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The Toledo Tenodesis Prosthesis—A Case History Utilizing a New Concept in Prosthetics for the Partial Hand Amputee

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Occasionally in orthotics and prosthetics we are faced with a challenging case that falls into the "orphan" category. These cases usually are lacking in the research and development area only because of the infrequency of their occurrence in the field.

One such category that falls short in research and development is the partial hand prosthesis. A prosthetist evaluating a patient who exhibits, for example, a transmetacarpal amputation has only a few avenues available because of the lack of data and material in this area (Figure 1). The current terminal hand devices are intended for use in conjunction with a wrist unit attached to the distal end of the socket that utilizes physiological shoulder excursion as a power source.

When the current prosthetic procedures are applied to the above-mentioned anomaly, certain cosmetic and physiological drawbacks become apparent. One such drawback pertains to the surplus length that is exhibited. The surplus length is due to the lack of room for the wrist unit at the end of the socket that contains the terminal device. The span of the prosthesis compared to the sound extremity produces a disproportioned, elongated appearance. Amputation at the wrist would ameliorate the distorted look, but usually the amputee is recalcitrant to the idea. Physiologically, the surplus length tends to inhibit potential proprioceptive sensations by limiting the operator's ability to accurately perceive environmental placement of the prosthesis. By eliciting proprioceptive sensations, the prosthesis serves as an artificial extension of the operator, a part of the functioning person.

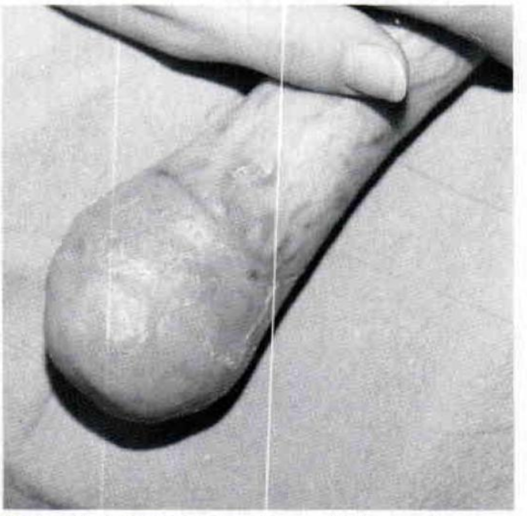


Figure 1. Transmetacarpal amputation, palmar aspect.

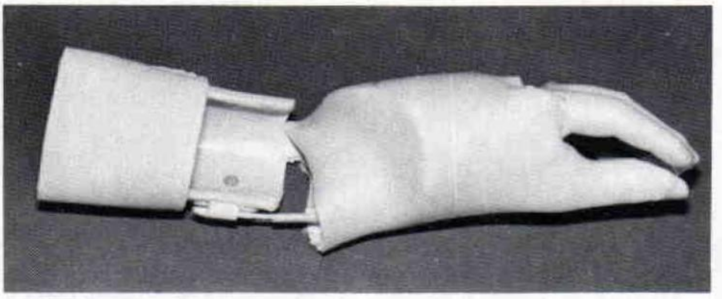


Figure 2. T.T.P. exhibiting wrist extension resulting in passive flexion of the fingers.

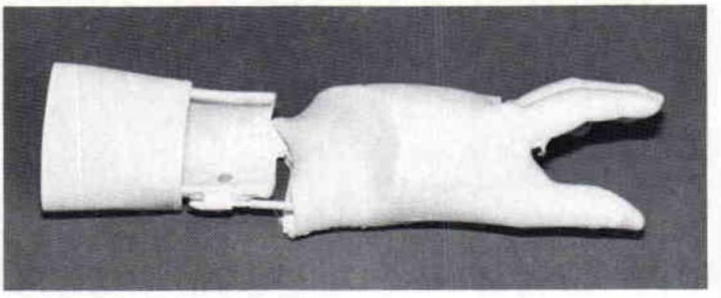


Figure 3. T.T.P. exhibiting wrist flexion resulting in passive extension of the fingers.

