Restoring Form and Function to the Partial Hand Amputee

Prosthetic Options from the Fingertip to the Palm

Emily M. Graham, BSN[a], Russell Hendrycks, BS[a], Christopher M. Baschuk, MPO, CPO[b], Diane J. Atkins, OTR[c,1], Lana Keizer, OTR, CHT[d], Christopher C. Duncan, MD[e,f], Shaun D. Mendenhall, MD[a,*]

KEYWORDS

• Partial hand amputee • Hand amputation • Finger amputation • Thumb amputation • Transmetacarpal amputation • Amputation • Prosthesis

KEY POINTS

- Partial hand amputations include amputations through the fingers, thumb, and transmetacarpal/palm region of the hand.
- Regardless of the amputation level, modern partial hand prostheses can be used to restore form and function to the hand.
- Prosthetic options are categorized into the following classes: passive functional, body-powered, and externally powered prostheses.
- Treatment outcomes are likely maximized when multidisciplinary teams including hand surgeons, prosthetists, occupational and/or certified hand therapists, and physical medicine and rehabilitation physicians collaborate.
- The paucity of published functional outcomes for partial hand prosthesis use is a limitation of this review and of amputee care.

BACKGROUND

Regular use of a prosthetic device increases the health and quality of life in patients with limb loss.[1] Although there are some who learn to adapt and achieve some functional independence without a prosthesis, there are numerous reports highlighting the benefits of consistent prosthesis use.[2,3] These benefits include a greater likelihood of returning to work and increased independence in activities of daily living (ADLs).[4–6] Regular use of a prosthesis is also associated with improvements in phantom limb pain, residual limb pain, and psychological well-being.[7–10]

[a] Division of Plastic Surgery, Department of Surgery, University of Utah School of Medicine, 30 North 1900 East Room 3B400, Salt Lake City, UT 84132, USA; [b] Handspring Clinical Services, 750 East 100 South, Salt Lake City, UT 84102, USA; [c] Department of Physical Medicine and Rehabilitation, Baylor College of Medicine, Houston, TX, USA; [d] Department of Occupational Hand Therapy, University of Utah, 590 Wakara Way, Salt Lake City, UT 84108, USA; [e] Department of Physical Medicine and Rehabilitation, University of Utah School of Medicine, Salt Lake City, UT, USA; [f] Craig H. Neilsen Rehabilitation Hospital, 85 North Medical Drive, Salt Lake City, UT 84132, USA
[1] Present address: 2205 Riva Row #2305, The Woodlands, TX 77380.
* Corresponding author.
E-mail address: Shaun.mendenhall@hsc.utah.edu

Hand Clin 37 (2021) 167–187
https://doi.org/10.1016/j.hcl.2020.09.013
0749-0712/21/

hand.theclinics.com

The benefits of regular prosthesis use also apply to those with partial hand (digits, thumb, and transmetacarpal) amputations.[10,11] Notably, partial hand amputations (PHAs) comprise most upper extremity amputations, with 1 in 18,000 individuals affected and an estimated prevalence of 2 million individuals in the United States.[12,13] However, this predicted prevalence is likely conservative because these studies did not clarify whether amputations of the fingertip contributed to the number of finger amputations. Higher rates are also expected for developing countries and regions.[14,15] These epidemiologic findings are understandable considering the frequency of use and vulnerability of the hands. Trauma, vascular compromise, infection, malignancy, and congenital differences may all contribute to the development of a PHA.[13,16–18] These diverse causes create unique population demographics, encompassing a wide spectrum of ages, education levels, and socioeconomic backgrounds.

Despite the large number of individuals affected, those with PHAs are less likely to consistently use a prosthetic device compared with lower limb amputatees.[19] There are many potential explanations for this. Ambulation largely depends on lower limb prostheses and likely motivates individuals with lower limb amputations to consistently use their prostheses. Injuries to nondominant hands may also contribute to the lower rates of prosthetic use in partial hand amputees.[20] Historically, upper limb prostheses were limited in their abilities to restore gross and fine motor function.[7,21] These limitations have been largely overcome by modern engineering advancements in the diversity and functionality of upper extremity prostheses. However, results of a recent survey the authors sent to hand surgery members of the American Association for Hand Surgery (AAHS) revealed that less than 36% of hand surgeons are familiar with these prosthetic options, and that only 24% work in a multidisciplinary upper extremity amputation team (Fig. 1).

The purpose of this article is to increase hand provider's knowledge of current prosthetic options for partial hand amputees, including amputations from the fingertip to the palm area of the hand. It discusses the available data and the current barriers to partial hand prosthesis use as well as the role of a multidisciplinary team approach in amputee care. Although it is not feasible to provide a comprehensive list of all the prostheses and companies used to treat PHA, this review provides categories of prosthetic options based on level of amputation and current devices that are readily available. For ease of organization, the authors created the following levels of PHA: (1) distal to distal interphalangeal joint (DIPJ); (2) through the DIPJ and middle phalanx; (3) through the proximal interphalangeal joint (PIPJ) and proximal phalanx; (4) through the metacarpophalangeal joint (MCPJ) and transmetacarpal; and (5) thumb, partial or complete. Each amputation level is marked by unique challenges and requires patient-specific treatment.[22–24] A thorough understanding of these options allows providers to better advocate for patients and help them achieve improved form and function following amputation.

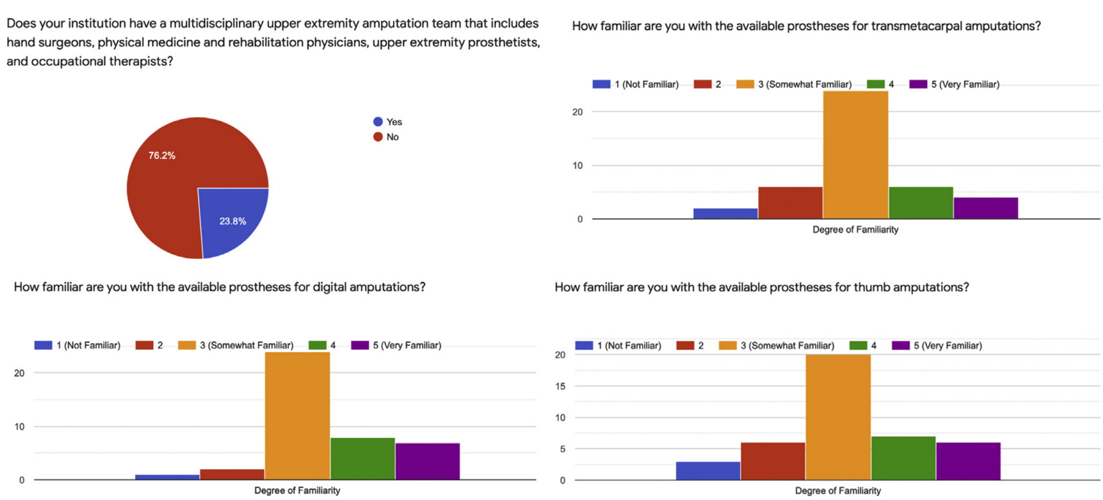

Fig. 1. Results of a survey conducted among surgeon members of the AAHS. Most surgeons report working at an institution without a formal multidisciplinary upper extremity amputation team. In addition, most hand surgeons do not express familiarity with partial hand prostheses.

PROSTHETIC OPTIONS FOR AMPUTATIONS DISTAL TO DISTAL INTERPHALANGEAL JOINT

Amputations of the distal fingertip are the most common amputations treated by hand surgeons.[25] On digits 2 through 5, the fingertip is the portion distal to the insertion of the flexor digitorum profundus (FDP) volarly and the extensor terminal tendon dorsally on the distal phalanx. These amputations cause functional and cosmetic deficits because of loss of digit length, partial or complete loss of the nail bed, reduction in sensation, and decreased perception of body wholeness. These amputations occur globally and are common in developed regions, although surgical management for these injuries varies by location. In the United States, most amputations through the distal tip and DIPJ are treated by revision amputation to expedite functionality of the residuum, whereas many Asian countries are more likely to attempt replantation to improve cosmesis and retain perceptions of body integration.[26–28] The decision to replant or amputate seems to be influenced by cultural norms and perceptions of PHA.[27] However, when attempts to replant are unsuccessful or when replantation is not feasible, prosthetic devices can be used to circumvent distortions of body integration and improve functionality.[29,30] This article presents prosthetic options designed to address the cosmetic and functional deficits caused by these amputations.

Passive Functional Prostheses

Passive functional restorations are among the oldest and most commonly prescribed prostheses used to restore length and improve aesthetic appearance. Within the realm of humanlike passive functional devices are low-definition and high-definition silicone prostheses. Regardless of the PHA level, low-definition and high-definition silicone prostheses can mirror the amputee's unaffected upper extremity and can be fit at any of the amputation levels. Functionally, low-definition and high-definition silicone prostheses behave similarly. As passive prostheses, they are frequently used to supplement movements, including pushing, pulling, and typing, while providing protection to the residuum. However, differences in cosmesis and cost exist between the silicone classes. Low-definition silicone prostheses typically provide less anatomic detail and are available at lower prices. Examples of low-definition prostheses include the readymade and semi–custom-made silicone prostheses by Regal Prosthesis Ltd. (Hong Kong Regal Prosthesis Limited, Hong Kong, China) and custom-rolled silicone finger extensions made in house at specialty upper extremity prosthetics clinics such as Handspring Clinical Services (Salt Lake City, UT). Note that, although these prostheses are humanlike in appearance, the inability to recreate precise, individual anatomic detail can produce a phenomenon termed the uncanny valley.[31] This phenomenon is frequently referenced by prosthetists and others who work with upper extremity prostheses. First described by Mori[31] in 1970, the uncanny valley describes the feelings of repulsion and eeriness humans feel toward objects that fall just short of appearing completely lifelike, whereas objects with major differences in form but that retain functional similarities to human anatomy are more well perceived. In terms of prosthetic devices, the prostheses that are perfect or near perfect in restoring the form of the amputee's hand, along with prostheses that are robotic in appearance, are generally better perceived by amputees, and by those with whom they associate, compared with the prostheses that are mannequinlike in appearance.[31–33] Thus, although low-definition prostheses may provide similar functional benefits to high-definition silicone prostheses, clinicians should discuss the uncanny valley with patients to ensure that psychological well-being and quality of life are maximized.

