The Two Stage Myoelectric Hand for Children and Young Adults

Eric Baron, C.P.O.
Susan D. Clarke, O.T.R.
Carol Solomon, M.S.W.

When myoelectric components became available for young below elbow amputees, the Child Amputee Prosthetics Project (CAPP) at the University of California at Los Angeles undertook a study to determine how children would benefit from such fittings. The goals of the study were:

- to establish criteria for selection of candidates.
- to identify maintenance needs unique to the myoelectric fittings for children.
- to evaluate the functional potential of myoelectric hands for children.
- to develop evaluation, fitting and training techniques appropriate for different age groups.
- to evaluate the attitudes of children and their parents toward the myoelectric prosthesis with regards to its functional and cosmetic potentials.

PROSTHETIC COMPONENTS AND EQUIPMENT EVALUATED

At the time of the study, two myoelectrically controlled hands were readily available in sizes which were appropriate to our population; the Otto Bock child size hand and the Systemteknik hand, number one (small) often referred to in the literature as the "Swedish Hand." Both were used in conjunction with the Otto Bock 6 volt two stage electrode system. A myoelectric hand and electrode set-up and the Otto Bock myotester with dual dials were used for electrode sight locations.

CRITERIA FOR SELECTION OF SUBJECTS

Following a review of criteria established for adult myoelectric hand candidates, the staff established the following list of criteria for selection of children to participate in the study.

- Child and family are highly motivated to participate in the myoelectric hand study.
- Child has a functional or cosmetic need that can be met by the myoelectric hand.
- Child is of an appropriate size for the myoelectric hands available.
- Child has two suitable electrode sites.
- Child has an appropriate length residual limb.
- Child has a consistent wearing pattern if currently wearing a prosthesis.
- Child can make the required visits for training and evaluation.
- Child and family are conscientious about maintaining current prosthesis.

• Child will restrain him/herself when activities may cause damage to the myoelectric hand.

• Child is able to wear an intimately fitting socket without a prosthetic sock.

• Child does not object to having restricted range of motion at the elbow.

The following operational definitions were used to apply these criteria.

• Approximate size: sound hand is the same size or slighly larger than available myoelectric hand.

• Consistent wearing pattern: wears prosthesis regularly for certain activities or periods of the day.

• Required number of visits: regular visits to CAPP facility and/or therapy training facility until prosthesis is completed and child has achieved developmentally appropriate functional use of the prosthesis.

• Appropriate length residual limb: the residual limb must be long enough to accommodate the electrode sites comfortably within the socket and short enough to keep the overall length of the finished prosthesis no longer than is cosmetically acceptable to the child and family.

DATA COLLECTION

Data used to complete this report were collected using a variety of methods. Standards medical reports provided information on individual treatment plans and outcomes. Individual records were kept by both prosthetists and therapists to record method of approach to treatment, hours of training, type of equipment, and treatment media used. These provided greater detail than the medical records. Electrical component and prosthesis maintenance records were kept by the prosthetists.

Two forms were created to gather information. The occupational therapists devised the Bimanual Functional Skills Evaluation to record functional use of the prosthesis and determine preference for the type of prosthesis used in each activity. This was administered for both the myoelectric prosthesis and the body-powered prosthesis if one was worn. The social worker constructed the "Attitudes Toward Change in Prosthetic Fitting" questionnaire which was used during an open-ended structured interview to gather information from both the children and/or their parents about attitudes toward the prosthesis and other persons reactions to it.

POPULATION

Fourteen subjects participated in this study. Nine were fit with the Otto Bock hand and five with the Systemteknik #1 hand. All of the participants were unilateral congenital upper limb amputees. Eleven children had below elbow deficiencies, and three had wrist disarticulation deficiencies. Age of subjects at the time of the myoelectric fitting ranged from three years and three months to 17 years of age. Two of the participants were male and 12 were female (Fig. 1).

