PRELIMINARY EVALUATION OF VARIATIONS IN CONTROL STRATEGY FOLLOWING TRANSHUMERAL OSSEOINTEGRATION

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ABSTRACT

While not as common as transfemoral applications, osseointegration at the transhumeral level has been performed across multiple clinical sites. Our experience with this amputation level has predominantly been with the use of the OPRA implant. We have followed a staged rehabilitation program inclusive of an early trainer to facilitate progressive positive and negative loading, a full-length, light weight, non-prehensile prosthetic arm and definitive arm prostheses. These have included both body-powered and externally powered definitive solutions. In the absence of a transhumeral socket, the facilitation of control strategies for both body-powered and myoelectric prostheses have required adaptation. For body powered systems, because of the direct attachment of a bone-anchored prosthesis, harnessing elements designed for suspension can be eliminated, while those that enable control of the terminal device, wrist or elbow most be modified and preserved. Accordingly, correct placement of the base plate and housing retainer for the control cable must be achieved in the absence of an external socket. This has been accomplished via external rigid outriggers for longer residual limbs or through their attachment to proximal endoskeletal or exoskeletal bridges with shorter residual limbs. For externally powered prostheses, the challenge lies in consistent placement of the surface electrodes that may be required over the residual limb, the ipsilateral chest wall or ipsilateral scapular region. This has been accomplished through outriggers, adhesive electrodes, non-custom electrode cuffs and custom silicone interfaces. These methods of facilitating traditional control strategies in the absence of the transhumeral socket will be described and discussed.

INTRODUCTION

While osseointegration has been predominantly performed and reported in transfemoral applications, several studies have reported upon its application at the transhumeral amputation level. In 2011, Jonsson et al reported upon their fitting protocols with 16 subjects. They describe their approach to staged prosthetic management with an early "trainer" device, a temporary light-weight, non-prehensile, long-arm prosthesis and ultimate definitive fittings of cosmetic, body-powered and myoelectric prostheses [1]. The 2- and 5- year survival rates for the implants in this cohort were subsequently reported at 82% and 80% respectively [2]. More recently, researchers have begun to explore the loads experienced in the transhumeral implant site across a range of physical movements and activities [3] as well as prosthesis types [4], both in vivo [3] and through mechanical simulation [4]. The prospective demand for osseointegration in this population appears to be high, with one survey suggesting 35% of those with unilateral transhumeral amputation would consider this procedure, with another 29% being undecided [5].

Notably, the factors that this group prioritized in considering this procedure included a capacity to do more activities with a durable, comfortable device [5]. These elements require consideration of an appropriate, consistent control strategy. For body-powered devices, harnessing is no longer indicated for suspension but remains necessary for cable-driven control the elbow, wrist and terminal device. Significantly, the base plate and housing retainer can no longer be mounted to the distal lateral aspect of the prosthetic socket but remain necessary for efficient cable-controlled activation of the prosthesis. For myoelectric devices, there is no longer a socket to house the surface electrodes. In this case series we will report upon our efforts and observations to date in establishing body-powered and myoelectric control strategies following osseointegration in the absence of a transhumeral socket.

TRAINING STAGES

Trainer

The use of the trainer is well described by Jonsson et al [1]. Its intent is to facilitate both positive and negative loading of the implant following surgical implantation. While patients are encouraged to move their limb in prescribed motions for recommended daily durations, as a static device, no control strategy is indicated during this phase (Figure 1)

Long Arm Trainer

The Long Arm Trainer is also suggested in Jonssen's original report [1]. This lightweight solution is an oppositional, non-prehensile prosthesis with no requirements for a control strategy. It is generally comprised of a friction or manual locking elbow and either a "passive static" hand or manually operated terminal device that does not required control cables or external powered componentry. The goal of the device is to increase torque loads from the trainer to a full-length prosthesis.

Figure 1: Trainer to facilitate positive and negative loading of the implant.

BODY POWERED ADAPTATIONS

Longer Arms

In socket-based body powered systems the harness/control cable provide both suspension and activation of the prosthesis. With osseointegration the harness no longer needs to suspend the prosthesis. This greatly increases user comfort as the harness no longer carries the weight of the prosthesis and does not need to be as tight. In many cases, this also allows increased functional range of movement of the extremity. However, the harness must still be designed to capture gross body motions, generating the required force and excursion to operate the prosthetic componentry. With friction or manual locking elbows, a figure-9 harness can be used. The application of a traditional cable-driven elbow lock requires a harnessing approach similar to the figure 8, with a superior harness strap running from the Northwestern ring over the contralateral shoulder where it attached to the elbow lock cable to facilitate cycling of the internal lock.