A second drawback to the use of traditional terminal devices on a partial hand is the need to utilize and isolate physiological shoulder movements as a source of power. During the process of conducting this research project, it became apparent that an alternate physiological power source had been overlooked, namely wrist motion.

The concept of utilizing physiological wrist action to power hand devices is not a novel concept. Orthotic devices such as the Engen or RIC tenodesis splints depend entirely on wrist extension to power the devices. Since the partial hand amputee still retains anatomical and physiological characteristics of the wrist, theoretically through the proper design and development of a prosthetic mechanism, physiological wrist generated output forces could be utilized to serve as an alternate power source.

The following article on the Toledo Tenodesis Prosthesis is the result of a recent research and development project conducted by the authors. The purpose for writing this paper is to educate and expand on the methodology techniques used to fabricate this prosthesis, and also to share the gratifying results we obtained.

OBJECTIVES

The objectives of this research project were to design and develop a functional and cosmetic partial hand prosthesis that utilized available sensory and motor capabilities of the transphalangeal/transmetacarpal amputee. The functional prostheses usually prescribed for this level of amputation are geared toward adequate prehension capabilities, but deficient in both aesthetic qualities and the ability to maximize available physiological wrist sensory and motor response. The need for a partial hand prosthesis that displayed function, cosmesis, and utilization of physiological proprioceptive wrist responses motivated this research and development project.

DESCRIPTION

In order to describe the Toledo Tenodesis Prosthesis (TTP) we must first review the term "tenodesis action." Tenodesis action is a method by which prehension of the three forefingers—index, middle, and thumb—is achieved through active wrist extension.

The TTP is designed so that active wrist extension results in passive flexion of the artificial fingers (Figure 2). The index and middle fingers are brought into opposition with the thumb, producing a three jaw chuck prehensive grasp. Once the object has been grasped, release is accomplished simply by flexing the wrist (Figure 3), which results in passive extension of the artificial fingers. These reciprocal actions are accomplished by two articulations, the wrist and metacarpophalangeal joints interconnected by means of a linkage cable. By connecting the wrist and MP's reciprocally, motion occurring at the wrist in the form of flexion or extension is directly proportional to the motion seen at the artificial fingers. This linkage connection also serves as an interface providing the user with valuable pressure-sensory proprioceptive feedback information.

PRESSURE-SENSORY PROPRIOCEPTIVE FEEDBACK

Pressure-sensory proprioceptive feedback pertains to the concept of providing a limb-prosthesis interface through which information regarding applied prehensive pressure to an object by the artificial fingers is transmitted to the physiological power source. It is the author's opinion that the proportionate kinetics the TTP inherits functions as an interface between the prosthesis and residual limb. The direct mechanical linkage between the input (wrist flexion-extension) and the output (finger flexion-extension) provides a significant amount of feedback information directly relating to the applied prehensive pressures on an object. By coupling the residual wrist motion to the prosthetic fingers, the position and movement of the fingers are at all times directly proportional to the position and movement of the wrist. This direct coupling of the physiological wrist joint with the prosthetic finger joint results in the communication of pressure sensory information to the user. The effectiveness of pressure sensory proprioceptive feedback when applied to the TTP is in a large part determined by the ability of the user to assess the information transmitted to the proprioceptors of the wrist.

Figure 4. N.W. displaying significant upper extremity limitations.

CASE HISTORY

N.W., a three year-old female, suffered third degree burns over 80 percent of her body as a result of a house fire approximately one year prior to fitting. Injuries from the burns necessitated amputation of all digits bilaterally at the metacarpophalangeal level (Figure 4). Upon initial contact, significant upper extremity limitations were noted in wrist and elbow motions with the following active range of motion:

	left	right
elbow flexion	10–15°	0–120°
elbow extension	−10°	normal
forearm supination	0–45°	0–80°
forearm pronation	0–90°	0–90°
wrist flexion	0°	0–25°
wrist extension	0–45°	0–50°
ulnar deviation	0°	0–5°
radial deviation	0–5°	0–5°

Shoulder range of motion was within normal limits bilaterally. Medical history over the past year included multiple skin grafts, and removal of the posterior muscle compartments of both legs and one lower extremity artery—eighteen surgical procedures in all.