Prosthetic fittings prior to the study varied. Five of the subjects had worn CAPP terminal devices. Three wore body-powered hands and three interchanged Dorrance hook and body-powered hand. One subject had worn an OCCC switch-operated electric hand, but was currently not wearing a limb, another child wore an opposition post, and one child had never been fit with a prosthesis prior to the myoelectric fitting. Many of the children had had experience with other types of terminal devices during their earlier prosthetic programs. Twelve of the subjects had been fit with a prosthesis before two years of age.

Prosthetic wearing patterns varied among the subjects. Of those wearing prostheses, nine were full-time wearers and two wore their limbs part-time, primarily for school and social occasions. The child fit with an opposition post wore it for specific activities only.

Initially, criteria established for selecting subjects were rigidly adhered to. As time passed some exceptions were made, notably two families with high motivation, but a poor history of attendance and follow-up were accepted. These exceptions substantiated the validity of the criteria as both these children failed to complete the study.

Figure 1
Subject Data—Two-Stage Myoelectric Hand for Children and Young Adults

Case Number	Subject Number	Age	Sex	Amputee type	Side of amputation	Accepted for study	Type of terminal device—body powered	Type of terminal device—myoelectric	Pre-study wearing pattern	Post-study wearing pattern
492	1	12-2	M	Sh. B/E	L	Yes	Hand	O.B. 7¼	F	F-Body/M
595	2	11-5	F	W/D	R	Yes	Hand/ Hook	O.B. 6¾	F	F-Myo
597	3	11-8	F	Sh. B/E	L	Yes	Hand	O.B. 6¾	F	P-Myo
1035	4	3-3	F	W/D	R	Yes	0	Swed. Hand	0	P-Myo
720	5	12-6	F	Sh. B/E	L	Yes	Hand	O.B. 7¼	F	F-Myo
739*	6	9-3	F	W/D	L	Yes	Post	O.B. 6¾	P	0
752	7	6-10	F	B/E	L	Yes	CAPP T.D.	O.B. 6¾	F	F-Body
939	8	4-8	F	B/E	L	Yes	CAPP T.D.	Swed. Hand	R	P-Myo/Body
946	9	3-8	F	B/E	L	Yes	CAPP T.D.	Swed. Hand	F	F-Myo
1015	10	8-0	F	B/E	R	Yes	Hand/ Hook	O.B. 6¾	F	F-Myo
1002	11	3-8	F	B/E	R	Yes	CAPP T.D.	Swed. Hand	F	F-Myo
682	12	10-4	F	B/E	L	Yes	Hand/ Hook	O.B. 6¾	F	F-Myo
977*	13	4-8	M	B/E	R	Yes	0	Swed.	0	0
726	14	7-2	F	B/E	R	Yes	CAPP T.D.	O.B. 6¾	F	F-Body/Myo

*Did not complete study.

METHOD

Subjects whom the staff felt might meet the criteria for participation in the study were asked if they would like to participate. Those who accepted were scheduled for an evaluation. At the first visit the family was given an orientation to the study. Estimated number of visits to the center were given, treatment techniques described and data gathering methods explained. The prosthetist and occupational therapist demonstrated the operation of a myoelectric prosthesis and described its functional potential.

If the child and his parents met all criteria and were interested in participating, testing to locate suitable electrode sites was begun. For children over six, it was usually possible to find sites at the first visit. Younger children sometimes required more than one session to grasp the concept of contracting a muscle to produce an action in the myoelectric hand.

The prosthetist scheduled time to take a negative impression for the initial socket as soon as the sites were well-established. When criteria established for the definitive socket were met, final fabrication and fitting were completed. Controls training was continued until the child could operate the hand smoothly and consistently. This was followed by use training.

Following attainment of prosthetic skills at a developmentally appropriate level, the child was asked to complete the *Bilateral Functional Skills Evaluation*. At the same visit or a later one, the social worker interviewed the parent(s) and/or child and completed the attitude questionnaire.

PROSTHETIC FITTING TECHNIQUE

Locating and Developing Electrode Sites

Criteria for the selection of electrode sites were established as follows:

• Selected muscles can be contracted voluntarily and consistently.

• Selected muscles are not used to actively move the elbow.

• Electrode sites fall within the socket area and will not interfere with fit or comfort of the socket.

