Comparison of Myoelectric and Conventional Prostheses for Adolescent Amputees

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We questioned whether myoelectric prostheses were a reasonable alternative to conventional prostheses for adolescents with unilateral, congenital, below-elbow amputations in respect to fit, function, cosmesis, and cost. Ten patients were studied. Each received a physical, functional, and psychosocial evaluation prior to prosthetic fitting. The physical evaluation included myopotential, residual limb length and circumference, active range of motion, terminal device grasp force, and mechanical range. The functional evaluation consisted of a questionnaire of 38 bimanual activities. The psychosocial evaluation included an assessment of both the patient and the family. Following prosthesis fabrication, each patient received 10 days of training, a 3-month checkup, and a 6-month reevaluation. Wearing patterns, perception of cosmesis, change in physical attributes of the residual limb, and functional performance were documented. Results indicate that for these subjects myoelectric prostheses with a hand were an acceptable alternative to conventional prostheses with a hook.

Since myoelectric prostheses became commercially available, a number of articles have been written describing their use in the pediatric population (Baron, Clark, & Soloman, 1983; Hubbard, Galaway, & Milner, 1985; Shaperman & Sumida, 1980; Sorbye, 1977, 1978, 1980).

One paper (Stein & Walley, 1983) described conventional and myoelectric prosthesis function in a mixed group of persons 9 to 69 years old with above- and below-elbow amputations. The comparison included number of standard tasks performed, number of tasks performed on an activities-of-daily-living (ADL) assessment, wearing time, speed of performance, and measurement of active range of motion.

The goal of our study was to compare myoelectric and conventional prosthetic function in a homogeneous adolescent patient population. In undertaking this project, we understood we were comparing the function of a hook prosthesis with the function of a myoelectrically powered hand. The hook terminal device is functionally far superior to the conventional hand prosthesis, but the myoelectrically controlled hand appears to more closely approximate the functional potential of a hook. We feel a more critical comparison is made if the hook terminal device rather than a conventional hand prosthesis is used as the basis for the comparison.

Four variables were studied:

1. Fit, which included elbow range of motion, effect of changing from harness suspension to self-suspension, effect of change to intimately fitting socket, and effect of use on growth when forearm musculature is used for operating the myoelectric system
2. Function, which included grasp force, wearing time, and number and quality of performance of ADL tasks with each prosthesis
3. Cosmesis, which included subjective responses and acceptance of each type of terminal device
4. Maintenance, which included repairs or replacements, time required, and cost

Method

Nineteen candidates, who were congenital, unilateral, below-elbow amputees, were screened for inclusion in the study that took place at Shriners Hospital for Crippled Children, Philadelphia Unit. Screening was done by an occupational therapist, a prosthetist, and a social worker. The occupational therapist evaluated conventional prosthetic fit and measured active range of motion of the shoulder, elbow, and residual forearm with and without the prosthesis. To assess skill, mechanical and active range of hook opening was measured in various planes, including behind the...
back, behind the head, close to the mouth, and with 90° elbow flexion. Grasp force was measured in kilograms. During the screening process, patients were asked whether they performed a number of bimanual activities (e.g., tying shoes, cutting paper, etc.) with their conventional prosthesis. All candidates were tested for myoelectric potential.

To assess the growth of the residual forearm, the prosthetist measured the length of the limb from the olecranon process to the distal end and the circumference at the cubital fold, at the midpoint on the residual forearm and at the distal end. He evaluated prosthetic history, including a description of the current prosthesis, wearing time, age at first fitting, and maintenance record. The candidate was also asked to list specific activities with which he or she would like to use a prosthesis.

The social worker interviewed each candidate and his or her family, covering demographics, psychosocial assessment and history, and a subjective report on attitude. The data collected included a subjective report of prosthetic function, cosmesis, comfort, and problems as well as the reactions of friends, family, and the public. Objective observations included demonstrated affect, school performance, peer interaction, physical appearance, and level of psychosocial development.

Study criteria included length of residual limb, myoelectric potential, and psychosocial assessment of both the family and the candidate. Ten candidates ranging in age from 12 to 18 years were selected as subjects. Their other characteristics are listed in Table 1. Reasons for nonselection included residual limbs that were too short to allow for electrodes to be placed inside the socket, family instability, and a history of abusing prosthetics and excessive maintenance requirements.

The subjects were measured for a myoelectric below-elbow prosthesis with a flexible, custom-molded, self-suspending socket; an Otto Bock 6V electric hand with a three-jaw grasp; and a cosmetic glove. Nine subjects were given two dual-site, single-channel electrodes; 1 received one single-site, dual-channel electrode. All 10 subjects received trial fittings of the prosthesis to verify the length of the prosthesis, socket fit, electrode site, and alignment. They were then admitted to the hospital for 10 days of training in the use of their myoelectric prosthesis.

