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Digit amputation prosthetics

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Abstract
Digit amputations are the most common amputation worldwide. This manuscript describes the impairments imposed by digit loss and the potential benefits of digit prosthetics. This review of the literature is designed to provide a reference for healthcare workers and patients for identifying and selecting prosthetic options for digit amputees.

Keywords: Hand surgery, amputation, prosthetics, outcomes, plastic surgery, orthopedic surgery, hand reconstruction

INTRODUCTION
Partial hand loss (e.g., digit loss) is the most common amputation of the upper extremity[1]. Over 500,000 individuals with upper extremity amputations live in the United States[2]. It is reported that 78% of upper extremity amputations involve finger loss[3]. These amputations can cause significant psychosocial stress as well as functional consequences. Despite this, much prosthetic development research focuses on major limb loss rather than digital loss[4]. Prosthetics has been shown to improve both functional and psychosocial impairment from digit amputation[5]. In this review, we will discuss the impacts of digit amputations on patients and prosthetic options for digit amputees.

IMPACT OF DIGIT LOSS

The functional loss of a digit has been well characterized. Chow *et al.* studied the effects on power grip, key pinch, pronation, and supination in subgroups based on amputation level. Patients with multiple digit amputations fared poorly in multiple categories. The loss of the thumb had a significant detriment to power grip and key pinch; power grip also suffered with the loss of the ring finger and small finger. 24% of patients in their series had to change careers after a digit amputation, and 20% of patients requested the use of prosthetics for cosmetic purposes[6]. Pilley *et al.* found that in a population of patients who suffered single digit amputation, aesthetics was the primary concern and functional outcomes were secondary, though patients often found prosthetics beneficial in daily tasks such as typing[5]. Thus, the loss of even a single digit can have significant functional consequences and lead patients to seek prosthetics to correct both functional and aesthetic issues.

PROSTHETIC TYPES

Patients often have different goals when selecting prosthetic types. Patients may desire prostheses to augment the function of the remaining hand, a more appealing cosmesis of the hand, or a blend of both.

PASSIVE/COSMETIC

One of the more common types of replacement is silicone finger extensions [Figure 1]. Silicone fingers can mimic well the appearance of the remaining fingers, making them an excellent option for patients who chiefly desire restored appearance of the fingers. There are numerous silicone restoration providers, including American Hand Prosthetics (New York City, New York, USA), Touch Bionics (Livingston, United Kingdom), and ARTech Laboratory (Midlothian, Texas, USA). These prostheses can be off-the-shelf or custom-made and are typically secured by vacuum suction at the base. However, they typically do not improve grip strength parameters. Kuret *et al*. compared grip strength before and after prosthetic use in a heterogeneous group of patients with different digits amputations at different levels; while the measurements of function for spherical and extensions grips improved based on the Southampton Hand Assessment Procedure (SHAP) test (a 26-item test on prosthetic hand function), they did not achieve a clinically meaningful level[7]. Prior studies have suggested that silicone prostheses may provide some increased function in striking activities, such as typing or playing the piano[8]. Video analysis by Fraser has also shown that amputees can often utilize "cosmetic" prostheses to assist in opposition and grasp[9]. In a study following silicone prosthesis use over a period of 3.9 years, O'Farrell *et al.* found that the majority of patients who received a silicone prosthesis felt that it helped them psychologically accept their injury. Notably, about one-third of the patients elected not to use their prostheses at all by the end of the study period, and this was at similar rates for men and women. Patient complaints included a fear that the prostheses would fall off with vigorous activity[10].

FUNCTIONAL

Patients often elect prosthetics that provide functional improvement of their hands. Chow *et al.* demonstrated that digit amputees often experience long-term loss of key pinch and power grip, especially when multiple digits are involved. The level of strength impairment can often exceed 50% of uninjured grip, which can often impair daily and occupational functions[6]. Patients often seek prosthetics to either replace entire injured digits or effectively lengthen remaining digits stumps to improve useful grasp.

One such example is Point Digits from Point Designs(Lafayette, Colorado, USA), which provides a silicone and nylon base on which titanium, hinged digits can be mounted. These fingers have a ratcheting mechanism and each model is custom fit based on impression kits sent to the patient, and the frames are then custom designed[11]. The prosthesis is designed to withstand the weight of over 308 lbs and move with

Figure 1. Silicone finger extensions. Silicone can be molded and colored to match the appearance of patients' native fingers.

anatomic flexion with 11 separate locking positions[1]. Other such models are the TITAN prosthetics by Partial Hand Solutions (Holliston, Massachusettes, USA) and the VINCENT prosthetics by Vincent Systems GMbH (Karlsruhe, Germany). These prosthetics allow fixation of the prosthesis into a flexed position via a ratcheting or similar mechanism. However, these fingers can be seen as difficult to operate since the contralateral hand must be used to position the fingers in the desired space[1,12].

Body-powered fingers attempt to couple flexion of the wrist or remaining digits to control the prosthetic device. However, these prostheses can cause significant fatigue to the wearer. Options for full-finger amputations include the M-Finger (Partial Hand Solutions) and X-Finger Didrick Medical Naples, Florida, USAThe MCP Driver by Naked Prosthetics (Olympia, Washington, USA) uses motion from an intact metacarpal-phalangeal joint to actuate the prosthetic device[1] [Figure 2].