High-definition silicone prostheses include brands such as Livingskin (Össur Americas, Foothill Ranch, CA) and Prosthetic Artworks (Prosthetic Artworks LLC, Northeastern, PA). These prostheses can be painted to uniquely match individual skin tones, hair patterns, freckles, scars, and tattoos (see **Fig. 7**). The precise recreation of anatomic detail makes these prostheses an attractive option for amputees desiring to restore the form of an affected hand. Even amputees with primary goals to improve hand function may still appreciate a passive functional high-definition prosthesis during certain social events and occasions.

Limitations to low-definition and high-definition silicone restorations include diminished tactile sensation and heat dissipation caused by the encapsulation of the residuum. Silicone restorations are also less durable than other prosthetic options and may be susceptible to damage and staining. As such, patient education regarding appropriate use and care of the prostheses before and after delivery is critical. In our experience, the passive functional prostheses serve users best when the primary goal is to conceal the injury and not draw attention to the finger difference or loss. Examples of where this has proved useful is for school teachers in classrooms full of younger children and for any jobs that have a high degree of customer interaction. They are also frequently used for social and religious engagement.

Body-powered Prostheses

To our best knowledge, there are no body-powered prostheses available for amputations distal to the DIPJ.

Externally Powered Prostheses

Like body-powered prostheses, there are no externally powered prosthetic options for amputations distal to the DIPJ.

PROSTHETIC OPTIONS FOR AMPUTATIONS THROUGH THE DISTAL INTERPHALANGEAL JOINT AND THE MIDDLE PHALANX

Similar to amputations of the distal tip, PHA through the DIPJ and middle phalanx can result in challenging cosmetic and functional impairments. Because the flexor digitorum superficialis (FDS) inserts on the mid–middle phalanx, amputations proximal to this can decrease grip strength, and limit pincer grip and other fine motor movements. Loss of flexion at the DIPJ is a major source of disability and early retirement, placing a major burden on individuals and society.[34–36] Thus, careful consideration is needed to ensure motor function and independence are maximized, especially if the amputation resides on the dominant hand.

Passive Functional Prostheses

The same classes of low-definition and high-definition silicone passive functional prostheses available to PHA distal to the DIPJ are also available to PHA through the DIP and middle phalanx (Fig. 2). These prostheses are especially useful because amputations at this level produce more notable changes in digit length, which can negatively affect whole-body perception and function. The use of a passive functional prosthesis can thus restore cosmesis and improve overall hand functionality.

Body-Powered Prostheses

In addition to passive functional prostheses at this level and proximal, body-powered (BP) partial hand prostheses are available. Mechanical in appearance, BP prostheses harness the amputee's remaining joints and anatomy to restore range of motion (ROM), including flexion and extension, along with restoration of digit length (Figs. 3 and 4). BP prostheses function independent from external batteries and electricity. Advantages of BP prostheses include improved sensory and positional feedback, decreased rate of amputee fatigue, and synchronous movement with natural hand movements.[37,38] In amputations through the middle phalanx not including the insertion site of the FDS, BP prostheses use the remaining middle phalanx and PIPJ to restore length of the missing digit and function of the lost DIPJ.

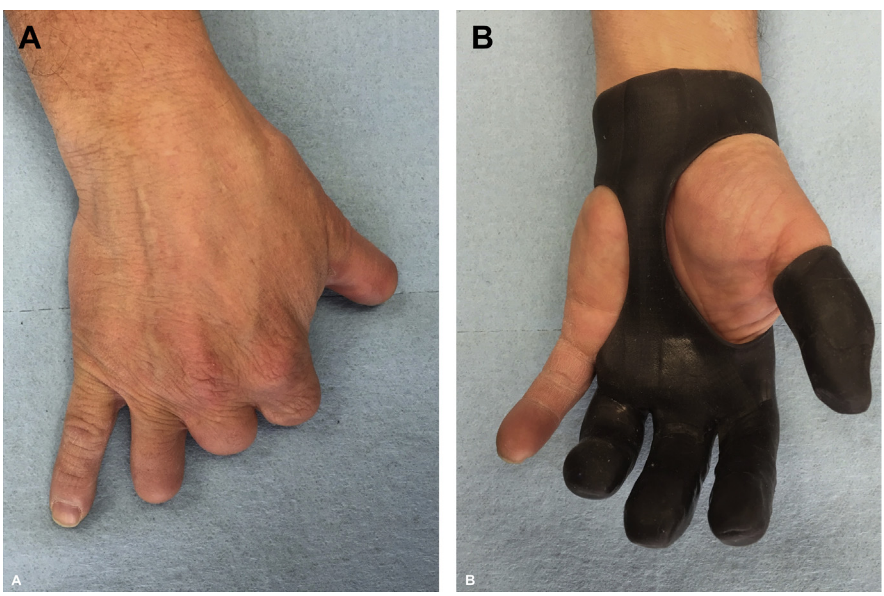

Fig. 2. An example of a custom silicone heavy-duty passive functional prosthesis that was created to be easy to use, durable, and cover less of the hand to improve heat dissipation. (*A*) The patient's hand in the pronated position without the prosthesis. (*B*) The patient wearing the prosthesis with his hand supinated. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

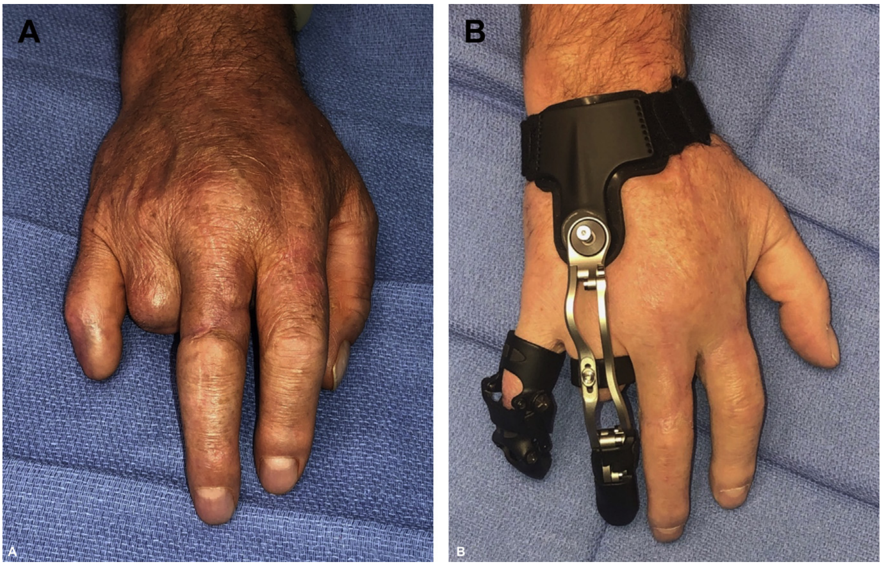

Fig. 3. (*A*) This patient experienced partial hand amputations to the fourth digit through the proximal phalanx and the fifth digit through the middle phalanx. Dorsal view of hand without his prostheses. (*B*) Patient wearing his prostheses. He was fitted with a Naked Prosthetics MCPDriver on the fourth digit and a Naked Prosthetics PIP-Driver on the fifth digit.

One BP prosthetic option for this level is the PIP-Driver by Naked Prosthetics (Naked Prosthetics Inc., Olympia, WA). Although functional outcomes are forthcoming, our experience is remarkable. Many patients report significant decreases in pain in the wrist, elbow, and shoulder after being fitted with the prosthesis because they are no longer required to make compensatory motions to grasp objects. The roll-cage–style design also lends itself to protecting the frequently hypersensitive distal end of the residual digit, which may further enable amputees to engage with their environments. Because of the intuitive nature of this prosthesis, acceptance and integration into ADLs is rapid. Even individuals with long-standing PHAs express high levels of satisfaction after being fitted with the PIPDriver. Tasks requiring grip strength and motor control, such as retrieving

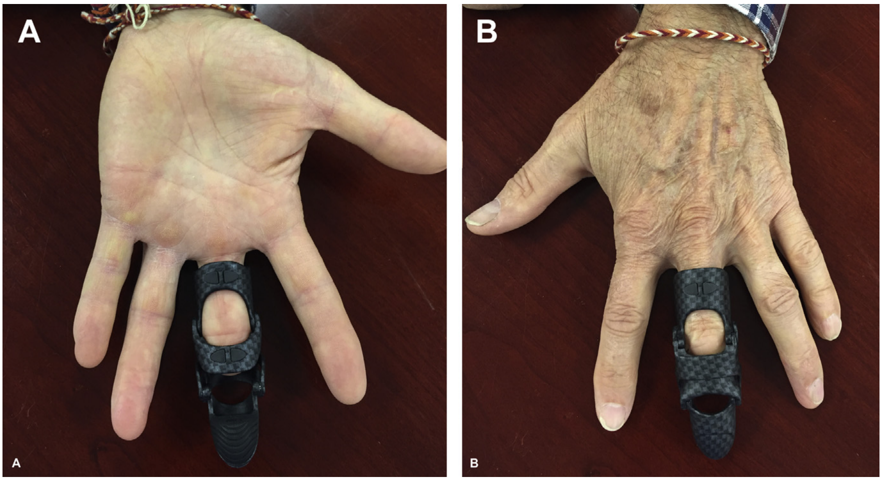

Fig. 4. (*A*) Volar perspective of a patient wearing a Naked Prosthetics PIPDriver on the third digit. (*B*) Dorsal perspective of PIPDriver on third digit. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

keys from pockets and pulling credit cards out of a wallet, are reportedly easier while using this prosthesis. The authors have witnessed patients returning to play musical instruments such as the piano and saxophone, file papers, open envelopes, use utensils, and tie shoelaces (Fig. 5). The improvement and ease of performing ADLs with the PIPDriver is especially notable when amputations at this level reside on the index finger, because it can restore up to 10% of hand function.[39]

Limitations to BP prostheses are primarily cosmetic. The design surrounds the digit, increasing the width around the remaining anatomic joints. If a glove is needed to cover the prosthesis for work-related activities, a larger size is typically needed on the affected side compared with the sound side.