At 3 months, the subjects returned to the Shriners clinic for follow-up and maintenance checks. At 6 months they received a complete reevaluation, which included the screening tests and the Bimanual Functional Assessment (see Table 2). This evaluation tool was developed for the study and consisted of a list of 38 bimanual activities grouped into 6 ADL categories. Subjects were asked to rate their performance for each activity with the conventional prosthesis and 6 months later, with the myoelectric prosthesis. Performance was then scored from 0 to 2. A zero indicated unilateral performance of the activity with the patient using the sound limb or the sound limb and mouth, legs, etc.; a score of 1 indicated bilateral performance, including the prosthesis, with assistance from another person; and a score of 2 indicated independent bilateral performance. The numerical data were summed to provide an assessment of change between the reports of the use of conventional prosthetics and the use of myoelectric prosthetics. These numbers were converted to percentages (see Table 2). Subjects and families were not given conventional prosthetic usage data prior to reporting myoelectric performance.

**Table 1**

| Subjects' Sex and Level and Side of Amputation (N = 10) |
|---|---|---|
| Sex | Level | Side |
| M | WD | L |
| M | WD | R |
| M | BE | L |
| F | BE | L |
| M | WD | L |
| M | BE | R |
| F | BE | L |
| F | BE | L |
| M | BE | R |

Notes: WD = wrist disarticulation. BE = below elbow.
Table 2
Bimanual Functional Assessment

Dressing—Increased 61.7%
1. Grasp shoelace and tie
2. On long-sleeved shirt or blouse, unbutton cuff on sound side
3. Grasp and pull coat on and off hanger
4. Grasp shirt sleeve and remove from sound side
5. Grasp and pull up socks using two hands
6. Grasp clothing while zipping zipper
7. Grasp and pull up trousers or skirt using two hands
8. Grasp and pull on gloves on sound side

Hygiene—Increased 50%
9. Grasp toothbrush and apply paste
10. Grasp nail file and file nail on nonprosthetic hand
11. Paint fingernails on prosthetic hand

Eating—Increased 51.85%
12. Cut meat with knife and fork
13. Hold glass and pour liquid into it
14. Grasp milk container or soda can and open
15. Grasp bread while buttering
16. Unwrap candy bar using both hands
17. Grasp orange and peel it

Tasks About the Home—Increased 55.77%
18. Hold dish while drying with towel
19. Grasp telephone and dial
20. Open screw-top bottle while holding bottle with one hand
21. Thread needle
22. Remove bills from wallet

School/Work Activities—Increased 79.48%
23. Draw a line using a ruler
24. Grasp and carry paper with terminal device
25. Hold paper while cutting with scissors
26. Sharpen pencil
27. Pull off top from pen
28. Carry lunch with terminal device
29. Hold paper/book/eraser while writing on blackboard
30. Steady paper and write
31. Hold book while turning pages

Play Activities—Increased 70.58%
32. Grasp and put together toys (models etc.)
33. Grasp bicycle handles
34. Grasp musical instrument
35. Grasp playing cards while discarding a card
36. Support camera and take photographs
37. Put records on phonograph
38. Use when driving

Note. Percentages reflect the accumulated effect of the switch from conventional hook prostheses to myoelectric hand prostheses on these activities.

residual limb occurs because of the intimate fit of the socket (Weiss, Middleton, Gonzalez, & Lovelace, 1983). Provisions were made in the socket with regard to electrode and skin contact, and growth measurements were taken to anticipate socket changes. Our findings tend to support the second theory that there is limited growth of the residual limb within the intimately fitted prosthesis. After 6 months of myoelectric use, the subjects' sound side consistently increased in girth at all measurements whereas the residual limb increased, at the most, 43% of the rate of the sound side. The residual limb showed a reduction in size at the distal end of the residual limb, which would have accommodated any growth in length (see Table 3). This area of muscle development with myoelectric prosthesis requires further investigation.

Function. The subjects' grasp force increased with the myoelectric prosthesis. The myoelectric hand provided an average of 7.5 kg of pinch whereas the conventional voluntary terminal device yielded an average of 1.06 kg of pinch. This finding was substantiated by subjective comments from the subjects, who felt that they were able to hold items more securely with their myoelectric prostheses.