Myoelectric options also exist, which use muscle activation in the residual hand/limb to control digit position. The i-limb by Touch Bionics and the partial active model by Vincent Systems GmbH use battery-powered motors that provide finger flexion[13,14]. These externally powered devices have the advantage of decreasing fatigue with use compared to body-powered prostheses. However, these devices have a significant learning curve, and the complex nature of these devices affects durability. It must also be noted that despite their potential, there are few data regarding the benefits of myoelectric partial hand prostheses for functional tasks[15,16].

There are also activity-specific prostheses that are commercially available. These prostheses are designed for patients with partial hand amputations who desire to perform specific tasks, such as in sports. Examples include the N-abler III from Texas Assistive Devices (Brazoria, Texas, USA) and the Pro Cuff orthoses from TRS Prosthetics (Boulder, Colorado, USA). Quick-release attachments to these devices allow for assistance with kayaking, shooting, fishing, musical instruments, and other vocations[15].

Besides the above, there are numerous other prostheses currently in development. 3D printing technology has allowed custom fits more easily with lightweight materials such as nylon[17]. Currently, a company known as Fingy3D (Morgantown, West Virginia, USA) is providing prototypes to patients that can be 3D printed from photos taken from a patient's hand on an app. The price of such a prosthesis is relatively low, with the currently listed base model at $299[18]. As technology develops, the accessibility of prosthetics to digit amputees will become easier.

Figure 2. Naked Prosthetic MP Driver. Prosthesis is powered by residual motion at remnant MP joints.

OSTEOINTEGRATED PROSTHETICS

Osteointegrated digital prosthetics have also been described. The advantages of these prosthetics include stable positioning of the prosthetic without the need for more cumbersome frames on the hand and the enhanced ability of sensation through osseoperception. Both cosmetic and functional prosthetics can be anchored with this technique. Doppen *et al.* described their experience with osteointegrated prosthetics using similar concepts as those with dental prosthetics. Patients underwent a staged procedure with placement of a titanium implant, and after 6 months, patients had a healing abutment placed and, subsequently, the permanent abutment was placed in 3-6 weeks. The authors report their experience with four patients, one of whom suffered a failure of osteointegration. The remaining three patients expressed high satisfaction with the prosthesis[19]. These prosthetics show great promise, though implantation is technically demanding and is not widely offered.

RATING OF PROSTHETICS

Currently, there is no widely accepted rating scale for how useful digit prosthetics are for patients. Leow *et al.*, when testing a resin-based prosthesis, used a simple score with a binary scale describing if a patient could or could not do an activity with and without the prosthesis[20]. Separate scales also exist for myoelectric control[21]. Perhaps a useful metric would be the use of a widely accepted and validated scale for upper extremity disability, such as the Disabilities of the Arm, Shoulder, and Hand score, with and without prosthetic use[22]. However, to this author's knowledge, no such study has been performed to date. The use of such a scale would allow quantitative and comparable data for the benefit of prosthetics and how prosthetic users compare to the general population with uninjured hands. The usefulness of each prosthetic type and/or brand could also be more easily compared if a standardized scale was adopted.

LIMITATIONS OF PROSTHETICS

Numerous authors have studied the improved psychosocial function allowed by prosthetics. However, it must be noted that the abandonment of prosthetics is relatively high. Pereira *et al.* noted that in a 2-year follow-up study of 30 patients, only 73% of patients used their prostheses daily. The authors noted that fit and perspiration issues can be a barrier to patient use, and the fabrication of high-quality, well-fit prostheses is paramount for persistent use by patients[23]. Others have noted persistent use as low as 64%[24].

Another limitation of current prostheses is the lack of sensory feedback. Since prostheses in their nature create a barrier between the outside world and sensate skin, their use may affect proprioception. Even for prostheses with simple goals, such as creating an opposition post with a thumb amputation, the lack of sensation can be a significant barrier[15]. Current research includes efforts to create passive prostheses that provide short-lasting vibrotactile bursts with contact with the environment[25]. These prostheses may provide some much-desired sensory feedback that is currently lacking in prostheses on the market.

Another limitation specifically regarding myoelectric prostheses is that their reliance on myoelectric signals can lead to difficulty of intended motion for patients. The motion of electrodes on the skin or poor signal from atrophic intrinsic musculature can lead to inaccurate signals to the device. To combat this, Gaston *et al* developed the Starfish procedure of transferring interossei with their neurovascular pedicles to more superficial areas of the remnant hand and reported an increased signal-to-noise ratio for myoelectric prostheses[26].

One observation by Imbinto *et al.* is that current prosthetics rely heavily on manual approaches by individual technicians rather than modern engineering principles; as prosthetics continue to grow in sophistication, the involvement of engineers in efficient and effective prosthetic design continues to grow in importance[27].

It should be noted that prosthetics currently do not help in the management of neuropathic pain, which is estimated to occur in approximately 18% of digital amputees[28]. In many instances, replantation can be offered in the acute setting for digit amputation, and patients undergoing replantation have been shown to have less neuropathic pain than amputees[29]. In acute amputation, replantation may avoid the need for a prosthesis and its associated limitations.

CONCLUSION

Digit prosthetics provide valuable methods of restoring form and function for patients after digit amputations. Digit prosthetics vary widely in their design and complexity. The individual needs of each patient must be assessed in selecting each type of prosthetics. Long-term disuse of digits prosthetics is a possibility, and patients should be offered well-fitting, high-quality prostheses that achieve their desired goals to maximize the chance of long-term use.

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The author contributed solely to the article.

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Ethical approval and consent to participate
Not applicable. The authors declare their consent to participate.

Consent for publication
The author has obtained the patient's informed consent document.

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