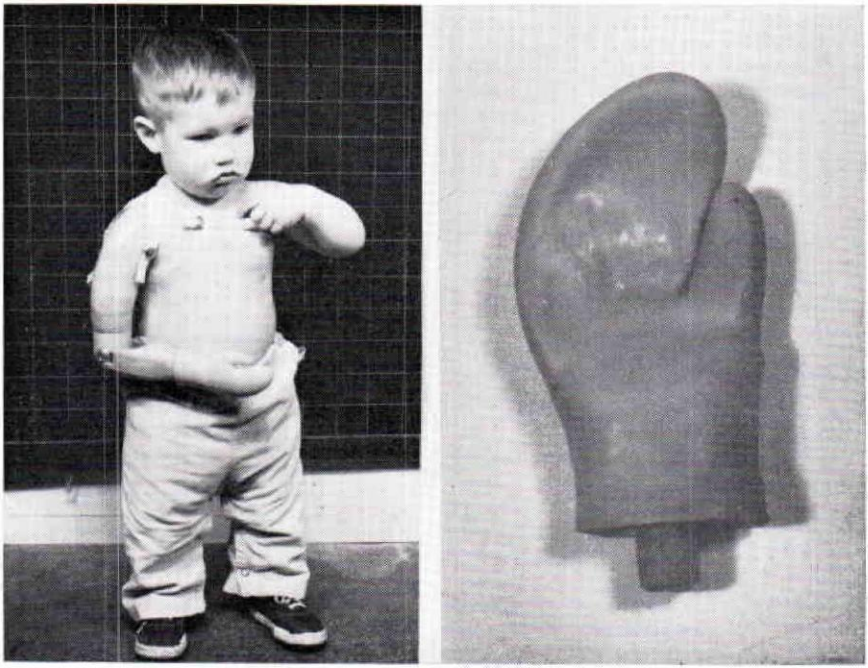

Figure 1. The infant on the left is wearing the commercially available model of the Infant Passive Mitt. On the right is the UCLA model of the mitt.

difficulty in accepting the appearance of the hook. Even though they could see the need for increased function, they resisted change because they had found the color and shape of the mitt sufficiently cosmetic to meet their own needs and to satisfy their feelings of having done something for their child.

Observations made of infants wearing the mitt and following the change to the hook with cable showed they were able to perform all of their gross activities of scooping, lifting, holding down objects, and holding large objects bilaterally with a skill equal to that of the mitt. Parents reported new activities their children could perform better with the hook such as hooking over bars or hooking over furniture while climbing. These observations, along with the developmental factors known about the learning of prehension by the infant, led the CAPP to look for an infant terminal device which would not have the deficiencies noted with the mitt.

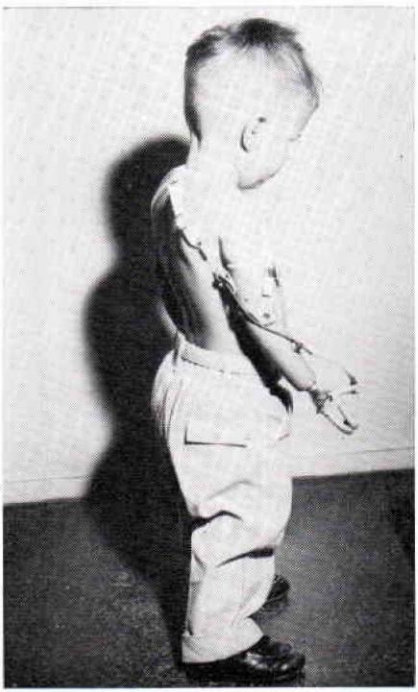

Figure 2. The Dorrance 10P hook with cable is worn by this infant.

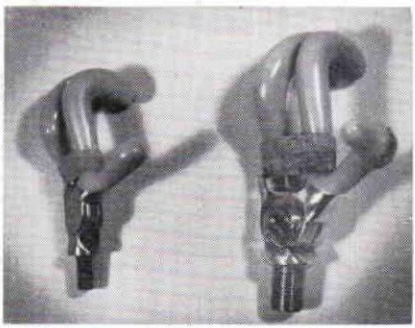

Figure 3. The smaller Dorrance 12P hook is seen on the left and the larger Dorrance 10P hook is seen on the right.