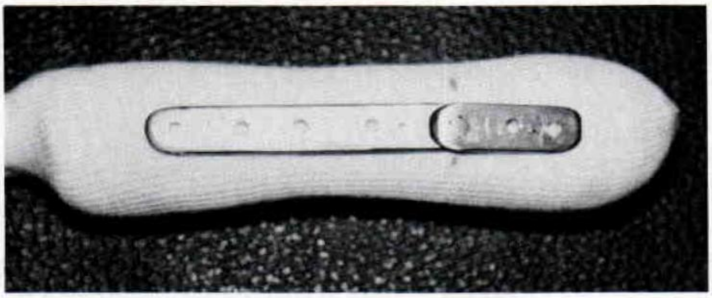


Figure 5. Hinged wrist joint attached to the ulnar aspect of cast prior to lamination of socket-forearm shell.

METHODOLOGY

1) Jointed Socket Design

The design of the TTP begins with the fabrication of a jointed laminated prosthetic socket and forearm shell. The prosthetic socket and forearm shell are connected by a hinged wrist joint that is laminated into the ulnar side (Figure 5). This wrist articulation permits free flexion and extension to occur between the socket and shell. The mechanical wrist joint is aligned anatomically in order to prevent excessive pistoning action. Once the lamination process is complete, the bulbous end of the socket is trimmed to allow ease of donning and doffing of the prosthesis. The trim line of the socket begins just distal to the wrist joint on the ulnar aspect and proceeds in a transverse oblique manner to the apex of the thenar eminence (Figure 6). The extended socket on the ulnar side serves as part of the suspension system that will be discussed later. The forearm shell trim lines extend across the arm for approximately two-thirds the circumference.

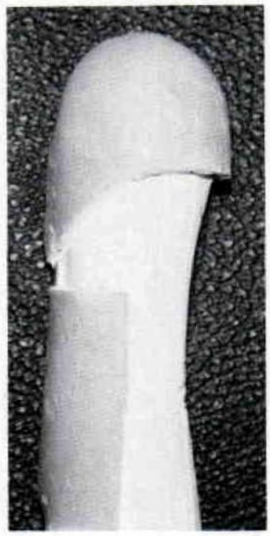


Figure 6. Trim lines of the socket begin distal to the wrist joint and extend in a transverse-oblique manner to the apex of the thenar eminence.

2) Modified Passive Hand/ Finger Module

Fabrication of the finger module first requires obtaining the proper sized passive hand. The passive hand is used to fabricate a rigid facsimile that will later be attached to the prosthetic socket. Before the facsimile is fabricated, the thumb on the passive hand requires an alignment modification to facilitate future opposition. This requires the amputation and reattachment of the thumb to the passive hand.

The thumb is amputated across the thenar eminence continuing to the palmar surface across the third metacarpal (Figure 7). The thumb is reattached with putty, aligning it directly beneath the second and third ray (Figure 8). The modified passive hand is then encased in an algenate mold. The modified passive hand is then extracted and plastic is poured into the mold.

When the plastic is hard, the rigid modified passive hand (Figure 9) is prepared for attachment to the socket. Attachment requires first removing and contouring the excess plastic in the palmar area in order to correctly position the hand on the socket (Figures 10 & 11). The hand unit is then attached with plastic and later sanded smooth (Figure 12).

3) Metacarpal-phalangeal articulation

The fingers are amputated just proximal to the M-P joints (Figures 13 & 14). The future articulation site for the finger module is then contoured to accept the appendages (Figure 15). The excess plastic should be removed down to the end of the socket. The attachment of the finger module to the socket requires drilling a $^{3}/_{16}$ inch hole through the M-P joint of the finger unit in a transverse manner (Figure 16). An equiva-

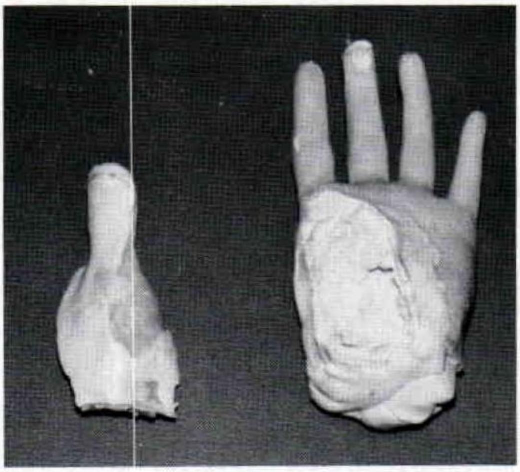


Figure 7. Thumb of the passive hand is amputated to allow for the necessary alignment modifications.

