Experience Fitting Partial Hand Prostheses with Externally Powered Fingers

J.E. Uellendahl a,* and E.N. Uellendahl b

a Hanger Prosthetics and Orthotics, Inc. – Scottsdale, Arizona (USA)
b New Touch Prosthetics, Inc. – Scottsdale, Arizona (USA)

Abstract: Prosthetic management of partial hand amputation poses many challenges to prosthetists and other treating professionals. Partial hand amputations have been challenging to fit with externally powered devices due to the limited space available for prosthetic mechanisms. It has long been the goal of prosthesis designers to mimic as many of the six commonly referenced grasp patterns as possible. With the commercial introduction of individually powered fingers exciting possibilities for fitting externally powered finger prostheses that can replicate various hand postures is now feasible. Powered fingers have allowed individuals with partial hand absence to regain some of the dynamic and conformable grasp functions they lost. This chapter will present a general overview of prosthetic options available for partial hand prostheses with specific focus on externally powered fingers.

Keywords: Partial Hand, Prosthetics, Powered Fingers, Multifunctional, ProDigits, Vincent Systems.

* Corresponding Author: J.E. Uellendahl – e-mail: juellendahl@hanger.com

INTRODUCTION

Prosthetic management of partial hand amputation poses many challenges to prosthetists and other treating professionals. Loss of a hand causes obvious functional disability but also has substantial psychological and social impact. The hand is an incredibly complex instrument with its many joints providing an almost unlimited numbers of possible hand postures. Sensory feedback provides a wealth of information of both hand position and information about the environment the hand encounters. Prosthetic replacement of these features represents a monumental challenge which is presently unattainable. Loss of sensation alone in an otherwise functional hand causes significant disability, this reality underscores the difficulty in replacing an amputated hand.

It has long been the goal of prosthesis designers to mimic as many of the six commonly referenced grasp patterns as possible [1]. To date there have been four multifunctional hands introduced for commercial distribution, the iLimb hand from TouchBionics (www.touchbionics.com), the BeBionic hand from RSL Steeper (www.rslsteeper.com), the Michelangelo hand from Otto Bock (www.ottobockus.com), the Vincent hand from Vincent Systems (www.vincentsystems.de). These hands are primarily designed for persons with amputations above the wrist. For the majority of partial hand amputees there are only two commercially available electrically powered options presently available; ProDigits from TouchBionics and Vincent fingers from Vincent Systems. With the introduction of these individually powered fingers exciting possibilities for fitting externally powered finger prostheses are now feasible. This chapter will present a general overview of prosthetic options available for partial hand prostheses with specific focus on externally powered fingers.

INCIDENCE

Partial hand amputation is the most common upper limb amputation level in the United States. In a review of hospital discharge records between 1988 and 1996, Dillingham et al. [2] found that approximately 18,496 individuals were reported to have upper-limb amputations or congenital limb deficiencies annually. Ninety two percent of these were below the wrist. Trauma is the predominant cause of partial hand amputations and it is important to note that often the remaining portions of the hand are also damaged. Limited joint range of motion, hypersensitivity, scarring and a lack of strength in the remaining portions of the hand may be complicating factors.

PROSTHETIC OPTIONS

Until recently prosthetic management of partial hand amputation has relied on three basic categories of prostheses: aesthetic passive hand restorations, opposition posts, and body powered designs. When deciding on the type of prosthesis to be prescribed, variables include age, sex, occupation, degree of physical activity, gadget tolerance, type of amputation and unilateral versus bilateral involvement. As with other upper limb amputations two or more prostheses may be required to meet the multitude of patient
needs. Use of a trial prosthesis can be invaluable in determining if a particular type of prosthesis will meet the users needs and expectations.

Silicone Hand Restorations

High definition custom silicone prostheses have been, and continue to be, the best option for reproducing the natural appearance of the hand [3]. Pillet pioneered the use of custom silicone hand prostheses that very closely match the color and form of the missing hand allowing the user’s hand absence to go unnoticed by the casual observer. This is an important point because if the individual with a hand difference resorts to hiding his hand in a pocket to avoid being noticed the extremity is functionally more disabled than necessary. Silicone prostheses have a long history of use and are generally well accepted [3, 4]. These prostheses provide static replacement of the missing parts of the hand and are often referred to as passive prostheses since the prosthetic components do not provide active motion. However, these prostheses do offer function in addition to the extremely important psychological benefit of restored body-image [3]. The amount of function they offer is dependent on the active features of the remaining hand. For example if the thumb is the only finger remaining the silicone fingers provide opposition for the thumb allowing the hand to grasp objects, a function that would not be possible without the prosthesis.