The Infant Passive Hook

Evaluation Procedures

Evaluation was undertaken of the effectiveness of fitting infants having attained independent sitting balance, with a very small plastic covered hook which was commercially available, the Dorrance 12P (see Figure 3). This hook was applied without a cable and is called a passive hook. It could be pulled open by the sound hand of the infant or by an adult to have an object placed into it. It was reasoned that even though the infant would not actively operate this terminal device, he would learn that it could hold objects.

At first the staff thought a hook might get in the infant's way or he might accidently hurt himself with it or get it caught on things. Also it was questioned whether the protruding hook tips and thumb lever would inhibit palmar prehension. It was also thought the parents might reject a prosthesis because of the immediate introduction of a hook. The problems the staff had anticipated did not occur. Twenty-three infants ranging in age from 7 months to 22 months have been fitted with this infant passive hook on their initial prosthesis.

In the two and one-half year period since this study was begun these infants have been observed in relation to pattern of development, manner of use of prosthesis, and pattern of learning active terminal device operation. Following fitting, checkout, and a brief period at CAPP for observation of the infant and orientation of the parents, the infant was seen once or twice a month by a therapist in his local community where his development and pattern of prosthesis use were observed. Movies were taken at regular intervals of all children so fitted. Parental reactions were recorded by the social worker. Prosthesis fitting and maintenance information was recorded by the prosthetist.

Results of Fitting the Infant Passive Hook

Parents who were motivated toward a prosthetic program accepted the small plastic covered passive hook for their baby's prosthesis. Some said that since the child would eventually wear a hook, it was easier to start out with one. A number felt that its appearance was more acceptable than the stylized mitt. By using a passive hook for the first fitting, parents learned to handle the questions and stares of others from the beginning. It was part of facing and dealing with the reality of their baby's amputation and the potential use of a functional prosthesis.

The pattern of motor development of the infants fitted with the infant passive hooks followed closely that seen in non-amputee children. There were no functions performed by infants wearing the mitt which infants were not able to perform equally well with the Infant Passive Hook. As young infants they had no difficulty using both arms together for gross activities such as scooping objects toward themselves, lifting large balls, and holding down objects while manipulating them with the sound hand (see Figure 4). They were able to use both arms to support their nursing bottles. (When the bottle rested in the angle between the passive hook fingers and the hook thumb it gained additional support.) When teething a number of infants enjoyed chewing on the plastisol covering of the passive hook. This plastisol covering also provided friction for stabilizing objects and body support.

Body support activities were also performed in their expected developmental sequence. Sveral of the infants crawled on the sides of the hook tips. Some crawled on their flexed forearms. At first some got "hooked" on furniture legs while crawling but quickly began allowing for this added length and shape and were able to free themselves. When sitting on the floor many of the infants leaned upon the passive hook tips for support while reaching out for a toy with the sound hand. When pulling to standing position a number of the infants did hook over a rail or piece of furniture gaining support on the prosthesis side. At first they did not trust the prosthesis enough to support their standing weight with it, but were soon able to develop enough confidence in it for this activity. When learning to walk and taking those inevitable first falls, the infants were observed to put both arms out to catch themselves and landed on the hook tip and sound hand. They then pushed themselves up from the floor with both arms. For these activities the

infants with the infant passive hook had equal or better function than those who had worn the mitt.

Objects placed into the Infant Passive Hook were not noticed at first by some infants under one year of age. Their earliest responses were to put the infant passive hook into their mouth and suck it; to pull an object out of the passive hook; to shake their arm and listen to the sound of the object in the passive hook, or simply to bang the passive hook against the floor or other hard object (see Figure 5). Later most of the children went through a period when they would not allow any object to remain in their infant passive hook for more than a moment. The parents were advised to place appropriate objects into the passive hook as long as the infant would tolerate this.