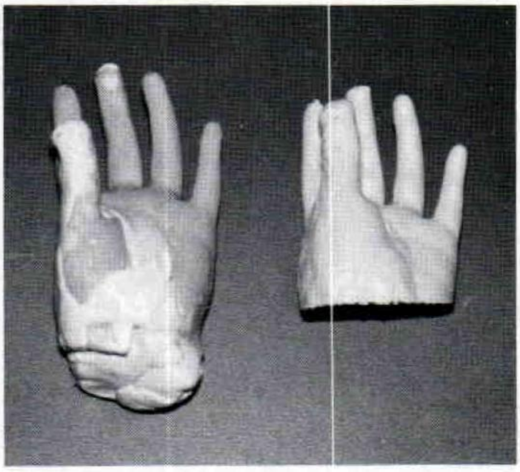


Figure 8. Thumb is reattached with putty and aligned directly beneath the index and middle fingers. Modified passive hand is then cast in an alginate mold required to fabricate the rigid facsimile.

Figure 9. Rigid modified passive hand is prepared for attachment to the socket.

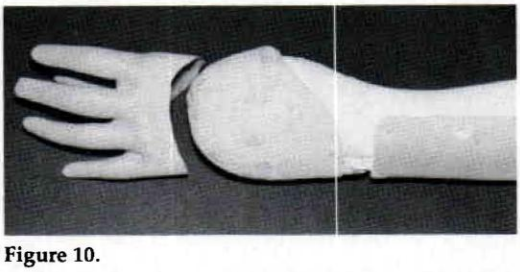


Figure 10.

Figure 11.

Figures 10 and 11. Attachment requires first removing and contouring the plastic in the carpal regions.

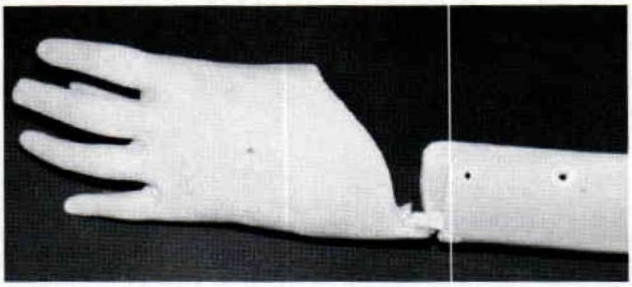
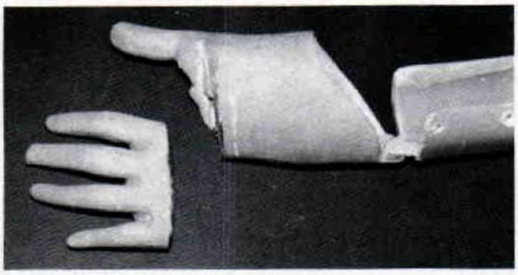


Figure 12. Hand unit is attached with plastic to the socket and sanded smooth.



Figures 13 and 14. A guide line is drawn transversely proximal to the M-P joints. The fingers are then amputated at this site.

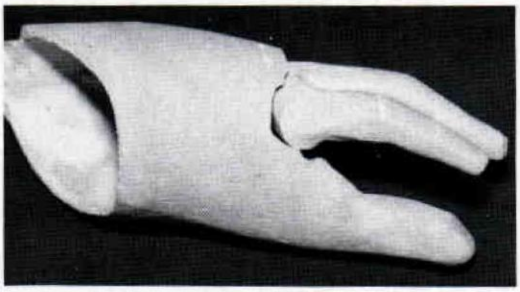


Figure 15. The rough M-P's of the finger unit are rounded smooth. The socket is then ground in a concave manner to accept the finger unit.