Externally Powered Prostheses

To the best of our understanding, there are no externally powered prostheses available for PHA through the DIPJ and middle phalanx.

Fig. 5. A patient wearing a Naked Prosthetics PIPDriver to restore digit length and functionality to play the saxophone. Image courtesy of Naked Prosthetics.

PROSTHETIC OPTIONS FOR AMPUTATIONS THROUGH THE PROXIMAL INTERPHALANGEAL JOINT AND PROXIMAL PHALANX

The more proximal the transphalangeal amputation occurs, the more pronounced the deficits become. Impairment ratings for PHA of the proximal phalanx are often classified as moderate with a 16% loss in total hand function when the index finger and/or middle finger is involved.[39] When the amputation occurs through the proximal phalanx, the actions of the FDS and FDP are lost, leaving the residuum under the control of the extensor digitorum communis for extension and the intrinsic hand muscles for flexion. Because the intrinsic hand muscles are susceptible to fatigue, it can be challenging finding a prosthesis that restores functionality without exhausting the capabilities of these muscles.[40,41] Although low-definition and high-definition silicone prostheses are used to rehabilitate amputations at this level (see Figs. 2,6,7), emphasis is often placed on supplementing with a prosthesis that can restore length and mimic the functions of the FDS and FDP to maximize gross and fine motor function.

Passive Functional Prostheses

Passive articulating (PA) prostheses are widely available and include the Point Partial (Point Designs LLC, Lafayette, CO), Titan Partial (Partial Hand Solutions, LLC, Warren, MI), and Vincent Partial Passive (Vincent Systems GmbH, Karlsruhe, Germany). Point Partial and Titan Partial are better suited for amputations through or proximal to the PIPJ, whereas Point Digit, GripLock, and Vincent Partial Passive are designed for amputations through or proximal to the MCPJ. Independent of amputation level, PA prostheses restore

Fig. 6. An example of a high-definition silicone passive functional prosthesis on a partial hand amputee. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

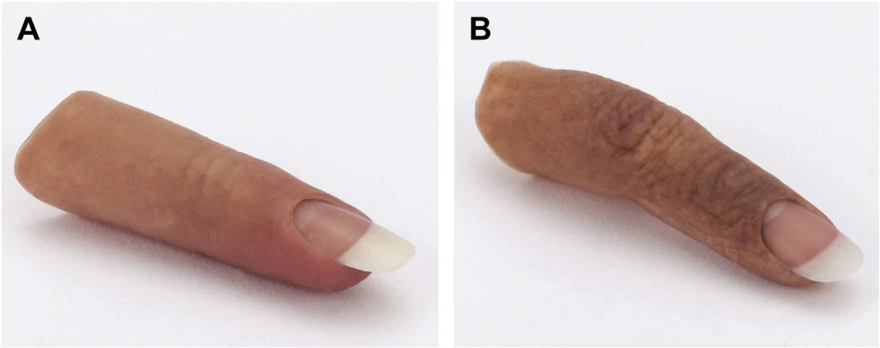

Fig. 7. (*A*, *B*) Examples of high-definition silicone passive functional prostheses used on separate patients. Images courtesy of Össur.

function by using a passive ratcheting mechanical mechanism to lock the prosthesis into various degrees of flexion to enhance functionality and overall movement. Use of the unaffected hand is common for positioning but is not necessary for adjusting the degree of flexion. When extension of the prosthesis is desired, the amputee can touch a button or use the spring-loaded release mechanism to reset the prosthetic to its normal resting position. Although changing the degree of flexion is simple, the inability of these prostheses to automatically flex and extend with movement of the residuum may be a limitation for some amputees. This type of prosthesis is ideal when heavy-duty bimanual tasks are required. Construction work, landscaping, welding, and automotive repair are a few examples of successful applications. Eating, food preparation, holding plates, holding grocery bags, and self-grooming are some of the ADLs where these prostheses are most useful.

Body-Powered Prostheses

Comparable to the PIPDriver, Naked Prosthetics (Naked Prosthetics Inc., Olympia, WA) also manufactures a BP prosthesis that uses the strength of an intact MCPJ to restore the length and functionality of the middle and distal phalanges. The MCPDriver restores finger flexion, extension, abduction, and adduction (**Figs. 8** and **9**). Another BP prosthesis option for this level includes the Partial M-Finger (Partial Hand Solutions, LLC, Warren, MI), which functions similarly to the MCPDriver. The primary difference between the M-Fingers and the MCPDriver are the mechanisms for capturing the motion of the intact MCPJs. The MCPDriver relies on a mechanical linkage for both flexion and extension, whereas the M-Fingers rely on a mechanical linkage for flexion but use spring-assist cable mechanism for extension. Although the cable system of the M-Fingers can be lower profile, the mechanical advantage of the MCPDriver is greater than that of the M-Fingers and facilitates higher overall grip strength. However, the M-Fingers make it easier to adjust the ROM and mechanical advantage than the MCPDriver, which has a fixed mechanical ratio that cannot be adjusted without ordering new custom-made linkages. Ideal candidates for these prostheses should have an intact MCPJ to power the prosthetic PIPJ and DIPJ, have enough residuum in the proximal phalanx to engage with the ring and/or harness, and be able to perform a minimum 60° of active ROM at the MCPJ.

Although randomized controlled clinical trials evaluating the effectiveness of these devices are forthcoming, our clinical experience with the MCPDriver is remarkable. This device has opened a new realm of functional possibilities that were not previously available to individuals with this amputation level. One anecdotal example from our practice includes a retired Air Force mechanic who had his thumb amputated proximal to the interphalangeal joint (IPJ) and middle finger amputated proximal to the PIPJ in a table saw accident. He was fitted with 2 custom MCPDrivers. Since his original fitting, he reports consistent, daily use of his prostheses. Through his prostheses, he can continue his passion of restoring classic cars. He recently reported that he was able to independently finish a hot rod remodel, which included a complete engine out overhaul and rebuild. He stated that he would not have been able to do all of the work himself had he not had his prostheses. The dexterity and grip strength provided by the MCPDriver, as well as the protection to his sensitive distal residual digits, are the factors that contributed to his success. Thus, the potential of this device to restore overall hand function and quality of life should not be overlooked by clinicians or insurers.

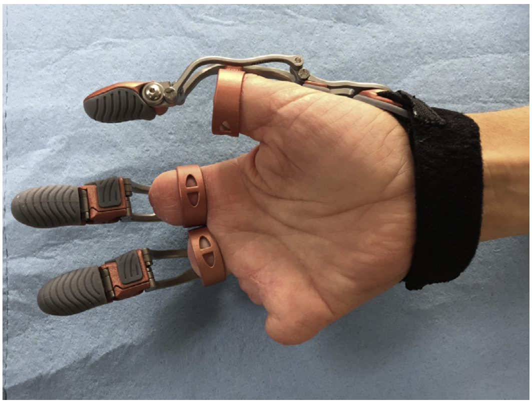

Fig. 8. An example of a Naked Prosthetics 3-digit system with a metacarpophalangeal (MCP) ThumbDriver and 2 MCPDrivers. The residual digits on digits 4 and 5 are not long enough to be used with the Naked Prosthetics MCPDrivers. Provision of point digits for digits 4 and 5 were considered; however, with input from the patient and a trial fitting, it was determined that the MCPDrivers alone provided the best functional return in this case. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

Externally Powered Prostheses

There are no externally powered prostheses for this amputation level currently available.

PROSTHETIC OPTIONS FOR AMPUTATIONS THROUGH THE METACARPOPHALANGEAL JOINT AND TRANSMETACARPAL

Injuries that result in amputations through or proximal to the MCPJ result in significant functional losses caused by destruction of intrinsic hand muscles, flexor and extensor tendons, MCPJ, and neurovascular structures. Transmetacarpal amputations immediately distal to the wrist often produce severe impairments, with an estimated 90% loss in total upper extremity function and a 54% decrease in whole-person ability.[39] These PHAs commonly result from trauma, peripheral vascular disease, and infection.[42] Amputations proximal to MCPJs and distal to the wrist result in partial or complete loss of grip strength because the index and middle fingers permit fine grasp, whereas the ring and small fingers support grip strength. Severity of impairment depends on the number of affected digits and metacarpals, and proximity of the amputation.[43] Although discussed separately, involvement of the thumb also contributes greatly to overall hand function. Because of the severity of this level of amputation and the accompanying decreased hand function, the prosthetic interventions are more involved to mitigate deficits. There is a greater variety of prosthetic options available at this amputation level. The more proximal the amputation, the more space available for prosthetic technology, including motors, batteries, and joints.

Passive Functional Prostheses

PA prostheses designed to treat proximal hand amputations include Point Digit (Point Designs LLC, Lafayette, CO), GripLock (Naked Prosthetics Inc., Olympia, WA), Titan Full (Partial Hand Solutions, LLC, Warren, MI), and Vincent Passive (Vincent Systems GmbH, Karlsruhe, Germany) (**Figs. 10** and **11**). These prostheses use a passive ratcheting mechanism to lock the prosthesis into various degrees of flexion, similar to the Point Partial and Titan Partial. Some of these prosthetics are touchscreen compatible, allowing amputees to interact with various modern touchscreen devices for additional functional use. The strength and carrying capacity of these prostheses are also reportedly higher compared with Point Partial, with

Fig. 9. An example of the fine motor restoration that can be provided to amputees with amputations through the proximal phalanx. Image courtesy of Naked Prosthetics.