Silicone prostheses also can serve to protect sensitive areas of the amputated hand. Custom silicone hands provide good stain resistance however the material can be damaged if subjected to use for manual labor. Since silicone prostheses do not provide active finger function they do not provide the grasping functions required by many partial hand amputees.

Opposition Posts

Opposition posts are best utilized by persons with either their thumb remaining and fingers missing or thumb missing and fingers remaining. As the name implies an opposition post consists of a rigid post attached to the remnant hand with a prosthetic socket in order to oppose any remaining fingers. Opposition posts are generally simple and durable (Fig. 1).

Body Powered Options

Historically there have been attempts to provide body-powered prostheses for partial hand amputations such as the Robin Aids hand which could be configured in various ways to replace complete loss of the fingers. This hand used a shoulder control harness. However, the Robin Aids hand is no longer commercially available. More recent body-powered systems include the X-Fingers (http://www.didrickmedical.com) and M-Fingers (http://partialhandsolutions.com). The X-Fingers use a multiple linkage design, typically used to power the distal interphalangeal (DIP) and proximal interphalangeal (PIP) joints with the force and excursion of the metacarpophalangeal (MCP) joint of the affected finger (Fig. 2). In the authors’ opinion the X-Finger has limited indications for use since it is primarily a finger driven design and requires enough lever distal to the MCP to produce useable force. Cosmetic covering is problematic.
The M-Fingers use a cable actuated wrist driven design where wrist flexion causes finger flexion at the MCP and PIP joints of the prosthetic fingers, the DIP joint is fixed [5] (Fig. 3). The M-Finger prosthesis uses a Whiffletree design to allow conformable grasp where finger motion continues until blocked by the object being grasped. Grip force is low due to the mechanical design, however due to the conformable grasp prehension is adequate in many cases. A disadvantage of the wrist driven design is that wrist motion is linked to finger flexion and neither can be positioned independently. Also sustained grip force requires maintenance of wrist position. Cosmetic finishing is difficult. The M-Fingers are also available in a finger driven design for partial finger amputees. These fingers use MCP flexion to drive PIP flexion by routing a cable from the dorsal side of the intact MCP joint to the palmar side of the prosthetic PIP joint (Fig. 3b). Use of the M-Fingers for finger driven control requires sufficient length of the involved finger distal to the MCP joint in order to produce adequate force and excursion.

Another body-powered partial hand option is the so called “handi-hook” (Fig. 4). This device uses a conventional hook prehensor attached in the palm of the partial hand prosthesis using a rigid socket, flexible hinges and a figure of 8 harness. Control is achieved with combinations of elbow, shoulder, and scapular motions. This type of control produces force and excursion for good terminal device function. The disadvantages of using proximal joints to control the terminal device are that the terminal device is linked to these proximal motions and cannot be controlled independently and these motions may appear unnatural. Body-powered cable actuated control has the inherent advantage of providing proprioceptive feedback to the user regarding force, position and speed of movement through the linkage of the controlled component to the proximal physiological joints [6].

**Externally Powered Options**

Partial hand amputations have been challenging to fit with externally powered devices due to the limited space available for prosthetic mechanisms. Early powered prostheses for partial hands such as those described by Weir [7], Gow [8], Putzi [9], Biden [10], and Lake [11] were not commercially available. The commercially available Otto Bock transcarpal hand is not configurable for different finger absences and is best suited, as the name implies, for the most proximal of partial hand amputations.

A distinction between the attempts at providing externally powered solutions for partial hand amputees is whether the drive mechanism is in the body of the hand or contained in the fingers. For the mechanism to be applied to the largest number of partial hand amputees the drive mechanism should be contained in the fingers. Only the designs originally proposed by Weir [7] (Fig. 5), Gow [8], and more recently Schulz [12] satisfy this requirement.