Equipment used to locate and develop electrode sites included a myoelectric hand set-up with battery and electrodes and the Otto Bock dual dial myotester. An elastic Velcro® strap to hold electrodes in place and water to dampen the skin and improve contact were sometimes used (Fig. 2). The myoelectric hand set-up proved to be the most effective feedback system for reinforcing appropriate muscle contractions in young children. The Otto Bock myotester was used for control training with some older subjects and for all subjects to evaluate the electrode sites more precisely before the actual cast of the limb was taken.

The prosthetist and therapist worked together to locate electrode sites. During the initial site location session, the electrode gains were set at five or six. This allowed the myoelectric hand to respond quickly to a minimal contraction which improved feedback. Muscle contractions in the child's residual limb were elicited by first asking the child to wiggle any residual nubbins or dimples while the trainer palpated to locate the belly of the muscle being used. This usually triggered a flexor muscle on the medial side of the residual limb. The appropriate electrode was then placed on the belly of the strongest muscle with the electrodes in line with the muscle fibers. Since it was usually a flexor, the closing electrode was used. The trainer opened the hand by touching the open electrode and encouraging the child to "wiggle his nubbin" and contract the muscle which closed the hand (Fig. 3). In this manner the child mastered one control at a time and was less confused. Once a consistent signal could be generated, as demonstrated by repeated controlled operation of hand closing, a second control site was located. To elicit an extensor muscle contraction in the residual limb, it was usually most effective to ask the child to forcibly extend the wrist and fingers of the sound hand. This produced a sympathetic response in the extensor muscles of the residual limb and usually stimulated a weak contracture which could be palpated on the lateral surface of the limb

Fig. 2. A myoelectric hand and electrodes were used to locate electrode sites.

(Fig. 4). The opening electrode was then placed over this muscle and the procedure for operating the hand reversed. The child was asked to open the hand by extending the sound wrist and tightening the muscle in the residual limb. The trainer closed the hand by touching the other electrode. Finally both electrodes were held on the residual limb and the child was asked to open and close the hand (Fig. 5).

Usually it was possible to generate at least minimal signals from two appropriate muscles at the first visit. When two sites were established the myotester was used to evaluate the child's ability to generate and separate the myosignals. If one muscle was obviously stronger than the other or they had difficulty separating signals, the gains on the electrodes were adjusted to improve the situation. When successful opening and closing of the hand was accomplished, the electrode sites were re-evaluated by the prosthetist to assure they could be incorporated into the socket. If either of the sites was not suitable, the trainer moved one electrode at a time toward a more suitable site keeping the contacts in line with the muscle fibers and re-testing until optimum sites for function and comfort within the socket area were located. If muscle contractions were weak or erratic, further training was carried out before final sites were selected.

Fig. 3. The trainer encourages the child to "wiggle the nubbin" on her residual limb to stimulate a contraction.

Fig. 4. Asking the child to extend the wrist of her sound arm often produces sympathetic extensor contraction in the residual limb.

Fig. 5. After locating the flexor and extensor sites, both electrodes were used at the same time.

Additional training for those children who could not generate adequate signals at the first visit consisted of using the techniques described above to strengthen the muscles and improve voluntary control and separation of signals. This was done by holding the electrodes in place with an elastic Velcro® strap and having the child practice opening and/or closing the hand. The addition of toys requiring two-handed manipulation at this time as well as during the initial evaluation provided motivation and reduced anxiety (Fig. 6).

NEGATIVE IMPRESSION PROCEDURE

Once adequate muscle sites were located, a 2-stage negative impression was taken of the patient's residual limb. The first stage consisted of a plaster splint encircling the proximal brim and cubital fold areas. A string was tied securely around the apices of the epicondyles (Fig. 7), olecranon, and through the cubital fold, and the limb was passively moved into full elbow flexion by the prosthetist and held until thoroughly dried (Fig. 8). This slight

Fig. 6. Encouraging the child to manipulate toys with the powered hand provides motivation and reduces anxiety.

Fig. 7. The string casting was used for the negative impression.