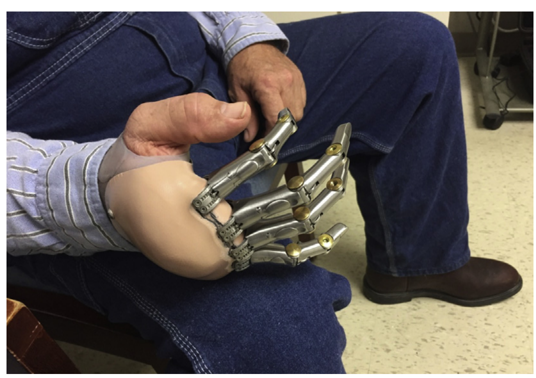

Fig. 10. At the MCP level, 4 Point Designs Point Digits are used to create a robust, heavy-duty prosthesis for this farmer. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

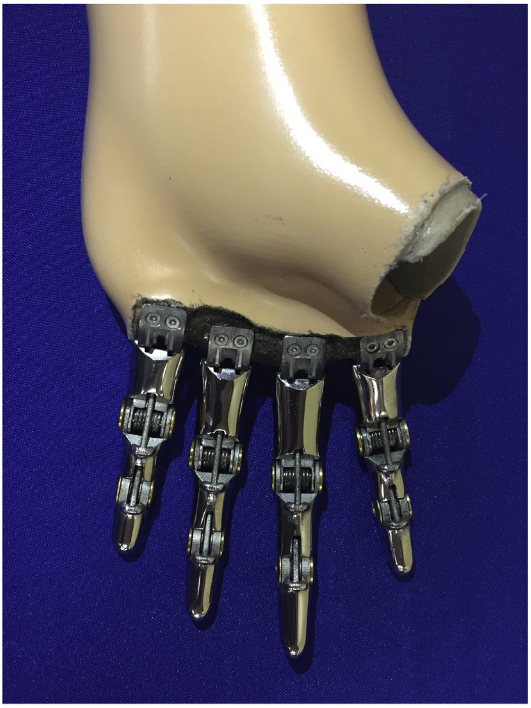

Fig. 11. Volar aspect of the 4 Point Designs Point Digits. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

carrying capacities near 90 kg (200 lb). The high strength and carrying capacities are advantageous compared with low-definition and high-definition silicone passive functional prostheses and externally powered prostheses because these classes of prostheses would fail under similar strenuous applications. In addition, PA prostheses are resistant to muscle fatigue because they do not depend on active muscle contraction to maintain flexion and grip, as do externally powered prosthetic devices. However, a limitation to these prostheses is a lack of spontaneous, natural body movement because the amputee must individually set the desired degrees of flexion for each prosthetic digit.

Body-Powered Prostheses

At this amputation level, BP prostheses are commonly referred to by their historical names, Robin-Aids, by the Medicare Healthcare Common Procedural Coding System (HCPCS) and by clinicians who work with upper extremity prostheses. Invented by George Robinson in the 1950s, this prosthesis consisted of a set of individual fingers linked together on a shared axis that are spring loaded and can be voluntarily opened by putting tension on a cable extending up the arm and looped around the contralateral shoulder. Although this device is no longer available, the concept used by the Robin-Aids prosthesis can still be used with commercially available components (Fig. 12). For transradial and more proximal level amputations, a wrist unit is typically used to attach various terminal devices depending on the desired function. These wrist units often allow quick changing between the different terminal devices. Two companies, Texas Assistive Devices (Brazoria, TX) and TRS Prosthetics (Boulder, CO), have developed quick-disconnect wrist units that have been adapted for the use at this partial hand level. The quick-disconnect unit is mounted either on the palmar surface of the residual hand or on a cuff on the residual wrist. The appropriate attachment is then connected to the quick-disconnect unit. This arrangement allows for use of traditional voluntary opening and voluntary closing terminal devices, as well as activity-specific terminal devices such as utensils and sport and recreational attachments, both also available from Texas Assistive Devices and TRS Prosthetics, respectively. For these devices to work, a custom silicone interface and laminated composite frame are necessary. This prosthesis is functionally robust and retains full ROM at the wrist. In addition, recent advances in the quality and strength of additive manufacturing materials has increased the opportunity for innovation in this space.

The M-Fingers by Partial Hand Solutions (Partial Hand Solutions, LLC, Warren, MI) is an additional BP prosthesis that is specifically marketed and manufactured for this level. The M-Finger prosthesis is designed to mimic tenodesis by flexing the fingers with wrist extension and allowing the prosthesis to extend the finger with wrist flexion. This prosthesis is larger than BP prostheses designed for more distal PHAs to maximize the movements of the remaining MCPJ and intrinsic hand muscles. However, similar to all BP

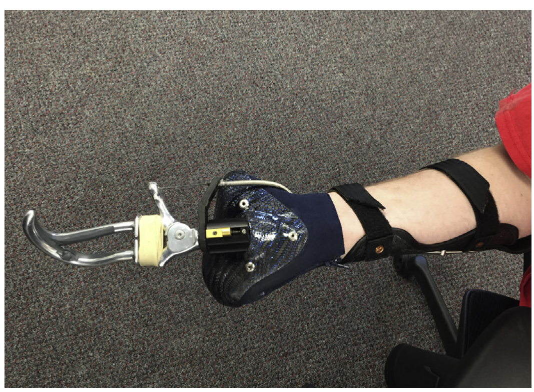

Fig. 12. An example of a BP prosthesis used for a transmetacarpal partial hand amputation. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

prostheses, this device restores length and the ability to grip, and naturally extends and flexes the digits with movement. One advantage to this design is that the control does not require a cable and harness that run up the arm and around the contralateral shoulder. Partial Hand Solutions also carries Pediatric M-Finger, which is a BP prosthesis uniquely designed to rehabilitate children with PHAs and those born with congenital differences.

Externally Powered Prostheses

Externally powered prostheses become an option at this amputation level. Myoelectric (MYO) prostheses are externally powered prosthetic devices that function by recording surface electromyography (EMG) signals from muscle contraction of the residual intrinsic hand muscles to move the prosthetic digits (**Figs. 13** and **14**). If insufficient surface EMG signals are present in the intrinsic hand muscles, then the extrinsic hand muscles in the forearm can be used to control the device. However, use of the extrinsic muscles is not ideal because wrist motion can inadvertently cause undesired activation of the powered digits. MYO devices are powered by a battery and microprocessor located in the amputee's device wristband. These prostheses have several advantages, including the ability to achieve various grip postures through independent and synchronous control of the affected digits. At present, the control of the digits produces a composite grasp, opening and closing the digits in a preprogrammed pattern selected by the user.

The i-Digits Quantum (Össur, Reykjavik, Iceland) is an example of an MYO hand prosthetic for individuals with partial hand amputation or deficiency distal to the wrist and proximal to the MCPJ and can include loss of 1 to 5 digits. The i-Digits Quantum has up to 32 automated grips and has features

Fig. 13. This patient is using an i-Digits Quantum from Össur to accomplish ADLs independently. Image courtesy of Össur.

Fig. 14. MYO options are often capable of sustaining various grip postures in addition to providing restoration of fine motor movement. Image courtesy of Össur.

including i-MO Gesture Control, Vari-Grip and Auto Grasp to enhance grip strength and functional use. Vari-Grip allows adjustable digit-by-digit strength and autograsp prevents objects from slipping. Gesture control is unique because it enables an automated grip to be accessed by moving the device in one of 4 directions. In addition, the amputee can enhance the speed and strength of the prosthetic and choose between several different preset grips by using the Biosim My i-limb app on a smartphone device. The i-Digits Access is a device that functions similar to the i-Digits Quantum except it only has 12 grips available and does not have as many functional enhancing features. The i-Digits Access was specifically developed for use with patients who have limited funding resources. This device is appropriate for low-impact to moderate-impact functions that do not exceed the maximum device load of 20 kg for the total hand and 5 kg for the digits. In addition to the i-Digits Quantum and Access, the Vincent Partial 3 Active (Vincent Systems GmbH, Karlsruhe, Germany) is the only other externally powered MYO digit system available for PHA.

When all 5 digits are involved in a transcarpal amputation or an extremely proximal transmetacarpal amputation, the option exists to use a full prosthetic hand that has a specially adapted lamination collar. There are multiple prosthetic hands that have this option, including the Transcarpal Hand and the Bebionic Short Wrist (Ottobock, Duderstadt, Germany), the Vincent Evolution 3 and Vincent Young (Vincent Systems GmbH, Karlsruhe, Germany), the Motion Hand, ETD, and ETD2, all with the short wrist option (Motion Control, Salt Lake City, UT), and the i-Limb Quantum, i-Limb Ultra, and i-Limb Access all with the wrist disarticulation option (Össur, Reykjavik, Iceland).

Fabrication for these devices requires a custom silicone interface with a rigid carbon fiber shell for the terminal device to mount properly. The custom silicone interface allows for retention of the anatomic motions of the wrist joint. Pockets in the silicone forearm portion can be created to house the electronics and batteries.

