CHALLENGES AND SOLUTIONS IN CONTROL SYSTEMS FOR ELECTRICALLY POWERED ARTICULATING DIGITS

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INTRODUCTION

The invention and clinical application of electrically powered and independently articulating digits is relatively new in the field of external upper limb prosthetics. When utilized for patients with amputations or absence at the partial hand level, these components offer the potential for a range of active functional grasping patterns that were unavailable with previous technology. Their application and examples of their use have been documented by various authors.1,2

The introduction of these systems is accompanied by the challenge of controlling them. Any electrically powered prosthetic system requires a method of concise, deliberate, and repeatable control be implemented in conjunction with focused therapy in order to be successful. Traditional control schemes of prosthetic devices for more proximal levels of absence are less straightforward when applied to an electrically powered partial hand device. Space constraints, limits of myoelectric input, the desire to maintain available residual anatomy range of motion, and complexity of potential prosthetic motion make the control of these systems particularly challenging. Integrating novel and creative systems of control with therapy will enhance the function of these systems for each user.

RESIDUAL HAND PRESENTATIONS

“The primary goals of amputation surgery are preservation of length and useful sensibility, prevention of symptomatic neuromas and adjacent joint contracture, early prosthetic fitting where applicable, and prompt return of the patient to work or play”3. The surgical principals guiding those performing amputations within the hand dictate the levels of amputation and generate a wide variety of partial hand presentations. This variety poses different challenges based on remaining anatomy and available range of motion and input sites.

Manufacturer’s component systems allow for fitting of digits at different amputation levels based on prosthetic digit build height and overall length. There are certain constant indications for application of articulating digits however. One indication is the complete loss of at least one and up to five digits. No manufacturer currently offers an electric partial finger prosthesis that can be fit when a substantial portion of the finger remains.

Another indication is a majority of the carpal bones remaining. The remaining carpus allows for the potential of active wrist motion. Wrist motion is well understood to be critical for functional activities and the lack of motion typically results in compensatory movements strategies. The advantages of even passive prosthetic wrists have been documented.4 Preservation of active wrist range of motion is therefore one of the essential design criterion of a partial hand prosthesis.

The thumb is the most important digit in its contribution to grasp and pinch. In the prosthetic treatment of any partial hand presentation where the thumb remains it is absolutely essential for the prosthetic system to allow as much active range of motion as is available. Residual finger anatomy should also be evaluated and in any case where useful motion is available should remain as unhindered as possible. In addition, therapy to improve thumb and finger strength as well as range of motion is critical to improve outcomes.

The restriction of physiological range of motion within a prosthetic system can come from limitations imposed by the structure of the prosthesis. Socket or frame trimlines, pressures within the socket, or even the materials used can affect the user’s ability to move. Restriction to motion can also be imposed based on positioning of the inputs to the control system. This occurs when undesirable or unintended prosthetic operation is elicited by motions that could otherwise be beneficial. For example, the location of electrodes for myoelectric control in transradial and wrist disarticulation systems is most commonly on the remaining wrist and finger flexors and extensors. When this same control scheme is applied to a partial hand system where wrist motion remains, the control of the fingers is directly tied to wrist flexion and extension. This presents a functional deficit and most certainly an obstacle to a successful outcome even with intensive therapy.

MIRCROPROCCESOR CONTROL SCHEMES

Commonly electric prosthetic systems are designed with myoelectric control of the various components. The preferred myoelectric control scheme consists of dual site agonist and antagonist muscle pairs. Each site controls one
degree of freedom for the component being controlled: hand, wrist rotator, elbow, etc. A switching mechanism, either myoelectric or electro-mechanical, is used to change the component currently operating. Generally these schemes are well understood by rehabilitation professionals and training for prosthesis control is straightforward.

Another more challenging scheme is single site control. A single myoelectric input is utilized to operate all functions of the prosthesis. Microprocessors determine the direction of motor motion based on differing algorithms. Alternating motion, rate dependent direction, and automatic closing are all examples of single site control methods. When more than one component is controlled another switch is necessary to move between components.

Rarely is prosthesis function as fluid when using single site control as compared to dual site. The necessity for additional switching or the inability to change directions seamlessly creates delays in control. However, when other input options are not logical or unavailable, the ability to utilize one input for control can be vital to the success of the system.

In addition to electrodes used for myoelectric control, alternate inputs can be used. Force sensing resistors (FSR’s), linear transducers, and strain gauges can all be used for proportional input into control systems. These devices can be used in conjunction with or as replacements to myoelectric inputs. In some cases three input systems are advantageous where the third input, typically an alternate input, has direct control over a component or is used as a switch.

Pattern recognition for myoelectric control is an emerging technology that is very promising. With the application of pattern recognition, isolation of individual muscles becomes much less important or problematic. The requirement of signal separation in dual site control is diminished and the potential for control of more degrees of freedom is gained. Undoubtedly when it becomes available to the prosthetics industry there will be applications for the powered partial hand prosthesis.