Fig. 8. The elbow is held in full flexion until the plaster is set.

variation of the German casting technique taught by Otto Bock is essential for independent suspension of the prosthesis due to the lack of developed humeral condyles in the children fitted. The second stage of the impression was completed with the arm extended incorporating the remaining portion of the residual limb in plaster bandage (Fig. 9). This two-stage technique allows for full displacement of the cubital fold tissue with maximized elbow range of motion without reducing the total suspension of the prosthesis. The dried cast was removed and a hole placed distally so the cast could be used as a check socket. By pulling the residual limb back into the cast, range of motion as well as suspension can be initially evaluated by the prosthetist.

Modification of the Positive Model

Variations in modification techniques primarily focused on the proximal brim area in order to achieve adequate independent suspension of the prosthesis. Because of the lack of well developed condyles and the amount of soft tissue coverage in children, suspension of the socket was best achieved by cupping the socket in tightly over the supre-olecranon area against the

Fig. 9. The elbow is extended and the remaining tissue of the residual limb is cast.

triceps tendon with the counter pressure rected from the cubital fold area which corresponds to the string placement from the cast (Fig. 10).

With the appropriate amount of tension created, the suspension of the socket is adequate as well as comfortable for the patient. Remaining cast modifications were completed in the usual manner for myoelectric fitting—for example, distal buildup for pull tube clearance and a slight flattening of the model over the established electrode placement sites.

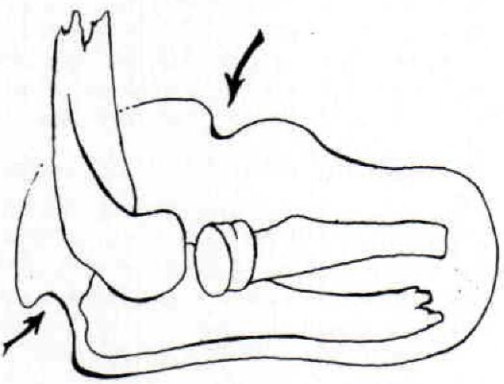

Fig. 10. Prosthetic suspension is enhanced by undercutting in the cubital fold and supra-olecranous areas.

The Definitive Socket

Flexible polyester resin was the primary choice of materials for socket fabrication. This proved to be adequate except for three cases in which allergic type skin reactions from the socket were observed. In these cases a highly inert thermoplastic was substituted (i.e., polypropylene or Surlyn®) and skin reaction diminished within 24 hours.

Once the plastic socket was fabricated a fitting took place which allowed the prosthetist to evaluate:

- Socket fit.
- Independent suspension of socket.
- Electrode placement contact against skin.
- The child's ability to operate the myoelectric controls.

Upon satisfactory accomplishment of these objectives the fabrication of the prosthesis was completed using the standard technique as recommended by Otto Bock. The only exception to this procedure is with the use of Swedish size #1 myoelectric system. With this system the interchangeable battery was used in conjunction with the Otto Bock clip receptacle (13E52=2) and the battery connection cable was replaced by #33 AWG-2 conductor retractile microphone cable (Fig. 11). The clip receptacle was attached to an elastic strap or polyethylene cuff and secured around the upper arm with the battery located posteriorly. The cable passed into the posterior proximal forearm and the terminal end connected to the Swedish hand connector. Once the cable was fed into the forearm of the prosthesis it was secured permanently in order to prevent any unwanted removal. This use of a small retractile cable in conjunction with the clip receptacle provided us with a reliable electric connection to the externally placed battery which remained intact throughout the young child's daily physical demands on the prosthesis (Fig. 12).

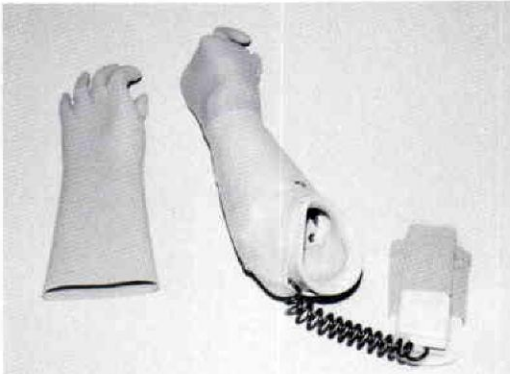

Fig. 11. When the Swedish hand was used, the Bock clip receptacle was used to hold the battery, and a retractile microphone cable replaced the battery connection cable. The battery is secured over the triceps.