Electrically powered partial hand prostheses offer advantages over the body-powered systems discussed above. No force or excursion is needed for operation and finger activation can be independent of proximal
joint position. Without the need for user produced force these systems may be better suited for individuals with sensitive residual limbs as may result from damage caused by a traumatic injury. Also grip is maintained without prolonged control input. The electric device is not back drivable and the prehension force is generally greater than that obtained with wrist driven devices.

Electric prostheses for partial hand prostheses also have disadvantages compared to body-powered designs. There is no direct feedback from the control system regarding finger position, speed of movement or force generated. The space needed for hardware to control and power the fingers is difficult to house within the normal confines of the natural hand space making cosmetic finishing difficult. It should be pointed out that in cases of more proximal amputations such as transthecal, wrist disarticulation and long transradial, powered finger systems can allow for improved cosmesis compared to other hand designs by affording room in the body of the hand for the control system and power supply (Fig. 6). With the commercial introduction of ProDigits by Touch Bionics Inc. in 2007, exciting possibilities for fitting externally powered finger prostheses became feasible.

DESCRIPTION OF PRODIGITS
ProDigits grew out of the Edinburgh Modular Arm System (EMAS) project headed by Gow at the Rehabilitation Engineering services, Princess Margaret Rose Orthopedic Hospital, Edinburgh, Scotland. The EMAS project began in 1988 and led to the development of an electrically powered full arm prosthesis fitted to a shoulder level amputee in 1998 [8]. The first clinical trials of ProDigits for partial hand prostheses was reported by Ronald in 2001 [13] (Fig. 7).

The present ProDigits system consists of fingers, a control unit, power supply and signal input sensors. Each finger consists of a motor and drive train which articulates the MCP joint (Fig. 8). A cable is routed so that MCP flexion causes PIP flexion on the index, middle, ring, and pinky fingers, the thumb IP does not articulate. There is no articulation at the DIP. There are two motor sizes allowing for four different
proximal finger lengths. Additionally there are interchangeable finger tip lengths. The present design requires finger absence 34 mm proximal to the MCP joint in order to achieve normal finger length. Since each finger is self-contained a variety of partial hand amputations can be accommodated.

The microprocessor control unit accepts two control inputs and has five motor drivers. The control unit is configurable using a wireless Bluetooth interface. Control strategies employing one or two inputs can be selected from drop-down menus according to the particular needs and preferences of the amputee. Signal gains and thresholds can be adjusted in the software.

Power supply is provided by a 7.4 volt Lithium power pack. There are presently two battery sizes, an 800 mAh and a 1300 mAh. Selection of the battery depends on the space available to house the battery, the number of fingers being driven, and the anticipated daily duration of use. Ideally a battery should provide enough power to operate the prosthesis for one full day. Requisite with the battery is a charge port and on/off switch. These two components require space and must be accessible to the user. The present charge port is much larger than would be ideal, however, at this time no suitable replacement is offered.

There are currently two types of control inputs recommended for use with ProDigits, myoelectrodes and force sensitive resistors (FSR’s). Both types of inputs can be used for single site or dual site control strategies.

**DESCRIPTION OF VINCENT FINGERS**

The Vincent© Systems GmbH - Medical Technics Group from Germany offers the latest powered finger system to become commercially available. The Vincent System grew out of the work by Schulz who has been involved in development of prosthetic and robotic hands at the Karlsruhle Institute of Technology for over a decade [14]. The Vincent powered finger system consists of individually powered fingers with articulation at the MCP joint and the PIP joint (Fig. 9). The MCP articulation is driven by the motor and the PIP joint is linked to MCP motion with flexible metal struts.

This design allows force to be exerted by the distal finger segment when the finger is moving in extension as well as flexion, a feature not available in designs that employ a unidirectional link to drive the PIP joint. Two motor sizes and several finger tip lengths are offered in order to match the finger lengths of a variety of hand sizes. In contrast to the mostly plastic construction of the ProDigits, the Vincent fingers are made of an aluminum alloy (AlmgCu) and are fitted with a soft and compliant finger tip. The size of the Vincent finger is significantly smaller than the ProDigits, especially the build height proximal to the MCP joint which is 22mm shorter when fitted with spring loaded electrical contacts and 25mm shorter when fitted with flying leads for motor connection. This short build height allows fitting of many more persons with partial hand absence while maintaining natural hand proportions [15]. The fingers are also much smaller in the anterior/posterior dimension providing a more slender hand (Fig. 10).

