RETHINKING THE SHOULDER DISARTICULATION PROSTHESIS: LET'S STOP THINKING OUTSIDE THE BOX AND MAKE THE BOX BIGGER

Christopher Fink, CPO; Timothy Bump, CPO; Debra Latour, OTD, OTR/L

Handspring Clinical Services

ABSTRACT

In this article, authors explore how reducing the amount of technology and modifying the traditional shoulder disarticulation prosthesis design can lead to an improvement in task completion, device satisfaction, and reduced prosthetic abandonment. While new devices demonstrate potential for improved function, appearance, and control, there is a lack of translation of these advancements to actual daily functional improvements for the upper limb population. Prosthetic abandonment continues to be extremely high in the upper limb population even with improvements in the latest technology.

Persons with shoulder disarticulation/ interscapular thoracic occupy less than 0.1% of the total population. With such a small population of potential users, many prosthetists default to caring for these individuals in a very traditional manner as they lack the experience to do so differently. Traditionally, shoulder disarticulation prostheses have consisted of a prosthetic shoulder, elbow, wrist, and terminal device. While these devices may be successful for some users, they are heavy and require an extensive amount of positioning before operating the terminal device. In a typical shoulder level prosthesis, there are six degrees of freedom to control and position prior to terminal device actuation. With current technology these degrees of freedom are typically sequentially controlled and may be positioned multiple times prior to attempting to operate the terminal device. The cognitive burden of positioning these movements and the time to do so are routine complaints of users. While offering access to function once correctly positioned, achieving the correct position is time consuming and fatiguing. The increased complexity and degrees of freedom for control in more proximal level users requires more cognitive load and could explain the higher level of abandonment with higher levels of limb difference.

To combat this, the practitioners explored a novel design to reduce the complexity of operating the shoulder level external powered prosthesis and combat the common issues of function, comfort, and weight. The novel prosthesis was designed around the criteria of access to function at multiple levels (seated at a table and standing at a counter) and be able to complete bimanual activities of daily living (ADLs) such as meal preparation, household chores, stabilizing paper to write with the contralateral limb, and eating with a knife and fork.

INTRODUCTION

The authors of this paper explore how reducing the amount of technology and modifying the traditional shoulder disarticulation prosthesis design can lead to an improvement in task completion, device satisfaction, and reduced prosthetic abandonment. Society continues to be enamoured with technology. From the latest smart phone or watch to self-driving cars, we have become people that love technology for the sake of innovation. This infatuation is not independent from the field of prosthetics. Innovations are developed daily, with a substantial amount of that technology concentrated to the upper limb. While new devices demonstrate potential for improved function, appearance, and control, there is a lack of translation of these advancements to actual daily functional improvements for the upper limb population.

Persons with upper limb absence (ULA) continue to derive a small percentage of the overall limb-different community. There are an estimated 2.2 million persons living with limb difference, with 185,000 persons with new loss each year [1,2]. Partial hand difference makes up a large majority of the upper limb population (92%) followed by trans radial/ wrist disarticulation, and trans humeral/ elbow disarticulation. Persons with shoulder disarticulation/ interscapular thoracic occupy less than 0.1% of the total population [1,2,3]. With such a small population of potential users, many prosthetists default to caring for these individuals in a very traditional manner as they lack the experience to do so differently. Many work under the pretext that a prosthesis needs to replace the anatomical limb in a mimicking manner such as a hand for a hand, an elbow for and elbow, etc. Development in technology has been driven around making the prosthesis more human-like. While this may be appropriate in some instances, it may not be the best course of action in all circumstances. For instance, many machines and robots have been developed to replace humans in manufacturing jobs that do not operate under this pretext.

Prosthetic abandonment continues to be extremely high in the upper limb population even with improvements in the latest technology [4]. More proximal amputation levels also show higher levels of abandonment [4]. Reasons included weight, temperature, sweating, durability, and aesthetics with a consensus of comfort and function being the leading factors [4,5,6]. The prosthetist is responsible to create well-fitting sockets, but prosthetic comfort can be influenced by factors such as weight or control mechanism. Function is extremely multifaceted and includes the tasks that are meaningful to the user, technology design and selection, control mechanisms, occupational therapy/ training, and socket fit/ comfort. Additionally, the increased cognitive load associated with using an upper limb prosthesis may lead to greater abandonment [7]. The increased complexity and degrees of freedom (DOF) for control in more proximal level users requires even more cognitive load and could explain the higher level of abandonment with higher levels of limb difference.