At about 18 months of age the therapist directed the infant's play toward increasing his attention span and encouraging him to follow directions. At some time during the infant's second year he shows interest in playing with and holding some small objects. The infant amputee used his axilla, bent elbow or teeth for this purpose. From the time this was first seen parents and therapists began placing objects into the infant passive hook and the infant began to experience some success in playing with these smaller objects. Parents reported that infants tried to place objects into the passive hook themselves but needed to ask someone to open it for them, or they pulled the hook open with their sound hand and then needed someone else to put the object into it. Some developed compensatory ways of holding the infant passive hook open to get an object into it such as holding it open with the mouth.[3]

Transition from Passive to Active Control

The cable was added when the infant showed an interest and desire to hold objects in the infant passive hook; was able to follow simple instructions; and had a sufficient span of attention to play with one toy at a time for a few moments. This usually occured at around the age of 2, but the period of excess negativism which most children have at around this time was avoided if possible.

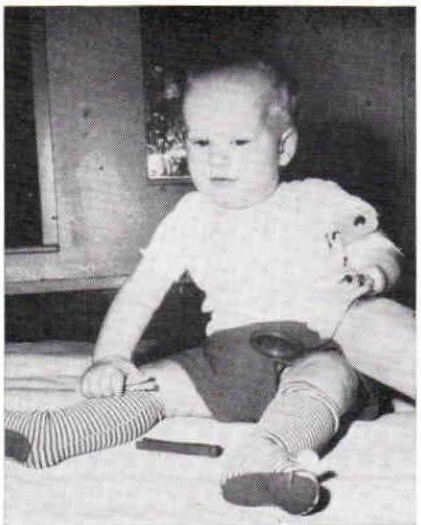

Figure 4. The infant holds down a plastic bottle with the prosthesis and places objects into the bottle with his sound hand.

Figure 5. The infant learns that his passive hook can hold objects and enjoys a simple bilateral activity.

It was found that usually by this time the child's prosthesis was slightly short and the 12P hook appeared small for the child. The Dorrance 10P hook which is three-quarters inches longer than the 12P was applied in its place. The 10P hook was applied with a cable. Except for the greater holding potential of the 10P hook, the shape, friction quality, and other features of the two hooks were the same. Even the weight was not markedly different as the 12P has a steel core and the 10P an aluminum core (see Figure 3).

Parents showed eagerness for the change from passive to active hook to occur. Some considered it a "promotion" for their child. The parents' eagerness had to be controlled and the activation prescribed when the child showed sufficient span of attention and ability to take instruction to be able to profit from the training period. At the time of this writing, about one-half of the infants fitted with infant passive hooks have matured sufficiently to have the terminal device control system added to the prosthesis.

Training which followed the addition of the cable was in some ways similar and in some ways different from that observed following change from mitt to hook. Those children who had worn the infant passive hook proceeded to learn active operation more rapidly but in the same controls sequence as has been observed with infants who had worn the mitt.[8] *The major difference occured in the spontaneous application of their skill outside the training situation. These children had learned that the hook was a holder of objects. They did not need to break old habits before they would use it spontaneously.* Follow-up training confirmed this and was continued to help the child refine his skill and develop the full potential of the device.

Infant Sockets and Harnessing

An infant's rounded contours, tender skin, and small size present challenges to effective fitting and harnessing. The gross use of his extremities in infant activities adds further complications. CAPP Prosthetists have found some ways of effectively fitting and harnessing the infant, making his prosthesis less bulky, and making it last longer than was previously anticipated.

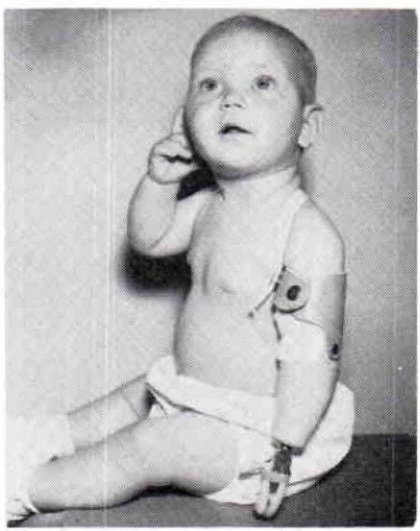

Figure 6. The leather cuff is attached to the socket with large speedy rivets.