Control of the Vincent fingers is provided by a microprocessor that accepts one or two control inputs. Two controller designs are available, a four finger controller or a 5 finger controller. The five finger controller offers the option of vibration feedback to the user regarding grip force. Signal gains and thresholds can be adjusted with the computer interface.

Power supply is provided by a 7.4 volt Lithium power pack. The most notable feature of the power supply system is the charge port/on-off switch module which is attached to the charger with a magnetic link. This provides a charge system that is low profile allowing a better appearance to the finished prosthesis compared with the charge port/on-off module supplied with the ProDigit system.
Finger tests comparing the speed and torque of the ProDigits and the Vincent System fingers reveals comparable performance. Testing was performed by an independent laboratory under the direction of Richard Weir. Both systems were purchased in the fall of 2010 and were tested as delivered by the manufacturer with the supplied control unit, power supply and FSR’s using the large motor fingers. The maximum speed for the ProDigits was 1.48 radians/second and 2.04 radians/second for the Vincent System fingers. Torque at the MCP joint measured 0.60Nm (0.44 ft-lbs) for the ProDigit and 0.49Nm (0.36 ft-lbs) for the Vincent System finger. The Vincent System controller offered a “Power Boost” mode that increases grip force by rapidly pulsing the finger motor. With “Power Boost” enabled the torque at the MCP was 0.58 ft-lbs. Although TouchBioinics offers a similar “Pulse” feature in the full iLimb hand, it was not an option in the controller supplied with the ProDigits.

CONTROL

Typically control inputs for powered fingers are provided by either myoelectrodes or force sensitive resistors (FSR). Other inputs are possible such as linear transducers and switches. Schulz has also suggested use of strain gauges for control of powered fingers, for example a strain gauge might be positioned at the MCP joint of an intact finger to provide control of one or more missing fingers on that hand [12]. Control schemes that have been used clinically include single site with fast/slow selection of open/close or with alternate direction control where one signal opens and the next signal closes and so on. Present controllers for powered fingers also can be set for voluntary open/automatic close or voluntary close/automatic open when using one input. Dual site proportional control is also possible and is generally the preferred method of control. In the primary prehension mode all fingers are driven simultaneously, each finger continues to move until an object blocks its motion or it reaches its mechanical stop thus providing a conformable grasp. A second prehension mode can be selected using a variety of mode selection commands such as maintaining a hold-open signal after the fingers have reached their extension limits, cocontraction, or rapid repeat contractions in the same direction. The typical second prehension pattern is precision pinch where the index finger and thumb become the only active fingers with the other fingers driving to a fully flexed position or remaining extended depending on the program selected or user input. If a powered thumb is not utilized then only the index finger would be active in this mode. This second mode is useful for fine grasp using tip prehension between the index finger and thumb or to allow the index finger to be extended for activities such as keyboarding or pressing buttons on a phone.

When myoelectric control is used the controlling muscles can either be in the hand or forearm. Using the muscles within the hand has the advantage of providing finger control independent of wrist motion and avoiding the need to cross the wrist joint with electrode wires. The thenar and/or hypothenar muscles have been used for control. When some fingers remain it is advisable to use muscles that do not control the remaining fingers, i.e. if the thumb remains the thenar muscles should not be used to control the prosthetic fingers. Use of intrinsic muscles for myoelectric control also has disadvantages. The size of the electrodes can make the hand bulky and it is difficult to house the electrode package within the hand space. Often when using intrinsic muscles only one usable muscle site is possible and experience and user feedback has suggested that two site control is preferable to single site control. Since the majority of muscles controlling the physiological hand are in the forearm it is natural to use these muscles for control of prosthetic fingers. Experience has shown that the users can isolate myoelectric activity sufficiently to control the prosthetic fingers without producing significant wrist motion when desired.