For all subjects the average wearing time with the conventional prosthesis prior to the investigation was 9.5 hours per day. After being fitted with the myoelectric prosthesis, the subjects' average wearing time was 10.4 hours per day. Thus, there was no major change in wearing time. Of the 8 subjects who had previously worn a prosthesis, 7 began to wear their myoelectric prosthesis exclusively. One subject continued to wear his conventional prosthesis, dividing his day between 6 hours of myoelectric prosthesis wearing time and 6 hours of conventional prosthesis wearing time. This subject was also the youngest and physically smallest

Table 3
Growth Discrepancies Between Residual Limb and Sound Limb

<table>
<thead>
<tr>
<th>Measure</th>
<th>Average residual limb change</th>
<th>Average sound side change</th>
<th>RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average residual limb length</td>
<td>0.55 cm</td>
<td>0.80 cm</td>
<td>0.69</td>
</tr>
<tr>
<td>Average residual limb proximal circumference</td>
<td>$-0.23$ cm</td>
<td>$0.58$ cm</td>
<td>$-0.40$</td>
</tr>
<tr>
<td>Average residual limb midlimb circumference</td>
<td>$0.06$ cm</td>
<td>$0.14$ cm</td>
<td>$0.43$</td>
</tr>
<tr>
<td>Average residual limb distal circumference</td>
<td>$-0.20$ cm</td>
<td>$0.16$ cm</td>
<td>$-1.25$</td>
</tr>
</tbody>
</table>

* The residual limb grew at 69% of the rate of the sound side. The residual limb showed a reduction in size compared with the initial measurements. The residual limb grew at 43% of the rate of the sound side at this level. The residual limb showed a reduction in size compared with the initial measurements.
of the 10 and needed to use a nonswitchable hand, that is, a hand that couldn't be turned off during the day when it was not in use. The 2 subjects who previously had not worn a prosthesis changed to wearing their myoelectric prosthesis 6 hours per day.

Summing all items from the Bimanual Functional Assessment, we found an overall increase of 65.65% in the use of the myoelectric over the conventional prosthesis for functional tasks (for specifics refer to Table 2).

A greater number of bilateral tasks were performed with the myoelectric prosthesis than with the conventional prosthesis. Of the 8 subjects, 3 reported increased difficulty in performing nine tasks (e.g., cutting meat with a knife and fork and grasping the shirt sleeve with the myoelectric prosthesis when removing it from the sound side). Three subjects reported decreased difficulty in performing 25 tasks with the myoelectric prosthesis, including holding a musical instrument such as a trumpet or French horn, grasping clothing while opening or closing a zipper, putting on a glove on the sound side, grasping a milk container or a soda can to open, opening a screw-top bottle, and carrying a lunch box with the terminal device. Two subjects reported neither an increase nor a decrease in task difficulty with the conversion. Overall patterns suggested an increase in the use of the prosthesis for functional tasks, an increase in bilateral task performance, and some decrease in task difficulty with the myoelectric prosthesis.

Cosmesis. Function and fit are crucial factors in determining the successful use of a prosthesis, but cosmesis is just as vital. Cosmesis translates into wearer acceptance and becomes even more important when the wearer is an adolescent. We believed that the myoelectric prosthesis might enhance self-esteem and be perceived by the wearers to be a cosmetically positive alternative to the conventional hook. We took into account not only the subject's physical disability and the mechanical properties of the terminal device but also the whole person. Self-perception, family attitudes, and the interaction between the two were considered. Emphasis was placed on the user's self-concept, view of his or her world, social functioning, and family attitude.

Congenital absence of a hand or arm causes many functional impairments in social interactions, communication, and manual dexterity. Hands are an important mode of interaction with the environment. Exploration, mastery of tasks, and independence may be impeded by the absence of a hand. The development of a sense of achievement, which is so important for a positive self-concept may be thwarted. In addition, hands are an important part of nonverbal communication. Absence of one may alter communication.

Eight of the 10 subjects liked the myoelectric prosthesis. The 2 older girls increased their use of jewelry, nail polish, makeup, and clothing, moving toward more colorful and eye-catching styles. They saw themselves as feminine and successful. The youngest girl began to be interested in these age-appropriate behaviors. Of the 5 boys who accepted and liked the myoelectric prosthesis, one who had previously expressed feelings of worthlessness, had been having significant problems in school, and had not been doing well with friends, improved his school performance and acquired several friends. He also appeared brighter; his parents reported him less sulky. Another boy gained some independence from his parents and attended school dances and ski trips; a third boy continued to play his trumpet and went on a public speaking circuit. Another young man, who was fairly well adjusted, began dating during the 6-month evaluation period. He took up roller skating and made some vocational decisions. The last and oldest myoelectric user began attending college, working two jobs, and became active in sports. Without exception, these young people did well. Of the 2 subjects who were not happy with the myoelectric prosthesis, one was pressured by her family to participate in the project and the other objected to the difference in the color of the glove and the skin. It should be stressed that without a control group, it is not possible to attribute these changes in behavior the fact that the subjects were wearing a myoelectric prosthesis.