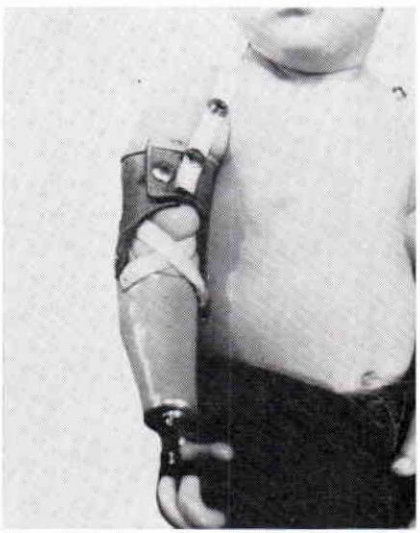

Figure 7. A figure-of-eight strap at the elbow allows full range of motion and keeps the socket in place on a short bulbous infant stump.

Socket

As much bulk as possible was eliminated from the elbow hinges. Leather cuffs were attached with rivet inserts or glove snap hinges (see Figure 6). Short and very short below elbow amputees were fitted with double walled sockets rather than with split sockets. The sockets were pre-flexed to provide as much range as possible with no attempt made to provide full range of elbow flexion on unilaterals with very short stumps. Some infants with very short bulbous below elbow stumps temporarily needed an accessory figure-of-eight strap at the elbow to hold the socket on (see Figure 7). The double-walled socket provided the infant with a rigid pillar for crawling and with a secure means of holding down objects. Additional weight and bulk were eliminated for the long below elbow amputees by using dacron tape for flexible hinges and eliminating the leather cuff (see Figure 8).

Baby fat is gradually displaced by muscle tissue as the infant develops. As this occurs socket shape adjustments can be made by heating the plastic to change its contour. The socket can be ground out and sanded at the distal end, over the olecranon, or humeral epicondyles as the infant's stump changes shape. This is possible when the socket has been made thick enough in these areas. If the arm is short a larger hook can be substituted.

Harness

An infant's shoulder area is so small that little space is available for a harness. Even the "simple" below elbow figure-of-eight harness is not simple to balance on the infant's prosthesis. It must suspend the prosthesis so it stays on the infant, does not excessively mark tender skin, and remains in correct alignment. For example, there is a temptation to attach the front

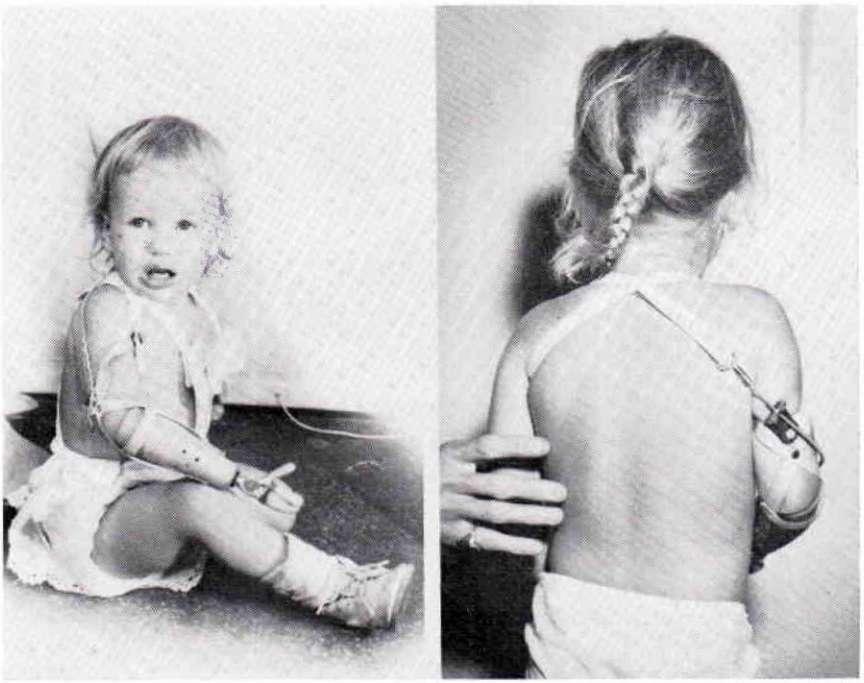

Figure 8. The long below elbow infant prosthesis can be made light weight and efficient by the use of dacron tape flexible hinges and "cuff." The infant on the left wears a passive hook. The cable has been added to the prosthesis shown on the right.