New technologies for prosthesis control are on the horizon. These include pattern recognition [16, 17, 18] as well as implantable myoelectric sensors (IMES).
With IMES it may be possible to control a greater number of finger motions directly or through pattern recognition. Already there have been a limited number of clinical trials involving control of ProDigits using more than two control inputs. One such example was fitted to an individual who retained slight motion at the MCP joints of his index, middle, ring, and pinky fingers. Each of these mobile remnants controlled a single FSR with a dedicated microprocessor for each finger. This configuration allowed direct control of each finger independent of the other fingers. Another approach for control of multiple fingers is to assign one of the two control inputs to specific fingers. One way to do this is to partially overlap two FSR’s so that a mobile limb segment can press in one of three locations i.e. only on one or the other FSR or on both together. Using this control method it is possible to have direct access to a variety of finger motion combinations. Other control methods that can produce interesting results are the use of fast/slow contractions, co-contractions, timed mode changes, and use of component position for mode changes. Using fast/slow (rate) control with two electrodes can produce four movement patterns from two electrodes. Co-contraction or one of the other mode change commands adds another dimension of control using the same two electrodes. Mode changes initiated by the component state have been used for many years such as the elbow hold steady used on the Utah arm (http://utaharm.com) where once the elbow is held steady the elbow locks and power is transferred from elbow to hand or the RSL Steeper mechanical elbow where cycling of the elbow lock also turns the electric hand on and off. A more recent example is the RSL Steeper BeBionic hand where the passively positioned thumb selects different grasp patterns depending on whether the thumb is in an opposed position or non-opposed.

**PROSTHESIS DESIGN**

**Sockets**

The role of the prosthetic socket is to provide a stable connection of the prosthetic fingers to the residual limb, to securely suspend the prosthesis and serve as a place to mount the prosthetic components such as battery and myoelectrodes. Traditional upper limb prosthesis construction utilizes plastics for both the interface material and structural components. With the introduction of high consistency rubber (HCR) silicones it is possible to design and fabricate silicone interfaces in new ways that take advantage of the unique attributes of this material and means of manufacture [15, 21].

Material thickness, stiffness, and elasticity can be selectively controlled. It is possible to incorporate hardware such as electrode mounts, screw attachments, zippers, battery compartments and wrist mounts into the silicone during fabrication (Fig. 11).

Custom silicone sockets have been reported to provide better comfort as well as the ability to protect fragile skin from breakdowns when compared to other materials used for prosthetic sockets [22]. Therefore, silicone has proven to be the socket material of choice in the authors’ experience [22, 23]. Since most partial hand amputations present with a hand remnant that is larger in circumference than the wrist, it is useful to incorporate a zipper to allow entry of the remnant hand and when zipped provide excellent suspension. Also the socket should not restrict useful limb motions such as those that may be available at the wrist, thumb, or other remaining joints. In cases where the distal limb is only slightly larger than the wrist the elasticity of the silicone material may expand sufficiently to allow entry of the limb without a zipper. The material can be made thin and flexible in select areas to allow joint mobility. HCR silicones are manufactured using a high pressure two-roll mill. These materials are clay-like in their forming state. The stiffness of these materials using the Shore A durometer scale is generally between 15 and 70. These different durometer materials can be precisely positioned to control regions of stiffness and elasticity as desired. The material can be blended to modify the durometer and other physical properties, has a high tear strength and produces no volatile by-products.

A critical attribute of the physiological hand is the exquisite sensation it provides. When possible it is advantageous to leave normally sensate areas of the hand exposed such as in cases where the thumb remains and the majority of the thenar eminence is left exposed [11, 22]. However, in some cases when dealing with an injured hand hypersensitivity may be experienced in which case the amputee may benefit from the protection provided by covering these sensitive areas with the silicone socket. Ultimately a balance must be achieved between exposing sensate skin, protecting hypersensitive areas, providing secure fixation of the prosthesis, and providing sufficient area to house and connect the required hardware.

**Prosthesis design related to thumb type**

In light of the vast variety of possible hand amputation configurations, one key feature that will categorize the type of prosthesis is the condition of the thumb (Fig. 12). Since the thumb is the most important finger representing 40% of hand function [24] the level of
thumb function retained deserves further consideration. In order to provide good function the thumb should afford sensibility, stability, opposition and length [7]. When the thumb is partially amputated it may be treated surgically with lengthening, web space deepening, toe transfer, pollicization or osseointegration [25, 26]. In many cases where the thumb is partially amputated other fingers are also damaged or missing. Communication and planning between the surgeon and prosthetist is important for optimization of hand function. Through early interaction using a team approach outcomes can be optimized.