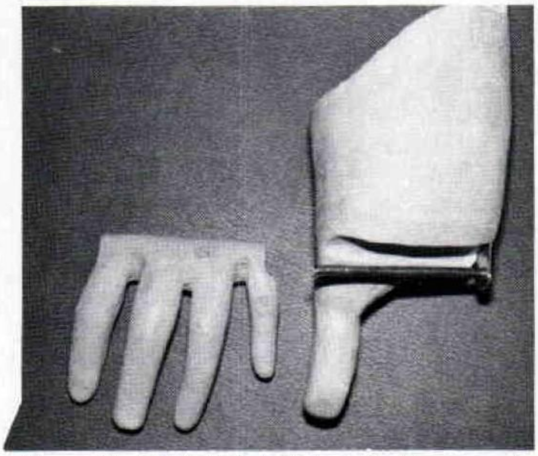


Figure 16. A 3/16 inch hole is drilled transversely through the M-P's of the finger unit to facilitate the drill rod articulation.

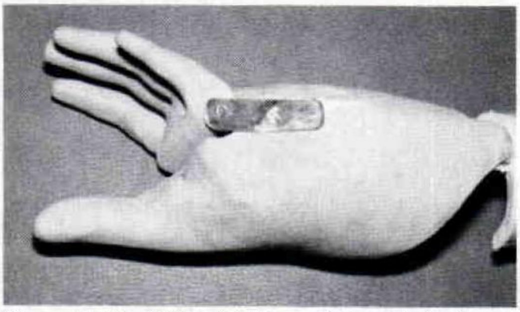


Figure 17. The drill rod is inserted through the finger unit and attached to the prosthetic shell by a stainless steel bracket. This articulation should pivot freely.

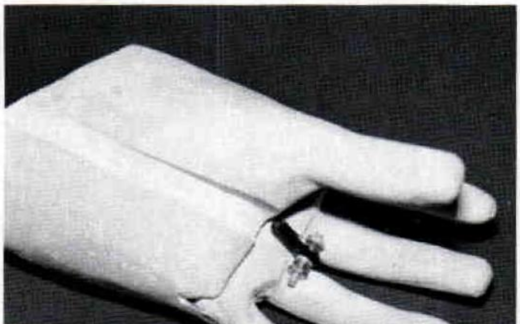


Figure 18. The pivot joint is prepared for attachment to the finger unit.

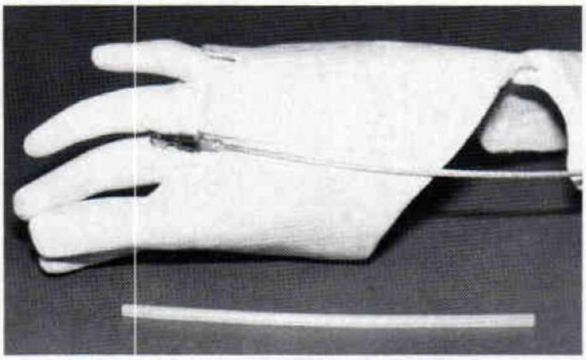


Figure 19. The linkage cable is attached to the pivot joint.

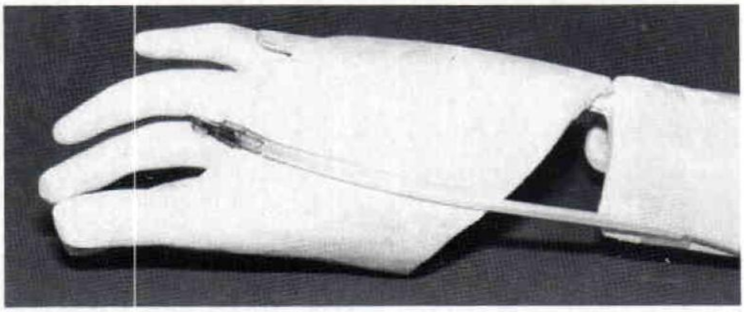


Figure 20. A protective sleeve slides over the linkage cable.