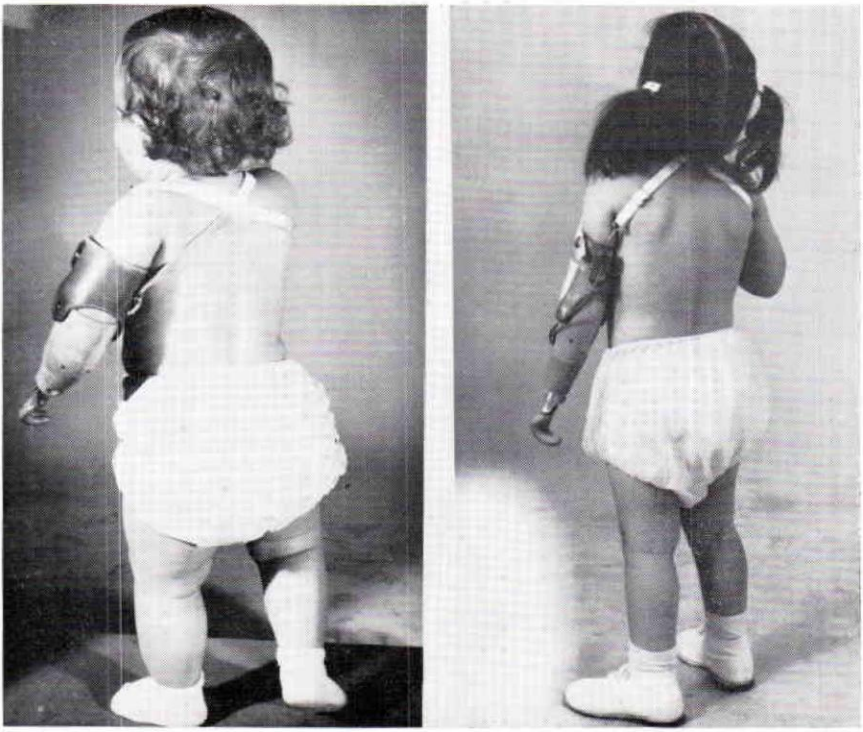

Figure 9. The infant below elbow passive prosthesis is shown on the left with the elastic strap substituting for the control strap and cable. At right the cable and control strap have been added. Note that the harnesses are stitched at cross points and attach to the cuff at front and back with glove snaps.

support strap on the medial side of the cuff and to pull it tight to keep it from sliding off the infant's rounded shoulder. This arrangement tends to rotate the prosthesis externally so that it is outside the infant's area of vision.[1]

The control attachment strap on the infant harness is replaced by an elastic strap as a substitute for the control strap and cable. (The elastic strap is used to keep a good balance on the harness when the hook is passively operated.) It attaches to a reaction point on the cuff for the below elbow or on the humeral section for the above elbow amputee (see Figures 9 and 10).

Maintenance

The socket and harness must be kept clean and in correct adjustment. Harness adjustments were easily lost when buckles were undone for laundering. A satisfactory solution has been to provide two harnesses to interchange while one is laundered and also to make all harnesses with fixed attachments (see Figure 9). CAPP prescribes all harnesses so they are stitched at cross points and attach to the prosthesis with large glove snaps. (A drop of oil on glove snaps after laundering keeps them working well.) Socket and harness fit and function need to be checked by the prosthetist at approximately three-month intervals to take care of any needed adjustments for the growing and changing infant amputee.

Conclusion

Habilitation of the infant upper extremity amputee can be accomplished through the application of prosthesis if detailed attention is given to his de-

velopmental needs and achievements. Experience at the Child Amputee Prosthetics Project in fitting forty-one infants with passive terminal devices has raised a number of questions and suggested some possible solutions.