Traditionally, shoulder disarticulation prostheses have consisted of a prosthetic shoulder, elbow, wrist, and terminal device. For individuals requiring active elbow motion and grasp, body powered prostheses are less preferred compared to external powered prostheses due to the lack of excursion available at this level of limb loss [8]. A typical external powered shoulder level prosthesis (Fig. 1) consists of a locking shoulder joint (mechanical or electric) to control shoulder flexion and extension with a friction ab/adduction setting to allow positioning of the shoulder in abduction; an external powered elbow joint that allows for flexion and extension of the elbow joint; a mechanical friction turntable on top of the elbow joint to mimic humeral rotation; an electric wrist rotator to supinate/ pronate the terminal device; and an external powered terminal device that could be in the form of a hook, simple prehension hand, or multi-articulating hand. Many terminal devices also have the option for changing the wrist flexion position as well.

While these devices may be successful for some users, they are heavy and require an extensive amount of positioning before operating the terminal device. In a typical shoulder level prosthesis, there are 6 DOF to control and position prior to terminal device actuation. With current technology these DOF are typically sequentially controlled and may be positioned multiple times prior to attempting to operate the terminal device. The cognitive burden of positioning these 6 DOF as well as the time to do so are routine complaints of users. While offering access to function once correctly positioned, achieving the correct position is time consuming and fatiguing. To combat this, the practitioners explored a novel design to reduce the complexity of operating the shoulder level external powered prosthesis and combat the common issues of function, comfort, and weight. Participants gave written consent to use of their images.

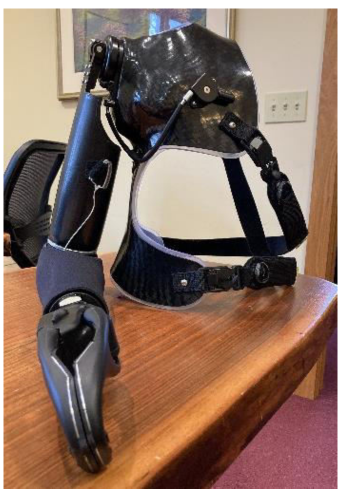

Figure 1: Example of a traditional external powered shoulder disarticulation style prosthesis

Figure 2: Novel shoulder disarticulation style prosthesis in its shortest position to function while seated at a table

Figure 3: Novel shoulder disarticulation prosthesis in its extended position to work at a countertop height while standing

The novel prosthesis was designed around the criteria of access to function at multiple levels (seated at a table and standing at a counter) and be able to complete bimanual activities of daily living (ADLs) such as meal preparation, household chores, stabilizing paper to write with the contralateral limb, and eating with a knife and fork. The device needed to be lighter weight, easier to operate and more functional than the typical shoulder level prosthesis. The novel prosthesis (Fig. 2 and Fig. 3) consisted of a universal friction shoulder joint to control elbow flexion/ extension, ab/ adduction, and humeral rotation; a telescoping “elbow joint” to provide a short operating position and long operating position; a standard electronic quick disconnect wrist unit to allow for passive wrist rotation; and an external powered multi-articulating hand.

CASE STUDY 1

Case study 1 (CS1) is a 28-year-old male who presents with acquired shoulder disarticulation of the right dominant upper limb due to a work-related accident. He demonstrates limited movement and has extensive scarring at the residuum and dorsal/lateral trunk and volar clavicular areas. Sensation is described as hypersensitive in the right anterior axilla. He experiences phantom and residual limb but denies pain in the left sound upper limb. Since January 2023, CS-1 has been using an externally powered device that includes a body powered locking shoulder joint, powered elbow joint, a powered wrist rotator, ETD2 with wrist flexion and FLAG, waterproof collar, and waterproof sleeve, 2 site touch pad control, electric switch, and chest straps for suspension harnessing. He received OT for prosthetic training and was able to use the device for some ADLs but continued to experience some limitations. Prior to his accident, CS-1 led an active life, working full time in construction at an asphalt company. He lived in the family home with his parents and siblings, contributing to home and property maintenance, and enjoyed diverse activities in his free time, including sports, working out, camping, fishing, and hunting. He also played musical instruments such as piano, trumpet and drums. He hoped that prosthetic technology would enable him to return to these activities. CS-1 expressed interest in trialling the idea of the novel prosthesis using the telescoping feature that could offer access to tasks at diverse heights more efficiently.