Surgeons should consider not only the cosmetic and functional results but also how a particular surgical intervention may affect the use of a prosthesis [11]. For example, in cases where all fingers have been amputated and the thumb is missing at the MCP joint it may be advisable to provide an osseointegrated thumb prosthesis in combination with powered fingers for the index, middle, ring, and pinky fingers. This would allow the prosthetic thumb to be positioned in opposition or for lateral prehension using intact mobility of the metacarpal. The powered fingers would provide force and a conformable grasp. The osseointegrated thumb provides direct proprioceptive feedback to the user regarding the force exerted on objects grasped.

In cases where the thumb is missing, and surgical options are not pursued, the options include provision of a powered thumb or a passively positioned thumb. When there is enough space a powered thumb can be provided. The powered thumb allows for a wider range of object sizes that can be grasped without manually repositioning the thumb compared to the passive thumb options. One disadvantage noted when using the powered thumb is difficulty targeting small objects that would be grasped using tip prehension. When both sides of the grasping unit are moving the users need to estimate the point in space that the fingers will meet. Users of a fixed thumb hand will place the object to be grasped against the thumb and allow the index finger to come against the object using the thumb as a fixed point of reference. Fixing the position of the thumb in space is a natural mechanism of grasp as reported by Wing who observed a pattern of natural hand usage in which the index finger rather than the thumb was responsible for reduction of grasp aperture as the hand approached an object [27]. This was observed in able bodied individuals as well as individuals using a prosthetic hand where compensatory proximal motions were used in order to keep the moving thumb in a relatively fixed location [27]. Compared to the full iLimb hand the current ProDigit design does not generally allow rotation of the thumb to a lateral prehension position. Due to the volume of

Fig. 12 – Examples of partial hand amputations that are candidates for fitting with powered fingers.

Fig. 13 – (a) the APRL thumb in the narrow opening positions; (b) the APRL thumb in the wide open position; (c) the M-Finger thumb rotated for precision pinch prehension.
the ProDigit thumb proximal to the articulation many individuals who are missing their thumb do not have sufficient space for mounting of the powered option. The Vincent System thumb attachment point is much closer to the MCP joint articulation allowing greater opportunity to fit a powered thumb within the normal volume envelop of the natural hand. In cases where the powered thumb is not possible either a passively positioned friction thumb or a passive locking two position thumb can be provided. The friction thumb from the M-Finger system (www.partialhandsolutions.com) offers rotation where the locking thumb from the APRL (www.hosmer.com) hand does not. The locking thumb is better suited to activities where higher loads are experienced since the friction thumb would move as a result of these high forces (Fig. 13).

CASE EXAMPLES

Carpometacarpal Level: Powered Thumb

Case one presents the prosthetic considerations for an individual who suffered a traumatic amputation at the carpometacarpal level (Fig. 15). This 67 years old male had a traumatic amputation of his non-dominant hand as a result of a water-skiing accident. His residual hand is scarred and there is very little motion at the wrist. The initial prosthetic recommendation was to consider revision surgery to the wrist disarticulation level. This change in amputation level would allow fitting of a wider variety of terminal devices. Without physiological wrist motion the benefit of partial hand amputation versus wrist disarticulation is mostly lost. This patient refused revision surgery and therefore fitting proceeded using five powered ProDigit fingers. The finished prosthesis was provided eight months after the injury. The finished prosthesis provided several grasp patterns due to the conformable grasp provided by five independently powered fingers. A second mode of operation was programmed into the controller. This second mode was accessed myoelectrically by a sustained hold-open signal. When second mode is selected the middle, ring, and pinky fingers fully flex and the thumb and index finger become the only active fingers in a precision pinch grasp pattern. All fingers resume function with another sustained hold-open signal. The socket was made of silicone and incorporated a zipper for easy donning and doffing. Full forearm rotation was retained in the prosthesis. The battery and charge plug assembly were housed within the silicone construction on the medial forearm surface. Control was achieved with two electrodes, one over the forearm flexors and the other over the extensors. At one-year follow-up this patient reports wearing his prosthesis “a few times” a week. On days he wears the prosthesis he tends to wear it all day, about 8-10 hours. He wears the prosthesis on days when he anticipates activities that the prosthesis will facilitate. He finds the prosthesis particularly useful when he needs to hold objects while manipulating them with his sound-side hand which is as one would expect for a unilateral amputee especially when the amputated hand is the non-dominant hand. His 1300 mAh battery is sufficient to operate the five powered