Maintenance. Although the subjects took good care of the gloves, the gloves were the most frequently replaced items for many reasons, including the occurrence of stains and the change of natural skin tone with the seasons (i.e., tanning of nonprosthetic body parts). Every subject required at least one glove change in the 6-month study period, and 8 required more than one. A problem encountered with the large, size 8 Otto Bock hands was that the short gauntlet of the glove was felt by many of the subjects to be uncosmetic. We corrected this problem by using a glove from a conventional body-powered hand with a longer gauntlet. Other repairs were spread out over several parts of the system, but some items such as rubber retainer rings from floating electrodes and batteries were frequent problems (see Table 4). It should be noted, however, that most manufacturers or distributors of myoelectric parts cover these components under a 1-year warranty.

Discussion
From this study of 10 subjects we found that myoelectric prostheses provided an intimate fit, freedom from harnessing, and increased pinch whereas conventional hook prostheses allowed more active range of motion of the elbow and forearm of the residual limb.
and were lighter. For those who had previously used a conventional prosthesis, there was minimal change in average wearing time with a myoelectric prosthesis. It appears that because of the increase in bimanual tasks, decrease in unilateral tasks, and general decrease in task difficulty, the myoelectric prosthesis provides an increase in functional use without a large increase in wearing time. We noted that the majority of tasks on the Bimanual Functional Assessment either scored 0 or 2. These results indicate that subjects performed the task either independently or bilaterally using the sound extremity or bilaterally using the prosthetic hand. However, none of the subjects received functional training with their conventional prosthesis, yet they did receive functional training with their myoelectric prosthesis. Even though this training was not task specific for items on the Bimanual Functional Assessment, it may have influenced functional scores by making subjects aware that they should use their prosthesis even if they actually didn’t. A pre- and postassessment by means of the Bimanual Functional Assessment with the subjects not knowing that they were being observed would have provided a better measure of actual change in the use of prostheses. However, when asked why there was a change in functional use, subjects commented on the combination of cylindrical grasp and increased force provided by the myoelectric prosthesis.

Eight of the 10 adolescents in the study felt that the myoelectric prosthesis made them look better and feel more like other people. After getting the myoelectric prosthesis, many of them engaged in new social and academic activities. This increase in social function was accompanied by an apparent increase in self-esteem, which seemed to be related to the introduction and use of the myoelectric prosthesis. These changes positively reinforced the use of the myoelectric prosthesis in the wearers and resulted in their accepting the device. Again, there was no control group for comparison.

Perhaps most important of all is the fact that these adolescent subjects preferred the myoelectric prosthesis with a hand over the conventional, body-powered limb with a hook. We recognize that our comparison involved both the change from body power to myoelectric power and from hook to hand. These variables need to be separated and studied individually. Although the initial cost of a myoelectric prosthesis is high ($6,500 vs. $1,800), we concluded that the myoelectric below-elbow prosthesis with a hand, because of the way it was received and used, became an important alternative to the conventional body-powered prosthesis with a hook for the adolescent congenital, unilateral, below-elbow amputees in our clinic. The individuals in our study were carefully selected, and we do not suggest that our results can be generalized to all adolescent unilateral, below-elbow amputees. More investigation is needed to define the guidelines for the selection of patients by clinic teams.

Acknowledgments
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References

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Table 4  
Problems Occurring With Myoelectric Prostheses

<table>
<thead>
<tr>
<th>Item</th>
<th>Description of Problem</th>
<th>Frequency of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glove</td>
<td>Torn glove</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Stains or change in skin tone</td>
<td></td>
</tr>
<tr>
<td>Hand</td>
<td>Bent thumb</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Broken clutch gear</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bad switch to demonstration hand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hand sheel not allowing full opening</td>
<td></td>
</tr>
<tr>
<td>Electrodes</td>
<td>Retainer rings on electrodes broken</td>
<td>4</td>
</tr>
<tr>
<td>Cables</td>
<td>Cable broken after fall</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Cables broke while socket was removed from forearm</td>
<td></td>
</tr>
<tr>
<td>Socket</td>
<td>Socket loose after 1 week</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Socket too tight, difficult to don</td>
<td></td>
</tr>
<tr>
<td>Wrist</td>
<td>Wrist unit not connected fully—poor signal transmission</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Wrist unit jammed—unable to connect hand to wrist</td>
<td></td>
</tr>
<tr>
<td>Batteries</td>
<td>Bad battery</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Bad charger</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blown fuse in battery</td>
<td></td>
</tr>
</tbody>
</table>

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