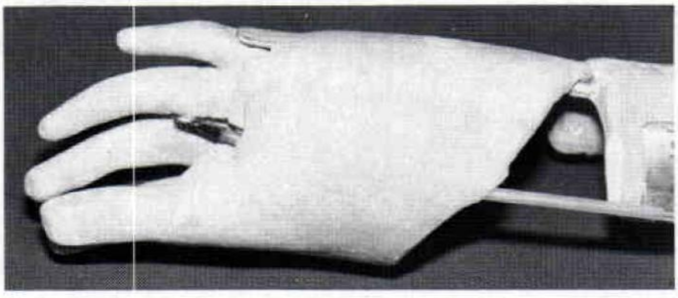


Figure 21. The linkage cable and protective sleeve are laminated into the palmar aspect of the socket.

lent sized drill rod is inserted through the finger unit and attached to the prosthetic shell by means of a stainless steel bracket (Figure 17). The MP articulation should pivot freely on the drill rod.

4) Linkage cable

The distal end of the linkage cable attaches to a pivot joint that is laminated into the finger unit (Figures 18 & 19). The pivot joint attaches at the I-P's of the third and fourth rays. A protective sleeve then encases the cable (Figure 20) and is laminated into the palmar aspect of the socket (Figure 21). The proximal end of the cable is attached to the forearm shell by means of a clamp assembly (Figure 22). The clamp assembly provides the prosthetist with an adjustment for regulating prehension characteristics. Adjusting the length of the cable regulates the prehension characteristics of the fingers and the range of motion at the wrist.

5) Cosmetic glove

The cosmetic glove as designed for a passive hand requires some modifications when applied to the TTP. The intrinsic qualities of the glove are too restrictive to allow freedom of flexion and extension of the fingers at the M-P joint. The remedy for this requires severing the glove transversely at the M-P joints (Figures 23 & 24). Although some of the aesthetics are lost in this procedure, it is necessary to obtain optimal function.

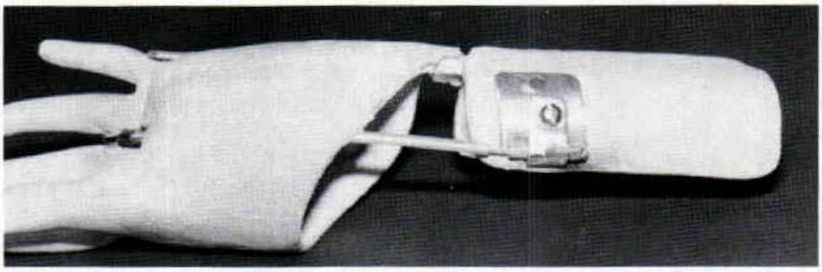


Figure 22. The proximal end of the cable is attached to an adjustable clamp assembly. This permits regulation of the prehensive characteristics by varying the length of cable.

Figure 23.

Figures 23 and 24. The cosmetic glove is severed transversely at the M-P's to allow free flexion and extension at the finger unit.

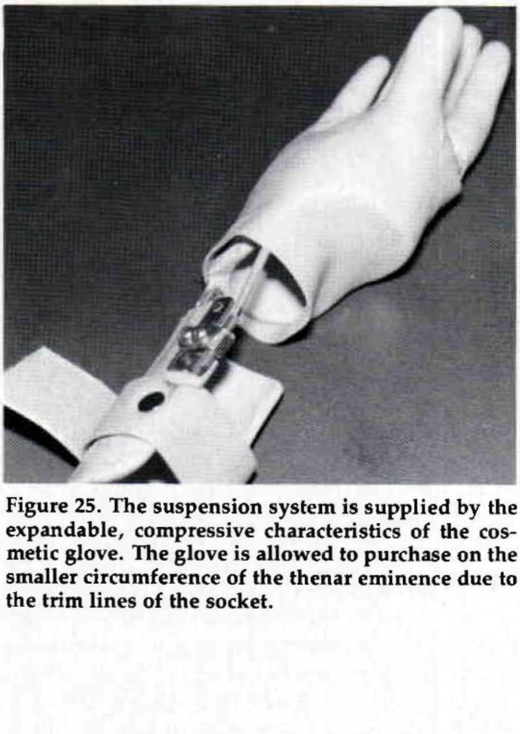


Figure 25. The suspension system is supplied by the expandable, compressive characteristics of the cosmetic glove. The glove is allowed to purchase on the smaller circumference of the thenar eminence due to the trim lines of the socket.