Several studies report functional outcomes and cosmetic appeal of BP and MYO prostheses in upper extremity amputees. Although many of these studies are not specific to PHA, they may provide insight while specific studies relating to PHA are forthcoming. MYO options are reportedly more aesthetically pleasing than BP prostheses because they better resemble the natural form of the hand.[37,44] BP prostheses are usually more mechanical and hooklike in appearance because these prostheses generally leave the harness and cables exposed. However, some individuals prefer the distinct appearance of a BP prosthetic to more traditional-appearing MYO devices. Exploring preferences in cosmesis should be performed before selecting a class of prostheses.[38]

MYO prostheses are also more commonly associated with improvements in phantom limb pain.[37,45,46] This association may be because of how the MYO prostheses are activated using the same muscles that would activate the anatomic digits. This feature creates a greater sense of embodiment of the device, which may contribute to the reduction in phantom limb pain. BP prostheses are activated using gross body motions, which may not reproduce the same level of embodiment. In terms of functionality, both are associated with advantages, and neither prosthetic has consistently shown superior outcomes. This finding continues to show that neither device category should be considered in opposition to one another. Each device type has its own unique purpose and function. No single prosthesis can make up for the deficits associated with upper limb loss.[47]

However, an advantage of BP prostheses includes improved sensory feedback compared with MYO devices.[37,48,49] Both MYO and BP prostheses use visual feedback as a means to control the prosthetic device. Proprioception and tactile feedback may be additional sensory modes available to amputees with BP prostheses through the external harness and cables.[37] BP prostheses are also thought to be more durable and easier for amputees to maintain, and require less specificity during fittings.[37,48–50] Rather than being joint driven and cable controlled like BP prostheses, MYO devices require stimulation from proximal muscles. Establishing a stable connection between the muscles and the prosthesis requires precise, patient-specific fittings. The time required to precisely fit the MYO device, along with the increased time needed to achieve success in performing ADLs, is another disadvantage of MYO devices. MYO devices may thus be better suited for amputees hoping to improve the natural form of the hand, for those only needing a prosthesis for light-intensity work, and for those with primary goals of alleviating phantom limb pain.[37] However, research on functional outcomes specific to PHA are needed to validate these conclusions.

PROSTHETIC OPTIONS FOR AMPUTATIONS THROUGH THE THUMB

The thumb is the most important digit of the hand. Although loss of the index or long finger can result in up to a 20% loss in total hand function, loss of the thumb results in a 40% reduction in total hand function and a 22% reduction in whole-person function.[39,51] The significance of the thumb is largely attributed to its ability to serve as a sensate post, enabling the hand to grip in multiple positions for gross and fine motor function.[52] Often quoted, the hand without the thumb is nothing more than an animated spatula, serving little to perform ADLs and maintain independence.[53] The thumb is also one of the most humanistic features of the body.[54] Loss of the thumb can impede social interactions and decrease self-esteem.[55] Whether the amputation to the thumb is partial, complete, or part of a polytrauma to the hand, restoring the length and actions of the thumb should remain a priority. Several surgical approaches are available, including toe to thumb transfers, pollicization, metacarpal lengthening, web space deepening, various flaps, and potentially osseointegration.[56] However, these procedures have contraindications and complications.[57–59] Often, the use of a prosthetic device may serves as a straightforward solution to correcting an amputation through the thumb.

Passive Functional Prostheses

One of the primary functions of the thumb is to serve as a post to allow opposition. Although flexion at the IPJ is important for fine motor tasks, restoring thumb length and rotation at the MCPJ can greatly improve overall hand function. For this reason, low-definition and high-definition silicone prostheses can be used for partial and complete thumb amputations (**Figs. 2** & **15**). Vincent Passive Thumb (Vincent Systems GmbH, Karlsruhe, Germany) is another passive functional prosthesis designed for thumb amputations through

Fig. 15. A medium-definition silicone passive functional prosthesis used to restore the form and length of an amputated thumb. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

the MCPJ that restores thumb length and can serve as a post (Fig. 16). An advantage of this prosthesis includes a rotating base near the MCPJ that allows thumb rotation and 2 degrees of freedom. The capability to rotate at the base can promote additional gripping positions. However, like silicone prostheses, this prosthesis cannot provide flexion of the IPJ. Titan Thumb and M-Thumb by Partial Hand Solutions (Partial Hand Solutions, LLC, Warren, MI) are PA prostheses that are better suited for movements requiring pincer grasp. Both prostheses are designed for thumb amputations at or proximal to the MCPJ and carry the same advantages as other PA prostheses previously mentioned. An added advantage of the M-Thumb is an artificial fingernail that allows amputees to pick up small objects and perform other fine motor movements. Although the Titan Thumb and M-Thumb are better at restoring hand function than low-definition and high-definition silicone prostheses, all prostheses in this class are unable to restore natural thumb flexion and extension.

Fig. 16. This is an example of a prototype prosthesis created with an opposition post. Thermoplastics, epoxy, and Velcro are all used in this important diagnostic phase of the fitting protocol in order to optimize the fit and very function before committing to the definitive prosthesis. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

Body-Powered Prostheses

ThumbDriver by Naked Prosthetics (Naked Prosthetics Inc., Olympia, WA) is one of the only BP prostheses available for thumb amputations (Figs. 17 and 18). Ideal candidates for this device are individuals with amputations occurring distal to the thumb MCPJ but proximal to the IPJ. Advantages of using a BP prosthesis on the thumb include synchronicity with the natural flexion and extension of the hand to rapidly interact with the environment. Gross and fine motor tasks such as catching and throwing a ball, playing a musical instrument, and opening and closing zip-lock bags are made possible by the intrinsic nature of BP prostheses. A limitation of the ThumbDriver is that it is not designed for distal partial thumb amputations. To combat this limitation, the authors occasionally use a custom variant of the PIPDriver (Naked Prosthetics Inc., Olympia, WA) for amputees with more distal thumb amputations and who desire a BP prosthesis. Although our implementation of the PIPDriver for distal partial thumb amputations is an off-label use of the prosthesis, we have seen remarkable improvements in total hand function.

Externally Powered Prostheses

Thumb amputations proximal to the MCPJ may benefit from MYO prostheses (Fig. 19). Both the i-Digits and Vincent Partial Active can be used to restore functional grasp in both lateral and opposition postures. However, for implementation of these devices to be successful, a sufficient amount of the ray needs to be resected. Also, as previously

Fig. 17. A demonstration of the dexterity and pinch force that can be generated with the Naked Prosthetics MCPDrivers and MCP ThumbDriver. The patient was able to easily open and close this coin purse using this custom prosthesis. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

Fig. 18. The restoration of gross motor function and thumb strength through the Naked Prosthetics MCP ThumbDriver. (Image courtesy of Naked Prosthetics.)

described, the use of an MYO partial hand prosthesis is for low-duty to moderate-duty tasks.

ACTIVITY-SPECIFIC PROSTHESES

A separate class of prostheses that can be described for many amputation levels is an

Fig. 19. A full 5-digit Össur i-Digits system used for a patient with amputation of all digits proximal to the MCPJs. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

activity-specific prosthesis (Fig. 20). As the name implies, this type of prosthesis is designed to assist with a particular function and is more of an assistive device or tool than a replacement. Unlike the previously described prostheses, these devices are not used for extended periods of time. They may be used only a few times per week. However, this does not detract from their importance in the overall prosthetic rehabilitation of an individual with a PHA.

Initial activity-specific prostheses can be made simply using Aquaplast (Performance Health, Warrenville, IL), a low-temperature thermoplastic. They are often fitted by a certified hand therapist (CHT) or occupational therapist (OT) during an inpatient rehabilitation stay. These prostheses tend to be beneficial in the short term but are not suitable as long-term use devices because of degradation over time. They can be beneficial as prototypes of a permanent long-term activity-specific device made from composites, leather, and/or from additive manufactured materials. Examples include a device made to specifically help with dressing and doing up buttons or a comb integrated into a mitt that allows easier grooming. They can also be more recreational, such as a prosthesis to hold onto handlebars, grasp a bow, or throw a ball (Fig. 21). A single activity-specific prosthesis can be made to perform a variety of activities through the use of a quick-disconnect unit, as previously described from TRS or Texas Assistive Devices. This device allows the attachment of any number of individual terminal devices.

A summary of the available prosthetic devices by level of amputation is provided in Table 1.

Fig. 20. A body-powered partial hand prosthesis for the same patient that uses the prosthesis in Fig. 12. This prosthesis uses a quick disconnect palmar wrist unit. The forearm shield and cable can be removed from this prosthesis and different activity specific terminal devices can be connected to the remaining palmar portion of the prosthesis. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

Fig. 21. Example of an activity specific prosthesis for throwing a baseball. The patient and his son were overjoyed when they were able to play catch together for the first time. (*Courtesy of* Handspring Clinical Services, Middletown, NY; with permission.)

SURGICAL INTERVENTIONS TO IMPROVE PROSTHETIC FUNCTION

Having a working understanding of partial hand prostheses, such as those mentioned in this review, can guide hand surgeons in initial treatment and secondary surgeries for PHAs. Furthermore, building a relationship with a specialized upper extremity prosthetist can prove invaluable when working with patients with PHA. Our survey of AAHS members showed that slightly more than a quarter of hand surgeons regularly consult with a prosthetist before performing revision surgeries on the PHA. This finding could be caused by the low number of upper extremity–focused prosthetists or simply by a lack of surgeon understanding of prosthetic options. Working in a multidisciplinary upper extremity limb loss team is the ideal scenario to maximize patient outcomes, although it is not always possible.

Surgical interventions to maximize prosthetic possibilities for PHA include performing procedures at the time of the initial injury and secondary revision surgeries. Examples of primary operative interventions include preserving or decreasing length to enable specific prosthetic use. As an example, a patient presented to us with a mutilating 5-finger saw injury. The thumb and index finger were salvaged and replanted, but the middle, ring, and small fingers were nonsalvageable. We chose to perform filet flaps to preserve as much length of the proximal phalange as possible and fitted MCPDrivers to the unsalvageable fingers, rather than disarticulating at the MCPJ (**Fig. 22**).