TRAINING METHODS

Control Training

Controls training refers to that part of the training process when the child is learning to operate the prosthesis, but does not yet have enough skill to incorporate it into functional activities. In the early stages of

Fig. 12. The battery location for the Swedish hand provides a reliable connection for children.

Fig. 13. Control training is undertaken before the prosthesis is completed.

our study most children were seen a number of times for controls training after electrode sites were identified and before the prosthesis was completed. The socket with the electrodes in place and hand attached was used for training before the prosthesis was assembled (Fig. 13). As the staff became familiar with the procedure, it became evident that once electrode sites which met our criteria were established, further training did not lead to developing better sites. Therefore, fabrication of the prosthesis could begin immediately. Further controls training was carried out in a manner that fit the needs of the family. Children who traveled great distances and had a limited time for training were usually seen daily and controls training was begun before the finished prosthesis was available. Using the electrode-hand set up and Velcro® strap to hold the electrodes in place or the socket and electrodes if they were available, the child was encouraged to place objects in the hand while operating the controls and to complete simple tasks such as threading beads or assembling nested toys. It was important to select activities that did not require active positioning of the hand as it had to be used while lying on the table in the supinated position. When children lived in the vicinity of CAPP, weekly visits were initially scheduled for controls training using this method during the period of fabrication. However, as the study progressed it became evident that controls training could be completed in the prosthesis and the variety of activities available to the child were far greater and more motivating than those that could be used when working with the incomplete set-up. Although children who had controls training daily learned to operate the hand more precisely in the beginning, their final functional use patterns did not appear to vary from those of children who received controls training in the completed prosthesis on a less frequent basis.

Use Training

Following fitting of the prosthesis, use training was carried out in much the same manner as for a child receiving a body-powered prosthesis with an unfamiliar terminal device. Instructions in donning and removing the prosthesis and care and maintenance were provided for the parents and children by the therapist and prosthetist at the time of delivery of the limb. Pulling into the socket with a pull sock was very important, especially for the child with a short below elbow deficiency, as it was the only way to assure that the electrodes and electrode sites lined up appropriately and provided consistent feedback.

Children who had had previous experience with body-powered prostheses needed encouragement to try tasks requiring firm grip and active use of the hand above shoulder level to break up old patterns established to meet the limitations of the body-powered limb (Fig. 14 and 15). Working away from the body and without the support of a table was important for the young child or those with a very short residual limb to develop tolerance to the added weight of the myoelectric prosthesis. If the child was not accustomed to a hand type terminal device, experimenting with placing objects of different shapes and sizes in the hand was emphasized. In general, trainig tasks were selected that were appropriate to the developmental level and the interest of the specific child. Emphasis was placed on activities which

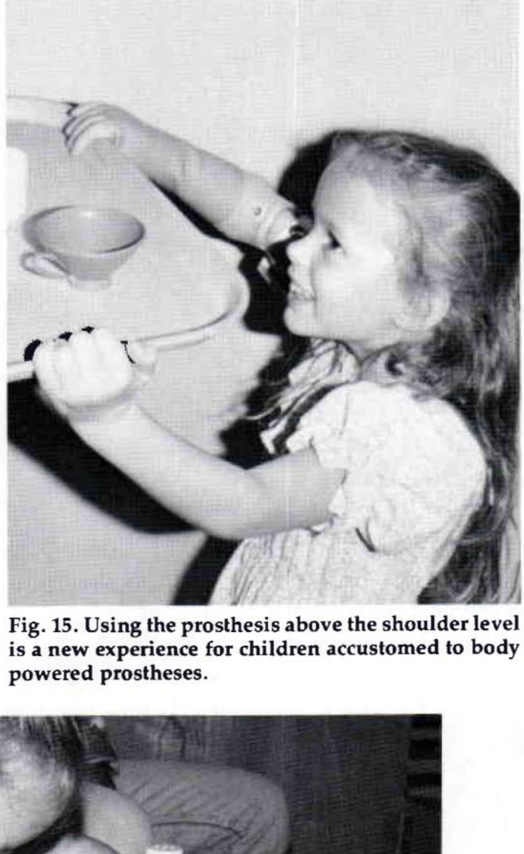

Fig. 15. Using the prosthesis above the shoulder level is a new experience for children accustomed to body powered prostheses.