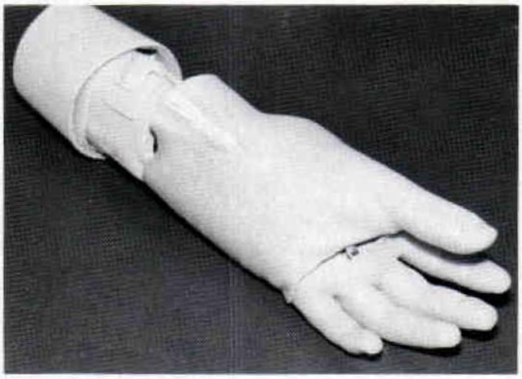


Figure 24.

SUSPENSION SYSTEM

The suspension system of the TTP is supplied by the compressive forces of the cosmetic glove on the thenar eminence (Figure 25). Reviewing the trim lines of the socket, plastic is removed beginning at the wrist joint and proceeding in a transverse oblique manner to the apex of the thenar eminence. This allows the cosmetic glove to purchase on the smaller circumference of the eminence, thus resisting migration of the prosthesis.

TREATMENT

Treatment consisted of nine occupational therapy sessions with the following purposes:

1. prosthetic evaluation
2. initial orientation and training in the use of the TTP
3. incorporation of the TTP into play, self-care, and developmental activities
4. family education

Initial activities were structured to deliver maximum positive reinforcement. Operation of the TTP was learned quickly during the initial session, and treatment proceeded to incorporating use of the TTP into age-appropriate activities. Prehension patterns consisted of three-jaw chuck and cylindrical grasp with which N.W. was able to perform the following types of activities: picking up various objects ranging in size from ¼" to 1½" width (Figure 26), releasing objects into her mouth or containers (Figure 27), stacking ½" and 1" cubes (Figure 28), pouring water from a small pitcher, using a toothbrush, hairbrush, and fork (Figures 29 & 30), scribbling with crayons, holding onto tricycle or rocking horse handles, pulling the ring of a "See 'n' Say," and banging a xylophone with a mallet. Initial focus was unilateral skill building with the less-involved right hand; the left hand served primarily an assistive role in bilateral activities (Figures 31 & 32), and is expected to develop with continued therapy.

The family was instructed in the use and operation of the TTP, care of the device, wearing schedule, appropriate home activities, and the need for continued therapeutic services.

Figure 26. Picking up variously-shaped objects ranging in size from ¼" to 1½" widths.

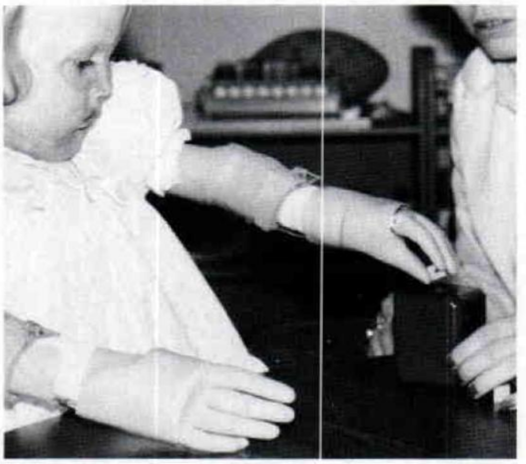
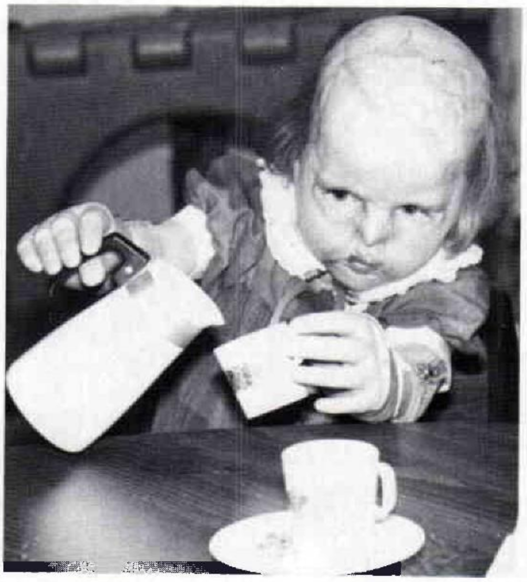