Examples of secondary revisions to optimize partial hand prosthesis fitting include digit shortening, lengthening, flap revisions/debulking, and muscle and nerve procedures. Gaston and colleagues[60] recently described a technique of dissecting and translocating the interosseous muscles of a PHA superficially for stronger EMG signals, allowing individual digit MYO function in the starfish procedure. Nerve procedures such as targeted muscle reinnervation and the regenerative peripheral nerve interface have also been described for improving prosthetic control in the setting of more proximal amputations and hold potential for improving prosthetic EMG signals and decreasing neuroma pain.[61–65]

As an example of a secondary revision to optimize prosthetic fitting in our practice, a patient presented with a crush/avulsion injury to his left hand in an industrial accident resulting in dorsal hand degloving with nonsalvageable amputations to the index through small fingers through the proximal phalanges. He was treated with groin flap coverage to preserve length. At the recommendation of the prosthetist, he underwent multiple debulking procedures and syndactyly releases of the second, third, and fourth web spaces (**Fig. 23**) to be fitted with MCPDrivers. In our practice, considering partial hand prosthetic devices and maintaining open discussion with the multidisciplinary team results in effective surgical planning and improved patient outcomes.

ROLE OF HAND THERAPY

As expressed throughout this review, the importance of the loss of a hand, or part of the hand, cannot be overstated. In addition to the necessary ADLs, the hand is also an organ of performance. It serves as eyes for the blind and enables the deaf to speak. It has become a symbol of salutation, supplication, and condemnation. The hand plays a significant role in the creative life of every known society. It has come to be symbolic of the whole person in art, drama, and dance.[66] Thus, the background and training of OTs and/or CHTs is critical in enabling individuals with PHAs to adapt and resume independence. Ideally, the relationship between the patient and OT/CHT should be

Table 1
Summary of partial hand prosthetic options by level of amputation

Amputation Level	Prosthesis Class	Prosthetic Options
Distal to DIPJ	Passive functional	Low-definition silicone High-definition silicone
DIPJ and middle phalanx	Passive functional	Low-definition silicone High-definition silicone
	Body powered	PIPDriver
PIPJ and proximal phalanx	Passive functional	Low-definition silicone High-definition silicone Point Partial Titan Partial Vincent Partial Passive
	Body powered	MCPDriver Partial M-Finger
MCPJ and transmetacarpal	Passive functional	Low-definition silicone High-definition silicone Point Digit GripLock Titan Full Vincent Passive
	Body powered	M-Fingers and Pediatric M-Finger Palmar Quick Disconnect Pro Cuff
	Externally powered	i-Digits Quantum Vincent Partial 3 Active
Thumb, partial or complete	Passive functional	Low-definition silicone High-definition silicone Vincent Passive Thumb Titan Thumb M-Thumb
	Body powered	ThumbDriver PIPDriver
	Externally powered	i-Digits Vincent Partial Active

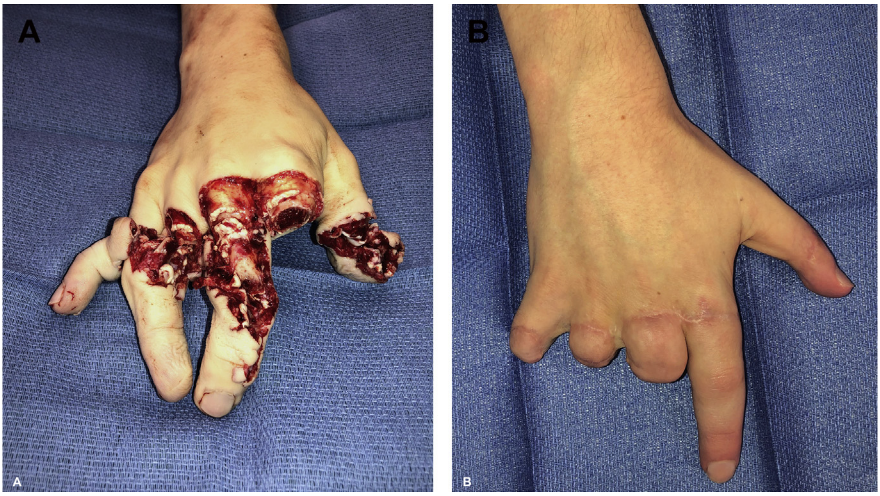

Fig. 22. After a traumatic partial hand injury, reconstruction with filet flaps was chosen to maximize residuum length on the middle, ring, and small fingers for later fit with MCPDrivers.

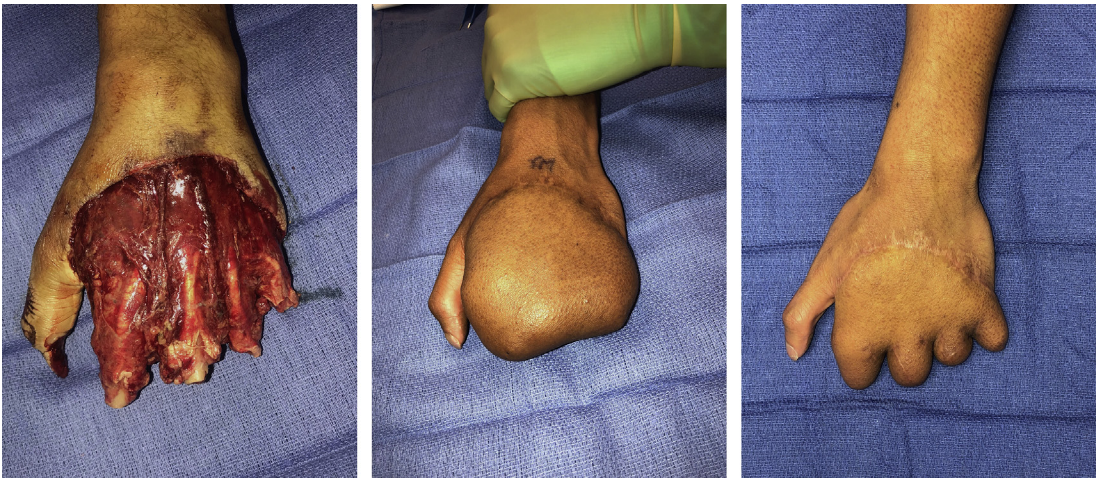

Fig. 23. A series of surgical revisions were completed to prepare the patient's hand to be fitted with a 4-digit Naked Prosthetics MCPDriver custom prosthesis after an industrial crush avulsion of the hand that was reconstructed with a groin flap.

established no later than 3 to 5 days after the initial presentation of PHA. Establishing an early patient-therapist relationship likely contributes to improved short-term and long-term outcomes because the OT/CHT serves to educate and support the patient and act as a liaison for the multidisciplinary team.

Preprosthesis Care

OT/CHT awareness of the preprosthetic principles of care is critical to the successful management of individuals who have sustained traumatic PHA. During the healing phase, emphasis is placed on providing wound care and teaching the patient how to maintain hand hygiene, control edema, stump shaping, promote hand desensitization, and perform active ROM (AROM) and passive ROM (PROM) exercises. Comprehensive hand therapy during the healing phase helps maintain skin mobility and muscle strength. Mirror therapy and laterality awareness are also used early to diminish phantom limb pain.[67] The time spent with an OT/CHT affords patients opportunities to express current and future hand function goals and time to explore prosthetic device options. During this time, OTs/CHTs are also able to evaluate patient needs for functional independence and can strategize which 1-hand techniques and adaptive equipment are needed. If a prosthesis is desired, an experienced OT and CHT can fabricate protective splinting and preprosthetic devices such as a thumb post to mimic future prosthetic use and can determine potential EMG sites if an MYO prosthesis is being considered.

During the time the partial hand prosthetic prescription is being discussed, there are many factors that the OT/CHT should document and explore with the patient to determine the best prosthetic option. Physical characteristics, including amputation level, amount of soft tissue coverage, AROM/PROM and muscle strength of the remaining hand, status of the unaffected extremity, presence and quality of remaining sensation, and the presence of adherent scars, should be noted on the physical examination during therapy. Social factors, including patient goals, attitude and motivation, ability to learn and adapt, vocational and avocational interests, and third-party payer considerations, should also be discussed with the multidisciplinary team.[68]

Postprosthesis Care

Once the multidisciplinary team, patient, and family decide on a type of prosthesis, successful outcomes can be attributed to early posttraumatic intervention, experienced team approach, patient-directed prosthetic training, patient education, patient monitoring, and follow-up. Regardless of the device, the following keys should be included in every partial hand prosthetic training program: (1) independence in donning and doffing; (2) orientation to a gradual prosthetic wearing program and monitoring skin status; (3) orientation to prosthetic controls training when an electric partial hand prosthesis is prescribed; (4) prosthetic practice in grasp and release function; (5) functional use training with an emphasis on bilateral tasks that will be possible with the partial hand prosthesis. Of these training principles, the most important is the emphasis placed on bilateral tasks that are considered important for the individual with partial hand loss to accomplish. These tasks should be practiced sitting and standing. Unless these tasks are identified, practiced, and reinforced, the true value of the partial hand prosthesis will not be experienced or appreciated. Successful use training is achieved when the amputee uses the prosthesis spontaneously and effectively for most daily activities.[69]

ROLE OF PHYSICAL MEDICINE AND REHABILITATION PHYSICIANS IN PARTIAL HAND AMPUTEE CARE

Physical medicine and rehabilitation (PMR) physicians, or physiatrists, are integral to the multidisciplinary team. Although hand surgeons readily value the contributions of prosthetists and OTs/CHTs, our recent AAHS survey revealed that many surgeons do not fully appreciate the contributions of PMR physicians. Note that, although hand surgeons provide amputee care initially, PMR physicians often provide short-term and long-term care throughout the amputee's life. Highlighting their role in the multidisciplinary team may thus improve outcomes and increase quality of life for patients with PHAs.