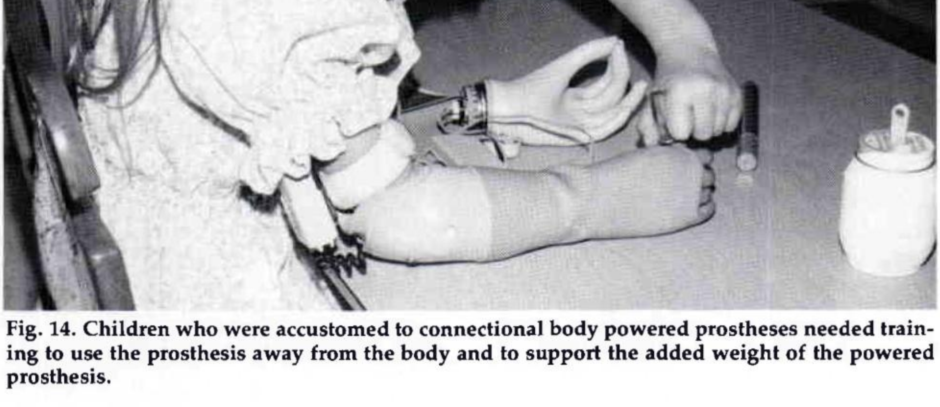

Fig. 14. Children who were accustomed to connectional body powered prostheses needed training to use the prosthesis away from the body and to support the added weight of the powered prosthesis.

required a wide variety of grasp patterns and working at varied heights and in different positions.

Although no children were sent to local facilities for controls training because of the requirements of the study, those children who had occupational therapy available in their home communities were encouraged to receive use and skills training in these facilities. It was found that therapists familiar with working with limb deficient children readily adapted their programs to working with the child with a myoelectric hand. The community therapists were invited to attend a session at CAPP at which time they received an orientation to the myoelectric hand, instructions in care and maintenance of the myoelectric prosthesis and were familiarized with the functional potential of the hand.

RESULTS

Prosthetic Maintenance Needs Unique to Myoelectric Prostheses

Data gathered on care required to maintain a well fitting and functioning prosthesis focused on three aspects of treatment. They were average life expectancy of the socket, component failures, and maintenance of the electrical parts of the prosthesis.

The average life of the socket was of particular interest because of the more intricate type of fitting required for the myoelectric prosthesis. Previous reports from England of myoelectric fittings for children suggested refitting at six month intervals in order to maintain proper fit of the prosthesis.

All of our subjects were fit using the variations of standard techniques as previously described. Eight of the patients have required at least one additional fitting since the beginning of the study. We have included these additional fittings in our report to give a more reliable figure. Based on a total of 22 fittings, the average socket life was found to be 15.4 months, the median was 14 months. Recognizing that potential and actual limb growth varies significantly among individuals it is interesting to note that the longest socket life was 30 months on a subject with a very short below elbow limb deficiency and the shortest was 8 months fit on a female with a wrist disarticulation limb deficiency.

There were few maintenance problems due to component failure during the study, and only two related to abuse or misuse of the prosthesis. In one case a child exposed her prosthesis to salt water while at the beach and the hand was destroyed. A second incident of abuse occurred when a child broke out the wrist unit and battery case of her prosthesis by using her prosthesis to serve a volley ball. There were two cases of component failure not related to abuse. One electrode and one cable proved faulty.

It should be noted that the criteria for selection of candidates related to previous maintenance history on prostheses, and willingness to restrict use of the limb in activities which may be injurious to it, automatically biases the sample away from the heavy duty prosthesis user. Only one young man participated in the study and of the eight rejected four were males. Interest in cosmetic aspects of the myoelectric fitting were also higher for females and also influenced the sample.