1. Infant upper extremity amputees do benefit from the application of prosthesis. Far from being a nuisance it helps him develop more normal and natural gross arm patterns, more normal motor development patterns, and more useful two-handed grasp patterns. Prostheses can be applied with good results and surprisingly few problems from the time the infant has achieved independent sitting balance. A prosthesis becomes incorporated into his body growth and developmental patterns when applied early and worn consistently.
2. The infant passive mitt is a satisfactory terminal device for gross palmar prehension and for some body support activities. However, it is seriously lacking in some respects. It does not provide hooking over objects for support when pulling to standing—this is an important need for the infant. It does not allow the infant to hold a variety of small objects or to develop bilateral prehensile awareness. The infants who had worn the mitt did learn to actively operate the hook but were slow to realize that it could hold objects. Parents had difficulty in accepting the shift from a mitt to a hook at the time active grasp was needed.
3. An infant passive hook, Dorrance 12P, appears to be a more functional infant terminal device than the mitt for the following reasons:
   a) It provides for gross palmar prehension and body support activities with equal skill to the mitt.

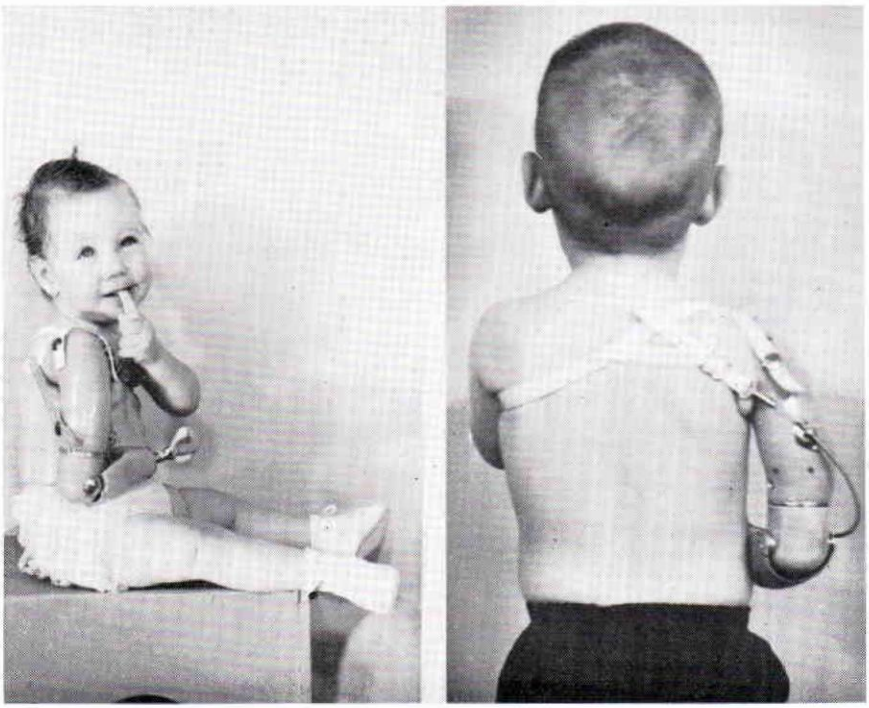

Figure 10. The infant's above elbow prosthesis is shown on the left with the elastic strap substituting for the control strap and cable. At right the control cable and strap have been added.

b) It allows the infant to hook over objects for support in pulling to a standing position.
c) It provides a holder for small objects which are placed in it.
d) It helps the infant develop bilateral prehensile awareness. He grows up in a two-handed world where equipment and facilities require a "holder" or "manipulator." The infants who had worn the infant passive hook and later received active control used the hook spontaneously for holding objects for their activities.
e) Parents who were willing to accept any prosthesis for their child readily accepted the infant passive hook terminal device.

4. The active control for the terminal device can advantageously be added when the child shows interest and readiness for this operation. This is usually sufficient some time between the ages of 2 and 3. Training should be given in the use of the active control to develop the potentials of the device. Early operation is crude but becomes refined in a relatively short time and the habit patterns of holding in the hook are retained.

5. Harnessing, socket design, and fitting of infant upper extremity amputees requires skill and knowledge. There are ways of making prostheses last longer which can make fitting the infant amputee economically feasible. These have been discussed in the text.

6. The infant and growing child and his family can be more successfully habilitated by a cooperating interdisciplinary treatment group. Good family orientation and patient evaluation, skillful fitting and harnessing, consistent training, and good medical, surgical and follow-up care are needed. Together they provide the infant upper extremity amputee with the kind of prosthesis experience from which he can grow and develop in a fashion parallel to a child with two arms.

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