PMR physicians are trained in diagnosing, assessing, and treating patients with physical disabilities. Although their profession is frequently associated with caring for chronic neurologic conditions, their training also prepares them to manage amputees. Within the multidisciplinary team, their role is to maximize physical, psychological, social, and occupational independence by restoring hand function. This goal is often accomplished through prescribing pharmacologic agents, teaching therapeutic exercises, and engaging amputees in holistic therapies, including cold, heat, massage, traction, electrical stimulation, and biofeedback. These interventions are frequently used to improve functionality in addition to alleviating pain. Pain at the residuum is a frequent obstacle to amputee care. Pain often decreases mobility and return to normal ADLs and increases prosthetic abandonment. PMR physicians are invaluable to combatting these sequelae. Managing amputee pain is complex and patient specific; however, physiatrists often provide relief using local and/or regional injections and other pharmacologic agents. Examples of common injection classes include local anesthetics (lidocaine), steroid injections (methylprednisolone acetate), and neuromuscular junction toxins (botulinum toxin type A). Other pharmacologic classes used in amputee pain management include *N*-methyl-D-aspartate (NMDA) receptor antagonists, opioids, anticonvulsants, antidepressants, and calcitonin.[70] Another important role PMR physicians play at our institution is in identifying and referring amputees who have failed standard pain management strategies for targeted muscle reinnervation to treat their neuroma and phantom limb pains. This role has become an important part of the multidisciplinary approach at the University of Utah.

Perhaps more valuable than their knowledge of pharmacologic pain management is the physiatrists' ability to prevent the development of pain and promote wellness. PMR physicians with clinical interests in limb rehabilitation often have extensive knowledge of prostheses and are proficient amputee educators. Prevention and early detection of poor prosthesis fit and/or pressure ulceration can prevent prosthetic abandonment and other negative sequelae. Ultimately, PMR physicians serve as powerful liaisons to multidisciplinary teams and as advocates for patients. As institutions expand and create upper extremity care teams, the role of the PMR physician should not be overlooked.

BARRIERS TO PROSTHETIC REHABILITATION

There are multiple factors that create impediments to the provision of prosthetic rehabilitation for partial hand amputees. Time from injury to provision of a prosthesis, patient involvement in prosthesis selection, perceived need, functionality, and comfort of the prosthesis were the top contributing factors in achieving a successful functional outcome.[71,72] Clinically, a perceived lack of options and poor outcomes historically have dissuaded many physicians and surgeons from prescribing PHA prostheses. It is the hope of the authors that the information provided in this review will change that perspective, noting that there are now many different options available for the different levels of amputation that can produce successful functional outcomes. There is a pervasive misapprehension that prosthetic technology is responsible for the success or failure of the outcome. It is easier to blame the device and technology than it is to introspectively assess the way in which the prosthesis was provided. It has been our experience that many users who have rejected the use of a prosthesis have done so because they were not fitted with the appropriate prosthetic technology. Even when amputees may have been fitted with the most appropriate prosthesis, not having a proper fit by a prosthetist that has experience in upper limb prostheses can also lead to subsequent prosthetic abandonment. According to the most recent clinical practice survey of all certified prosthetists in the United States, on average prosthetists only spend 2% of their time caring for individuals with PHA.[73] Most of their time is spent caring for individuals with lower limb absence or difference. Because the functional restorative needs for the upper and lower limbs are distinct, so is the expertise to be able to properly treat and care for these different patient populations. Fortunately, there are prosthetists that have dedicated most of their practices to the care and provision of upper limb prostheses. These upper limb prosthetic specialists tend to work in and around regional metropolitan centers. It is critical for the prosthetic outcome that individuals needing a partial hand prosthesis be cared for by a prosthetist with extensive experience in treating this level of amputation, which may mean the individual seeking care having to travel to regional centers. An inexperienced prosthetist may not be able to provide an objective clinical evaluation to determine the most appropriate prosthetic recommendation. An inexperienced prosthetist may also not be able to produce a well-fitting prosthetic socket, which can contribute to discomfort, pain, and potentially skin breakdown, all factors highly likely to contribute to abandonment.

Insurance authorization and reimbursement for partial hand prostheses can be a barrier to a successful outcome, but it is possible to achieve. Over the past several years, payers have become increasingly aware of some of the newer technologies and have begun to provide coverage with appropriate clinical justification. However, the established HCPCS L-Codes used by Medicare and private insurance to describe and reimburse for prostheses are often outdated and limited in scope. For this reason, miscellaneous codes are often necessary in billing. Any time miscellaneous codes are used, the burden of documentation of medical necessity increases. Also, many insurance policies include language deeming prostheses distal to the wrist as experimental and investigational, which is no longer accurate.

A collaborative team approach including a surgeon, physiatrist, OT/CHT, and upper limb prosthetist is the most effective way to overcome reimbursement barriers.[74] When members of the multidisciplinary team are unified in outcome objectives, a comprehensive rehabilitation plan can be formulated and implemented. It is important to document all clinical decisions during treatment and collaboration sessions. This documentation shows that a process was followed, and that the recommended treatment plan is based on solid clinical practices rather than simple appeal to novelty. When possible, prototype prostheses should be constructed and trialed to prove clinical viability and functionality. When a prosthesis is provided within the golden window of 6 months after amputation, there is a significant increase in the probability of successful integration of the prosthesis into ADLs, a reduction in the likelihood of abandonment, and a drastically improved likelihood that the individual will be able to return to work and active participation in society.[71,72] The authors' combined experience shows that the sooner an upper limb prosthesis is fitted and delivered, the better the outcome and likelihood of use in daily activities. Prosthetic training by a skilled OT/CHT in amputee rehabilitation is of paramount importance in ensuring success.

For insurance authorization purposes, the prescribing physician's documentation must include medical necessity and justification. Other members of the rehabilitation team can help produce this documentation, but it ultimately needs to be included in the prescribing physicians' clinical progress notes. The prescribing physician must be prepared to defend this clinical justification in a peer-to-peer session with the medical reviewers from the payer. When this model is implemented, the authors have seen success in having medical policies overturned and the various described devices authorized.

SUMMARY

PHAs are the most common upper extremity amputation. Because the fingers, thumb, and transmetacarpal regions can be affected, treatment options restoring form and function are essential to alleviating the burdens on individuals and communities. Through recent advancements in engineering, prosthetic devices are increasingly available and provide straightforward solutions for partial hand amputees. To enhance clinician familiarity and promote patient care, this article highlights many of the current prosthetic options by amputation level, as well as some of the critical elements to successful prosthetic fitting. Understanding the application of these devices allows more proficient amputee care, especially while working within a multidisciplinary team. As partial hand amputee care expands, this article may provide a foundation for future research and serve clinicians during patient care and advocacy.

DISCLOSURE

D.J. Atkins is a former consultant at Össur and Touch Bionics. C.C. Duncan is partially funded by a National Science Foundation grant. S.D. Mendenhall is a consultant for PolyNovo. The other authors have no disclosures.

REFERENCES

1. Akarsu S, Tekin L, Safaz I, et al. Quality of life and functionality after lower limb amputations: comparison between uni- vs. bilateral amputee patients. Prosthet Orthot Int 2013;37(1):9–13.
2. Durmus D, Safaz I, Adiguzel E, et al. The relationship between prosthesis use, phantom pain and psychiatric symptoms in male traumatic limb amputees. Compr Psychiatry 2015;59:45–53.
3. Pasquina CP, Carvalho AJ, Sheehan TP. Ethics in Rehabilitation: Access to Prosthetics and Quality Care Following Amputation. AMA J Ethics 2015; 17(6):535–46.
4. Burger H, Marincek C. Return to work after lower limb amputation. Disabil Rehabil 2007;29(17): 1323–9.
5. Craig M, Hill W, Englehart K, et al. Return to work after occupational injury and upper limb amputation. Occup Med (Lond) 2017;67(3):227–9.
6. Sheikh K. Return to work following limb injuries. J Soc Occup Med 1985;35(4):114–7.
7. Raichle KA, Hanley MA, Molton I, et al. Prosthesis use in persons with lower- and upper-limb amputation. J Rehabil Res Dev 2008;45(7):961–72.
8. Dietrich C, Nehrdich S, Seifert S, et al. Leg prosthesis with somatosensory feedback reduces phantom limb pain and increases functionality. Front Neurol 2018;9:270.
9. Bouma SE, Postema SG, Bongers RM, et al. Musculoskeletal complaints in individuals with finger or partial hand amputations in the Netherlands: a cross-sectional study. Disabil Rehabil 2018;40(10):1146–53.
10. Grob M, Papadopulos NA, Zimmermann A, et al. The psychological impact of severe hand injury. J Hand Surg Eur Vol 2008;33(3):358–62.
11. Kuret Z, Burger H, Vidmar G, et al. Adjustment to finger amputation and silicone finger prosthesis use. Disabil Rehabil 2019;41(11):1307–12.
12. Varma P, Stineman MG, Dillingham TR. Epidemiology of limb loss. Phys Med Rehabil Clin N Am 2014;25(1):1–8.
13. Ziegler-Graham K, MacKenzie EJ, Ephraim PL, et al. Estimating the prevalence of limb loss in the United States: 2005 to 2050. Arch Phys Med Rehabil 2008; 89(3):422–9.
14. Chang DH, Ye SY, Chien LC, et al. Epidemiology of digital amputation and replantation in Taiwan: A population-based study. J Chin Med Assoc 2015; 78(10):597–602.
15. Panagopoulou P, Iakovakis I, Mentis AFA, et al. Epidemiology and Prevention of Hand Amputations in Greece: Data from the Emergency Department Injury Surveillance System. Inj Prev 2010;16:A173.
16. Bahar Moni AS, Hoque M, Mollah RA, et al. Diabetic Hand Infection: An Emerging Challenge. J Hand Surg Asian Pac Vol 2019;24(3):317–22.
17. Shale CM, Tidwell JE 3rd, Mulligan RP, et al. A nationwide review of the treatment patterns of traumatic thumb amputations. Ann Plast Surg 2013;70(6):647–51.
18. Clasper J, Ramasamy A. Traumatic amputations. Br J Pain 2013;7(2):67–73.
19. Davidson J. A comparison of upper limb amputees and patients with upper limb injuries using the Disability of the Arm, Shoulder and Hand (DASH). Disabil Rehabil 2004;26(14–15):917–23.
20. Adamo DE, Taufiq A. Establishing hand preference: why does it matter? Hand (N Y) 2011;6(3):295–303.
21. Burger H, Maver T, Marincek C. Partial hand amputation and work. Disabil Rehabil 2007;29(17): 1317–21.
22. Kearns NT, Jackson WT, Elliott TR, et al. Differences in level of upper limb loss on functional impairment, psychological well-being, and substance use. Rehabil Psychol 2018;63(1):141–7.
23. Imbinto I, Peccia C, Controzzi M, et al. Treatment of the partial hand amputation: an engineering perspective. IEEE Rev Biomed Eng 2016;9:32–48.
24. Imbinto I, Peccia C, Controzzi M, et al. Corrections to "treatment of the partial hand amputation: an engineering perspective. IEEE Rev Biomed Eng 2018; 11:322.
25. Wang K, Sears ED, Shauver MJ, et al. A systematic review of outcomes of revision amputation treatment for fingertip amputations. Hand (N Y) 2013;8(2): 139–45.
26. Sebastin SJ, Chung KC. A systematic review of the outcomes of replantation of distal digital amputation. Plast Reconstr Surg 2011;128(3):723–37.
27. Shauver MJ, Nishizuka T, Hirata H, et al. Traumatic finger amputation treatment preference among hand surgeons in the United States and Japan. Plast Reconstr Surg 2016;137(4):1193–202.
28. Payatakes AH, Zagoreos NP, Fedorcik GG, et al. Current practice of microsurgery by members of the American Society for Surgery of the Hand. J Hand Surg Am 2007;32(4):541–7.
29. Ozer K, Kramer W, Gillani S, et al. Replantation versus revision of amputated fingers in patients air-transported to a level 1 trauma center. J Hand Surg Am 2010;35(6):936–40.
30. Soucacos PN. Indications and selection for digital amputation and replantation. J Hand Surg Br 2001; 26(6):572–81.
31. Mori M. Bukimi no tani [The uncanny valley]. Energy 1970;7(4):33–5.
32. Buckingham G, Parr J, Wood G, et al. Upper- and lower-limb amputees show reduced levels of eeriness for images of prosthetic hands. Psychon Bull Rev 2019;26(4):1295–302.
33. MacDorman KF, Ishiguro H. The uncanny advantage of using androids in cognitive and social science research. Interact Stud 2006;7(3):297–337.