The connection of the clip receptacle wire in the fittings requiring an external battery was the major repair problem. We used a variety of types of wire to connect the clip receptacle to the electric hand, all of which failed at some point during the fitting. Once the retractable cable was used, a consistently reliable electric connection could be maintained. Subsequently all of the clip receptacle wires have been replaced by the retractable cable and we have had no failures to date.

A second problem developed related to battery use and charging requirements. Our initial instructions to the patients and families were to charge batteries after each use. After a period of time patients began to experience a shorter use period from each battery. Our concern led us to become better informed on the proper use of nickle-cadmium batteries requiring us to alter our instructions for proper use. Patients or parents were then instructed to fully drain batteries before charging due to the inherent "memory" properties of the rechargeable battery. These new instructions as well as recommending annual replacement of the batteries have greatly improved the reliability of this particular component.

Functional Skill Levels

Data on functional use of the myoelectric prosthesis were gathered by observation of the children while they completed the *Bimanual Functional Skills Evaluation*. Nineteen tasks which required bimanual manipulation of objects were included in the evaluation. Typical items were shoe tying, hammering nails, and jumping rope. Some of the items, such as cutting meat, were above age level for the younger children. All subjects were able to accomplish all age-appropriate tasks presented with the their myoelectric and their body-powered prosthesis when one was available.

Upon completion of the evaluation they were asked how they preferred to accomplish each of the 19 tasks. The overwhelming preference was for use of the myoelectric prosthesis. Out of a total of 209 responses to 19 different tasks, preference for the myoelectric prosthesis was indicated 112 times. The body-powered prosthesis and the myoelectric one were rated equally functional for completing tasks 66 times, and the body-powered prosthesis was indicated as preferable only five times. The subjects indicated a preference for accomplishing a task without using a prosthesis only six times out of the possible 209 responses.

Graceful arm movement and ease of operation of the myoelectric prosthesis as well as the added advantage of the stronger grip provided by the hand was observed in children using the myoelectric hand. The skillful use of "body english" and alternate grasp patterns such as holding objects against the chest rather than in the terminal device made it possible for the children to complete the tasks requiring power grip with the body-powered limb. Although functional levels were not remarkably different, the esthetic and energy saving features of the myoelectric limb were definitely observable.

Attitudes Toward Myoelectric Prostheses

Twelve children and/or their parents were interviewed by the social worker who completed the "Attitudes Toward Change In Prosthetic Fitting" questionnaire. The interview took place after the child had become reasonably proficient in operating the myoelectric limb. The major reasons given for wanting to try the myoelectric hand were cosmesis (40 percent) and freedom from the restrictions of a harness (40 percent). Curiosity in new advances or better function accounted for the remaining 20 percent. Sixty percent of the respondents felt the myoelectric prosthesis met their original expectations. Reasons most often given for the prosthesis not meeting expectations included disappointment in cosmesis and function.

The major advantages of the myoelectric hand were identified as stronger gripping power, which improved function; better cosmesis; and improved comfort and convenience because of the elimination of the harness. Major disadvantages identified were lack of durability of the glove, fear of injuring the mechanism of the hand, problems with batteries and, for the younger children, the added weight of the hand. Both parents and children were asked to identify the major problems with the myoelectric prosthesis. Heat and skin reactions to wearing the prosthesis without a sock was cited most often, added weight and mechanical breakdowns were each cited three times. Four children could not think of a major problem although their parents listed some of the above.

Wearing patterns were reviewed following the experience with the myoelectric fitting. Eleven children continued to wear their myoelectric limbs exclusively or in combination with their body-powered limbs. One child has reverted to full-time wearing of her body-powered prosthesis due to financial hardship (they moved out of the Variety Club area).

Of those wearing myoelectric limbs, eight wear them exclusively and three in combination with their body-powered limb. Three children have increased their wearing time, two slightly reduced it and five have maintained the same wearing pattern. All children combining wear of both prostheses have maintained the same wearing pattern as before myoelectric fitting. The child who had not been fit before the study maintains a part-time wearing pattern.