Figure 27. Development of controlled release of objects into containers.

Figure 28. Development of proprioceptive placement of objects.

Figure 29. Development of self-care activities with emphasis on maintenance of grasp outside field of vision.

Figure 30. The use of cylindrical grasp on feeding utensils.



Figures 31 and 32. Development of bilateral activities emphasizing proprioceptive placement skills.

DISCUSSION

N.W.'s rapid acceptance of both prostheses does tribute to the cosmesis, ease of function, and the proprioceptive awareness of the devices. Utilization of available muscle power, relying on a natural body motion, is a definitive advantage of this device over other prosthetic systems which necessitate the teaching of a complex set of shoulder girdle maneuvers, for example. The lack of any such harnessing also minimizes certain aspects of fitting/operational difficulties, such as abrasion.

As with any prototype, research continues to be a need if the TTP is to evolve into a cost effective, componentialized, readily available alternative to traditionally promoted solutions, such as hooks and surgical procedures. Further research and development is under way in the following areas:

1. The flexibility of the cosmetic glove, which needs to be improved to allow a more cosmetic appearance (without a "break" at the points of articulation) and unrestricted motion.
2. Adjustments in the selection of hardware and resins, to improve cosmesis and reduce weight.
3. Exploration of alternate suspension systems.
4. Componentialization of parts.*

ACKNOWLEDGMENTS

We would like to express our appreciation to those individuals who contributed to the development of the Toledo Tenodesis Prosthesis, particularly Vern Swanson, C.P. for his assistance in fabricating and fitting procedures, and to N.W.'s family for their patience and trust in this project.

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Additional information regarding the Toledo Tenodesis Prosthesis can be obtained by contacting the authors.

BIBLIOGRAPHY

Anderson, M.H., *Upper Extremities Orthotics*, Charles C. Thomas, Publisher, 1965.

Bernstein, N., *The Co-ordination and Regulation of Movements*, Pergamon Press, New York, N.Y., 1967.

Conwell, E.H., "Movements of the Wrists," 1970, *Clinical Symposia*, Vol. 22, Number 1,

Doubler, J.A., "An Analysis of Extended Physiological Proprioception as a Prosthesis Control Technique," *Journal of Rehabilitation, Research and Development*, Vol. 21, Number 1, BPR 10-39, pp. 5–18.

Hopkins, H., and Smith, H., *Willard and Spackman's Occupational Therapy, 5th edition*, J.B. Lippincott Company, 1978.

Lambrou, R.W., *A manual for the congenital unilateral below elbow child amputee*, American Occupational Therapy Association, 1981.

Malick, M.H., & Meyer, C.M.H., *Manual on Management of the Quadriplegic Upper Extremity*, Harmarville Rehabilitation Center, Pittsburgh, Pennsylvania, 1978.

Mann, R.W., "Force and position proprioception for prostheses," *The Control of Upper Extremity Prostheses and Orthoses*, C.C. Thomas, Springfield, Illinois, 1974, pp. 201–219.

Prosthetics for the limb deficient child and young adult; workshop May 19–21, 1983, Department Rehabilitation Medicine, Tufts University School of Medicine, New England Medical Center.

Trombly, C., & Scott, A., *Occupational Therapy for Physical Dysfunction*, Williams and Wilkins Co., 1977.

*Component parts are available in child and adult sizes through U.S. Manufacturing Co., 180 N. Gabriel Blvd., P.O. Box 5030, Pasadena, California 91107-0030.