The considerations in prosthesis design provide a basis for socket design but also for input determination and prosthesis control. Each partial hand presentation has its own limitations and challenges but also provides different opportunities for control.

**CONTROL SYSTEM CONSIDERATIONS**

**5 fingers absent**
The prosthesis for the residual limb with all fingers missing is arguably the easiest to control of any those discussed. The lack of fingers allows for the preferred method of dual site myoelectric control with intrinsic muscles of the hand. The most logical when available are the hypothenar and thenar eminences due to their size and typical signal separation. The simplicity of control is balanced by the decrease in residual hand function due to lack of a thumb. The lack of any digital sensation severely complicates training and function. One decision that must be made is whether or not to motorize the prosthetic thumb but the control of either system is likely to be similar.

**4 fingers missing – thumb remaining**
The presence of a thumb makes the use of the thenar eminence as a myoelectric site inadvisable as thumb motion and prosthesis function would be linked. This would create a conundrum of control for the user. Hypothenar musculature is still very viable for control with this presentation.

For dual site intrinsic myoelectric control the second site is likely the lumbricals or dorsal interossei. Imagined 2nd, 5th digit MP flexion along with PIP and DIP extension generally results in the best signal for these groups. This can be described as having the patient “fold” the hand at the knuckles while keeping the fingers straight. These small intrinsic muscles are viable contributors of myoelectric signal but certainly require training to have sufficient stamina and strength to be used functionally.

Dual site control is still the preferred method of control, but only if achievable, consistent, and functional. Single site control is a viable option at this level due to the relatively strong and isolated hypothenar muscles.

**3 fingers missing – thumb and 2nd digit remaining**

Having the 2nd digit and thumb with active range of motion and sensibility provides what the previous levels do not have: true pinch and grasp native to the residual hand. Fine dexterity is typically not an issue. Powerful and stable grasp of larger items, however, can still be a challenge as grasp is limited to a “ring” created by the two digits.

Myoelectric input is certainly available from hypothenar muscular if present. When attempting to find a second myoelectric site again the small intrinsic muscles of the lumbricals and dorsal interossei are candidates. Intensive training to separate 2nd digit motion from this second site is imperative in order to have this be a successful outcome. Due to the complexity involved in training isolation of 2nd digit motion from activation of the dorsal interossei and lumbricals the potential for control error is great. Single site control does not have these same issues and is less error prone but lacks the responsiveness of dual site control.
3 fingers missing – thumb and 5th digit remaining

This presentation is the most difficult to address from a control standpoint as the only intrinsic myoelectric site available that doesn’t involve the thumb or 5th digit are the 1st and 2nd dorsal interossei and lumbricals. Only single site myoelectric control is achievable with intrinsic musculature and this is by no means straightforward due to the motion requirements of the two remaining digits. Dual site myoelectric control can be achieved through use of one electrode on the 1st interosseous with a second electrode on wrist extensor compartment. This does indeed tie prosthetic finger opening with wrist extension but separating the finger closing signal out minimizes the functional deficit. Therapy to train in the use of these motions for function is critical to a successful outcome.

NOVEL SOLUTIONS

The four partial hand presentations and potential control schemes discussed offer real solutions. However, being creative with control schemes and inputs, in conjunction with directed therapy, can reward the user with improved control.

One such potential solution is to the quandary of intrinsic dual site myoelectric control. In cases except that of 5 fingers missing, dual site control is achieved with at least one site being of smaller interrelated muscle groups. Retaining one myosite over the hypothenar eminence and replacing the second input with an alternate input can significantly reduce the crosstalk associated.

A technique utilizing a FSR has been used with good success. (fig 1) In a prosthetic design with flexible socket and rigid frame, the socket has been extended proximally on the dorsal aspect of the wrist. This socket flexes with the patient during wrist extension. The rigid frame is adjusted to terminate distal to the wrist crease thus not interfering with wrist motion. Placing a FSR between the socket and frame creates pressure on the sensor during a defined amount of wrist extension.

The benefit of such a solution is to allow for very repeatable and reliable dual site control of the prosthesis without placing electrodes on more proximal muscles. The FSR produces a signal during wrist extension but the degree of extension at which the FSR is triggered is adjustable. Thus opening of the fingers can be reserved for the last 10 or 15 degrees of motion. This minimizes the functional deficits of prosthesis function related to residual joint ROM.

Similarly a linear transducer can be used as the alternate input. By anchoring the transducer above the wrist and to the dorsal aspect of the frame, wrist flexion can be captured to produce input signal. As with the FSR, the point at which the signal is produced is adjustable.

Figure 1: example of FSR placement

CONCLUSION

Electric partial hand prostheses with individually articulating digits are currently being fit. The variety of residual limb presentations creates numerous challenges of control for these complex systems. By utilizing and training the user in innovative control schemes improved control of the prosthesis can be achieved.

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REFERENCES


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