34. Fujioka M, Hayashida K. Proximal interphalangeal replantation with arthrodesis facilitates favorable esthetics and functional outcome. J Trauma Manag Outcomes 2015;9:7.
35. Sears ED, Chung KC. Replantation of finger avulsion injuries: a systematic review of survival and functional outcomes. J Hand Surg Am 2011;36(4): 686–94.
36. Sprague BL. Proximal interphalangeal joint injuries and their initial treatment. J Trauma 1975;15(5): 380–5.
37. Carey SL, Lura DJ, Highsmith MJ, et al. Differences in myoelectric and body-powered upper-limb prostheses: Systematic literature review. J Rehabil Res Dev 2015;52(3):247–62.
38. Whelan L, Flinn S, Wagner N. Individualizing goals for users of externally powered partial hand prostheses. J Rehabil Res Dev 2014;51(6):885–94.
39. Rondinelli RD. American Medical Association's guides to the evaluation of permanent impairment. Chicago: American Medical Association; 2008.
40. Danion F, Latash ML, Li ZM, et al. The effect of a fatiguing exercise by the index finger on single- and multi-finger force production tasks. Exp Brain Res 2001;138(3):322–9.
41. Danna-Dos Santos A, Poston B, Jesunathadas M, et al. Influence of fatigue on hand muscle coordination and EMG-EMG coherence during three-digit grasping. J Neurophysiol 2010;104(6):3576–87.
42. Maduri P, Akhondi H. Upper limb amputation. Treasure Island (FL): StatPearls; 2020.
43. Landi AA, Leti A, Rosa ND. The historical odyssey of the mutilated hand. In: Weinzweig N, Weinzweig J, editors. The mutilated hand. Mosby; 2005. p. 3–14.
44. Meredith JM. Comparison of 3 myoelectrically controlled prehensors and the voluntary-opening split hook. Am J Occup Ther 1994;48(10):932–7.
45. Mioton LM, Dumanian GA. Targeted muscle reinnervation and prosthetic rehabilitation after limb loss. J Surg Oncol 2018;118(5):807–14.
46. Lotze M, Grodd W, Birbaumer N, et al. Does use of a myoelectric prosthesis prevent cortical reorganization and phantom limb pain? Nat Neurosci 1999; 2(6):501–2.
47. Passero TD, K. Aesthetic prostheses. In: Smith DG, Michael JW, Bowker JH, editors. Atlas of amputations and limb Deficiencies: surgical, prosthetic and rehabilitation Principles. 3rd edition. Rosemont (IL): American Academy of Orthopedic Surgeons; 2004. p. 303–10.
48. Williams TW 3rd. Progress on stabilizing and controlling powered upper-limb prostheses. J Rehabil Res Dev 2011;48(6):ix–xix.
49. Uellendahl JE. Upper extremity myoelectric prosthetics. Phys Med Rehabil Clin N Am 2000;11(3): 639–52.
50. Kejlaa GH. Consumer concerns and the functional value of prostheses to upper limb amputees. Prosthet Orthot Int 1993;17(3):157–63.
51. Flatt AE. Our thumbs. Proc (Bayl Univ Med Cent) 2002;15(4):380–7.
52. Duncan SF, Saracevic CE, Kakinoki R. Biomechanics of the hand. Hand Clin 2013;29(4):483–92.
53. Napier JR, Tuttle R. Hands. Rev. ed. Princeton (NJ): Princeton University Press; 1993.
54. Marzke MW. Evolutionary development of the human thumb. Hand Clin 1992;8(1):1–8.
55. Snoek GJ, MJ IJ, Hermens HJ, et al. Survey of the needs of patients with spinal cord injury: impact and priority for improvement in hand function in tetraplegics. Spinal Cord 2004;42(9):526–32.
56. Li Y, Kulbacka-Ortiz K, Caine-Winterberger K, et al. Thumb amputations treated with osseointegrated percutaneous prostheses with up to 25 years of follow-up. J Am Acad Orthop Surg Glob Res Rev 2019;3(1):e097.
57. Lin PY, Sebastin SJ, Ono S, et al. A systematic review of outcomes of toe-to-thumb transfers for isolated traumatic thumb amputation. Hand (N Y) 2011;6(3):235–43.
58. Goldfarb CA, Monroe E, Steffen J, et al. Incidence and treatment of complications, suboptimal outcomes, and functional deficiencies after pollicization. J Hand Surg Am 2009;34(7):1291–7.
59. Kumar B, Acharya A, Bhat AK. A re-look at pollicization. Indian J Plast Surg 2011;44(2):266–75.
60. Gaston RG, Bracey JW, Tait MA, et al. A novel muscle transfer for independent digital control of a myoelectric prosthesis: the starfish procedure. J Hand Surg Am 2019;44(2):163.e1-5.
61. Kuiken TA, Li G, Lock BA, et al. Targeted muscle reinnervation for real-time myoelectric control of multifunction artificial arms. JAMA 2009;301(6):619–28.
62. Daugherty THF, Mailey BA, Bueno RA Jr, et al. Targeted muscle reinnervation in the hand: an anatomical feasibility study for neuroma treatment and prevention. J Hand Surg Am 2020;45(9): 802–12.
63. Chepla KJ, Wu-Fienberg Y. Targeted muscle reinnervation for partial hand amputation. Plast Reconstr Surg Glob Open 2020;8(6):e2946.
64. Vu PP, Vaskov AK, Irwin ZT, et al. A regenerative peripheral nerve interface allows real-time control of an artificial hand in upper limb amputees. Sci Transl Med 2020;12(533):eaay2857.
65. Hooper RC, Cederna PS, Brown DL, et al. Regenerative peripheral nerve interfaces for the management of symptomatic hand and digital neuromas. Plast Reconstr Surg Glob Open 2020;8(6):e2792.
66. Alpenfels EJ. The anthropology and social significance of the human hand. Artif Limbs 1955; 2(2):4–21.

67. Ramachandran VS, Rogers-Ramachandran D. Synaesthesia in phantom limbs induced with mirrors. Proc Biol Sci 1996;263(1369):377–86.

68. Atkins DJ. Postoperative and preprosthetic therapy programs. In: Atkins DJ, Meier RH, editors. Comprehensive management of the upper-limb amputee. New York: Springer New York; 1989. p. 11–5.

69. Meier RA, Atkins DJ. Functional restoration of adults and children with upper extremity amputation. 2nd edition. New York: Demos Medical Publishing; 2004.

70. Hsu E, Cohen SP. Postamputation pain: epidemiology, mechanisms, and treatment. J Pain Res 2013;6:121–36.

71. Biddiss E, Chau T. Upper-limb prosthetics: critical factors in device abandonment. Am J Phys Med Rehabil 2007;86(12):977–87.

72. Biddiss EA, Chau TT. Upper limb prosthesis use and abandonment: a survey of the last 25 years. Prosthet Orthot Int 2007;31(3):236–57.

73. Whiteside SA, MJ, Bick JA, et al. Practice analysis of certified practitioners in the disciplines of orthotics and prosthetics. Alexandria (VA): American Board for Certification in Orthotics, Prosthetics & Pedorthics, Inc.; 2015.

74. Dolhi CD. Comprehensive Management of the Upper-Limb Amputee - Atkins, Dj, Meier, Rh. Am J Occup Ther 1990;44(10):955.