In October 2023, CS-1 was fitted with the novel prosthesis. He noted that the adjustable length feature of the forearm/ humeral section was at a perfect length for tasks while seated at a table and extended an appropriate length to work at a countertop while standing. He was able to change the arm length quickly and was happy with the added and improved features of the new prosthesis. His control continues to be excellent and ability to use the prosthesis. Initial measures show improved his perception of disability, work, and recreation scores (QuickDASH) and prosthetic satisfaction (McGann Feedback Form). CS-1 continues to be monitored for ADLs via performance measures, however he has demonstrated improvements in ability to complete many bimanual tasks such as cutting food, preparing meals, and carrying heavy objects.

CASE STUDY 2

Case study 2 (CS-2) presents as a 42-year-old male with a right shoulder disarticulation amputation with full root avulsion that occurred in 2013 from a traumatic motorcycle injury. He continues to experience pain, anxiety, PTSD, and depression. CS-2 was initially fitted in 2015 with a passive activity-specific prosthesis, and then with an externally powered prosthesis in 2017. He has since lost the passive device during relocation and the externally powered device no longer fits due to weight gain. CS-2 complains of limited function with his device because of the weight complexity to operate the components.

In October 2023, prosthetists discussed the novel prosthesis with a telescoping locking elbow instead of a flexing/extending elbow. CS-2 was interested and discussed the potential for control using touch pads at the right shoulder. Following trials with a developing prototype, a device with single-site, posterior motion to open/close; elbow with 2 telescoping positions, and an i-limb quantum with power grip was delivered to CS-2 in January 2024. He was able to operate the device and to initiate bimanual tasks such as zip up a jacket, manipulate a knife and fork to cut food, and manage a wallet and mobile phone. CS-2 stated, “It has been a long time since I had this much hope to accomplish tasks.”

Initial measures show improved his perception of disability, work, and recreation scores (QuickDASH) and prosthetic satisfaction (McGann Feedback Form). CS-2 continues to be monitored for ADLs via performance measures, however he has demonstrated improvements in ability to complete many bimanual tasks such as cutting food, preparing meals, and carrying heavy objects.

DISCUSSION

These case studies demonstrate that the novel prosthesis has several advantages over the traditional prosthesis including decreased overall weight, decreased weight perceived by the user, improved function to complete tasks at table (seated) and counter (standing) heights, and increased wear time. Additionally, the users were able to correctly position the TD faster and more efficiently compared to the traditional prosthesis. Once the user adjusted the telescoping “elbow joint” at the proper length, the TD was positioned by moving the universal shoulder joint and rotating the wrist unit. This resulted in a total of 3 actions before operating the TD in the novel prosthesis (positioning the telescoping elbow joint, the universal shoulder joint, and the wrist rotator) compared to five actions required to actuate the traditional prosthesis (positioning the shoulder for flex/ extension, abduction, humeral rotation, elbow flexion, and wrist rotation).

Users of this device were able to complete tasks they could not perform or struggled to perform with the traditional prosthesis. Seated at a table the novel prosthesis outperformed the traditional prosthesis because the angle and position of the prostheses allowed the user to interact with items on the table. With a traditional prosthesis the subjects were unable or struggled to use the prosthesis to grasp objects from the tabletop, hold a water bottle or cup and cut with a fork and knife. The novel prosthesis, however, easily permitted access to complete these tasks. The lack of a traditional elbow joint allows the TD on the novel prosthesis to access objects on the tabletop in a more intuitive, efficient, and easier strategy to control motion.

Currently there is no knowledge of any other prosthesis that has been designed with the characteristics of the novel prosthesis. While both subjects found value in the novel prosthesis, one of the subjects continues to use his traditional prosthesis on occasion because both prostheses serve purposes to his daily life. This action coincides with the findings that no one prosthesis can replace the human arm/hand and that multiple devices are required to achieve the vast array of functions of the human arm. Further examination of this prosthesis design is required to further determine its merits for the wider shoulder level prosthetic community. Future design considerations will include other tasks beyond household chores, eating, meal preparation and writing.

ACKNOWLEDGEMENTS

Thank you to our patients for their patience, dedication, and critical feedback to create the best prostheses for them and others, and acknowledge Tom Passero CP, Handspring Clinical Services, for his support in this process.

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