The children and their parents were each asked which limb they would choose if they had to make a choice. The response was in favor of the myoelectric fitting (66 percent). Reasons given by the children and their parents for choosing to wear the myoelectric limb were "I love it," "it feels more natural," "my arms are freer," "it's easier to operate," and "more cosmetic." Reasons for choosing the body-powered prosthesis were durability and cost factors.

When asked how friends reacted to the myoelectric hand the response was universally positive from both parents and children. Initial curiosity with the hand was cited often, but no negative responses were elicited.

SUMMARY AND RECOMMENDATIONS

Review of the criteria established for the selection of subjects for the study substantiated their validity. In all, 22 children were considered for the study. Eight were rejected; three because their residual limbs were too short to allow comfortable placement of the electrodes within the confines of a self suspending socket, two because they were not developmentally ready to focus on learning to operate the myoelectric hand, and two because required maintenance on their current prostheses due to hard wear indicated that the myoelectric hand would not hold up under their use pattern. One was rejected for a history of poor follow-up and maintenance of the body-powered prosthesis. Two others with poor follow-up histories were fit and failed to complete the study and are currently not wearing any prosthesis. Of the twelve who completed the study, all met each of the criteria. Since the study was completed, an additional ten subjects have been selected and fitted using the original criteria. All are currently wearing their prostheses consistently.

The results of our analysis of maintenance needs on myoelectric prostheses have allowed us to predict socket life expectancy more accurately, reduced our maintenance procedures, and improved our instructions for parents and therapists. The myoelectric fittings have required the same or fewer visits to the prosthetist for general maintenance as compared to traditional body-powered fittings. Harness adjustments and cable breakage are no longer necessary and the life of cosmetic gloves is similar to that of those worn on body-powered hands in spite of greater use of the device for prehensile skills.

The functional potential of the myoelectric hand as measured by the *Bilateral Functional Skills Evaluation* proved equal or superior to the body-powered prosthesis worn by those children who were previously fit. In no case did a child become dependent in an activity previously performed independently. Tasks which were more easily completed with the myoelectric hand were those which required power grip and working in positions above shoulder level, or with the humerus extended. Fitting of a body-powered prosthesis as well as a myoelectric prosthesis was necessary for those children who were full-time wearers and participated in activities that might be injurious to the mechanism or glove of the myoelectric hand.

The evaluation, fitting, and training techniques developed and refined during this study have become standard procedures for fitting of myoelectric limbs at CAPP. Variations in the negative impression procedure developed for congenital amputees have made it possible to fit shorter residual limbs than were previously expected. Techniques for use training developed for this study are easily taught to therapists and allow most children to receive the majority of their training in their own community.

The study of attitudes toward the myoelectric hand revealed that it is well accepted by the children and their families as substantiated by the wearing and use patterns of the subjects as well as their personal preferences for the myoelectric hand. Repeated statements that the myoelectric prosthesis feels more natural and allows more freedom of movement indicate that, to the children, the fitting appears closer to a natural limb than previous fittings.

This study has successfully established the feasibility and functional benefits of fitting children with myoelectric hands. The findings also dispell any concern that children with congenital limb deficiencies might be unable to master coordinated use of myoelectric control systems. The data most surprising to the staff was the 15.4 month average socket life, which far exceeded previous reports. The reliability and durability of the components, especially the hands, were also above expectation, considering the unique demands placed on them by children. Although considerable amounts of sand were poured out of a number of Swedish hands none failed to function well during the study. The discovery of the retractible cable was a turning point for both subjects and prosthetists. It solved the major breakdown problem which had required extra trips to the prosthetic facility for the parents and reduced wearing time for the children. Attitudes toward the prosthesis improved considerably on all counts when this problem was eliminated.

Unfortunately, children with high level and/or bilateral upper limb deficiencies, who are most in need of the potential advantages of myoelectric controls, were not served by this study. It is hoped that future research can build on the knowledge gained from myoelectric fittings and lead to development of more functional prostheses for this group of children.

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