Coverings

Covering of the prosthesis is desirable for aesthetic reasons, to keep dirt out of the finger mechanisms, and to improve the functional grasp of the hand with the addition of a soft compliant covering. A variety of coverings have been utilized including very thin leather athletic gloves, textile gloves, and silicone gloves (Fig. 14). The silicone iLimb skins have been used in some cases where the finished hand was not excessively large. In cases where some fingers are remaining off-the-shelf silicone gloves have been cut to avoid covering the intact fingers. Custom silicone gloves have also been provided. Certainly finding a suitable covering is difficult and remains one of the goals of future development. The external covering is a critical component providing not only the final aesthetic appearance but also must provide increased compliance and friction for better stabilization of objects. Ideally the covering material should have high elasticity under low deformation forces, be tough, and capable of being shaped and colored to match the user’s hand characteristics. Since every hand has a unique shape, provision of a custom glove would be ideal. However, manufacturing a custom glove is both time consuming and expensive. One solution for custom glove manufacturing may be found with computer aided design and manufacturing [28].

Fig. (14) – (a) a leather athletic glove; (b) TouchBionics iSkin silicone glove; (c) TouchBionics LivingSkin custom silicone glove.
fingers all day for his typical usage pattern. When not wearing his ProDigit prosthesis this patient wears a custom silicone socket to protect his scarred residual limb which is prone to abrasions.

**Transmetacarpal Level: Friction Thumb**

Case two reviews the fitting of a transmetacarpal level amputation for an individual who sustained a traumatic amputation 18 years before this episode of care. This 45 years old man presents with good wrist motion. He has previously been fitted with body-powered hook prosthesis as well as a myoelectric transcarpal hand. These previous prostheses were rejected due to the excessive length and bulk of the finished prostheses. Since too much of the hand remained to fit a powered thumb within the normal geometry of the hand a friction thumb and four powered fingers were provided (Fig. 16). The friction thumb acts as a static back stop for the powered fingers during grasping. Since the thumb does not move, small objects are easier to grasp then generally is the case for a moving thumb design. This user demonstrated good ability to grasp small objects by placing the thumb against the object and then closing the powered fingers to achieve grasp. The socket design used was the same as described in case one. Due to the flexibility of the silicone wrist motion is hampered only slightly. The zippered silicone socket provides excellent fixation on the residual limb. Initially, during the test socket phase of fitting, intrinsic hand muscles were evaluated for control using the hypothenar muscle signal to alternate direction of the fingers. Also during the fitting two site control using forearm musculature was evaluated. This patient felt that use of the forearm muscles was preferable due to the ease of control and the direct access to the open or close functions. At eight months follow-up this patient reports wearing the prosthesis all day (12 hours) almost every day. He uses the prosthesis to carry his computer bag, hold his cell phone, and other daily activities such as cooking, cleaning and home maintenance. With the 1300 mAh battery the prosthesis operates for a full day with few exceptions.
**Thumb Remaining**

Case three is a 50 years old man who presents with a diagonal amputation of his index, middle, ring and pinky fingers starting at the transmetacarpal level of the index finger and approaching the carpal level of the pinky. The thumb is intact (Fig. 17). The amputated hand was his non-dominant hand. The amputation resulted from trauma sustained by a hydraulic press. Since the thumb provides normal motion and sensation, it can be expected that function with four powered fingers will be superior to the first two case examples. The intact thumb provides for a variety of grasp patterns where the thumb is in opposition as well as for lateral prehension. The thumb provides excellent proprioceptive feedback regarding objects grasped and can modulate grip force. Of primary concern for ProDigit fitting is the length of the fingers. The ProDigits require approximately 34 mm proximal to the MCP articulation to achieve physiologically natural length. In order to provide a prosthesis that is as close as possible to the normal length the shortest fingers were provided. The disadvantage of using the short fingers is that they provide less force than the longer fingers due to the smaller motors. In this case that trade-off was acceptable because the thumb was capable of producing enough force as well as detecting any slippage of objects held. The silicone socket was designed similar to the previous cases with attention to maximizing thumb range of motion as well as exposure of normal skin of the thenar eminence for tactile sensation. Since the thumb remained the thenar muscles were not considered for control due to their involvement in thumb function. Single site control using hypothenar muscles was evaluated as was two site control using forearm muscles. Two site control using forearm muscles was preferred. At an 18 month follow-up this patient reports full-time use of his prosthesis. He is employed full-time and performs shipping and receiving functions that require him to lift and manipulate packages using both hands. After two years of daily use the ProDigit prosthesis was replaced due to normal wear and tear accelerated by exposure to the corrosive environment encountered working at a salt mine. At this time the Vincent System fingers were provided. Two forearm located myoelectrodes again provide control of the four powered fingers. Due to the much shorter build height of the Vincent System fingers compared to the ProDigits, the large motor fingers were provided for all four digits while maintaining anatomical overall length of the hand. The longer fingers provided a noticeable improvement in grasp due to the greater encapsulation of objects grasped. Most noticeable to this user was the lighter weight and more natural and slender appearance of the hand.

---

*Fig. (17) – (a) appearance of partial hand amputation without prosthesis; (b) ProDigit prosthesis fitted allowing restoration of a variety of prehension patterns; (c) Vincent System showing anatomically correct finger lengths; (d) Vincent System shown utilizing index point feature for keyboarding.*
**Thumb and Index Finger Remaining**

Case four demonstrates ProDigit fitting when multiple fingers remain. This 16 years old male suffered a traumatic farming accident that resulted in amputation of his middle, ring, and pinky fingers. The index finger remained but was limited in function with a 75 degree flexion contracture at the MCP joint. The thumb function was normal (Fig. 18). Without a prosthesis, grasp between the thumb and index finger was weak and instability of objects grasped was noted. Powered fingers were provided for the missing fingers. This fitting achieved greater stability of objects grasped due to the larger contact area and conformability of the powered fingers. The thumb, including the majority of the thenar eminence, was exposed from the silicone socket as was the complete index finger. Control was achieved with forearm flexors and extensors. At initial follow-up this patient reported that the prostheses was useful for holding objects that he could not hold without it. He wore the prosthesis “most days”, usually for 4-5 hours at a time. At later follow-up, one year after delivery, this patient had outgrown the prosthetic socket and refitting of the prosthesis using the existing components is being pursued.

**CONCLUSIONS**

Powered finger prosthesis for partial hand amputation is in its infancy. Powered finger prostheses have allowed individuals with partial hand absence to regain some of the dynamic and conformable grasp functions they lost. This experience as well as new technologies for fitting, manufacturing, and controlling powered fingers will undoubtedly lead to improvements upon these early designs in the near future. New prototype ProDigits are in the design phase to significantly reduce the size and build height of the finger proximal to the MCP joint [29]. The Vincent fingers already provide a minimal build height proximal to the MCP joint. A short build height allows many more persons to be fitted with powered fingers that achieve a physiologically appropriate length. Shorter build height also allows for provision of a rotating thumb mechanism that can be fitted in some partial hand prostheses to allow lateral positioning of the thumb. Rapid manufacturing techniques may allow customized structural components to be made in a time and cost efficient way [30]. Computer aided manufacturing may also offer a way to create molds for custom silicone coverings that match the unique shape and size of any individual powered finger partial hand prosthesis [28]. With the many hand postures possible with individually powered fingers comes the task of controlling these motions. In recent years much progress has been made in development of real-time pattern recognition that could allow direct access to various grasp patterns. In this regard IMES also offer interesting possibilities. Whatever control method is employed it should provide consistent and reliable control and with experience use should become subconscious.

**REFERENCES**


[13] Ronald JR. Prodigits clinical trial at Nottingham Mobility Center, 10th World Congress of the International Society for Prosthetics and Orthotics, Glasgow (Scotland), 2001.