Figure 2: A rigid distal outriggers is used to mount the baseplate and retainer of a body powered prosthesis.

Ideally the proximal base plate location should keep the control strap along the distal ⅓ of the scapula to maximize available cable excursion generated from anatomic glenohumeral flexion without bridging clothing. With longer residual limbs, this proximal base plate location is over the residual limb. In such cased an outrigger can be designed and attached to the prosthetic elbow bridge. (Fig 2).

Shorter Arms

With shorter limbs if the ideal proximal base plate location falls within the length of the custom bridge, it can be mounted directly to the endoskeleton or exoskeletal segment. (Fig 3).

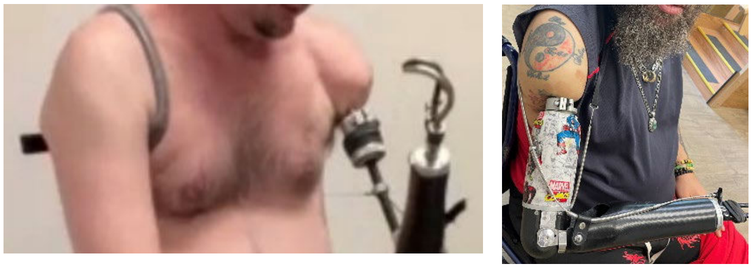

Figure 3: In the case of shorter residual limbs, the housing retainer is mounted to the proximal bridge segment of the prosthesis between the implant connection and the elbow table.

Bilateral applications

For bilateral OI harnessing the base plate location and mounting would be similar to the above examples. The harness can be designed to facilitate independent use of a single prosthesis or as a connected pair. In the case of the former the user can wear one prosthetic at a time by securing the control strap to the contralateral axilla via a figure-9 harness as described above. Another option is to join the harnesses together for bilateral use (Figure 4). The advantage of bilateral application is the elimination of axillary pressure caused by the axilla loop. Provided that the power required to operate the elbows and/or terminal devices of the two sides are similar, the inherent friction in the cable system allows the user to operate one side without inadvertent operation of the contralateral side.

While the harness is no longer required for suspension, it still plays a vital role in enabling cable excursion for both elbow & hook position and cycling of the elbow lock. Thus, the anterior suspensor straps continue to provide an anchor point for cycling the ipsilateral elbow lock as well as an anchor point for the contralateral control cable. The standard dacron anterior elbow lock strap, coupled with the anterior elastic webbing permits cycling of the elbow as observed in standard body powered transhumeral harnessing techniques.

Figure 4: Harnessing approach to a bilateral, body-powered transhumeral presentation.

MYOELECTRIC ADAPTATIONS

Currently we are limited to commercially available surface EMG sensors that were traditionally placed in the prosthetic socket. With osseointegration the socket is eliminated but there is still the need to use surface electrodes for control. These surface electrodes must maintain skin contact with the patient's limb throughout a significantly expanded functional range of motion. In the case of shorter limbs or limbs lacking usable myoelectric signal sites, the control sites may be moved to the chest wall or poster scapular region to capture available myolectric signals.

Outrigger

The outrigger approach was first described by Jonsson et al [1]. Outriggers are fabricated from a rigid material and attached distally at the laminated coupling that connects the elbow to the connection adaptor. This represents a simple method of providing consistent electrode location in dual site control (Figure 5).

Non-custom Electrode Bands

For more elaborate control strategies requiring multiple inputs, when the residual limb is long enough with a cylindrical shape, non-custom commercial electrode bands can be used. These systems may require frequent recalibration due to inconsistent placement during donning (Figure 6).

Figure 5&6: Two strategies for positioning electrodes of midlength and longer transhumeral limbs

Adhesive Electrodes

Adhesive electrodes represent an alternative for shorter limbs when the distance between the prosthetic elbow and the electrode placement is too long for outriggers and the limb is too conical for commercially available cuffs to stay in place without distal migration (Figure 7).

Custom Silicone Interfaces

An attractive alternative to adhesive electrodes is a custom silicone interface that accommodates the unique contours of the limb segment. This is especially desirable with the use of pattern recognition where multiple electrodes sites are required. (Figure 8).

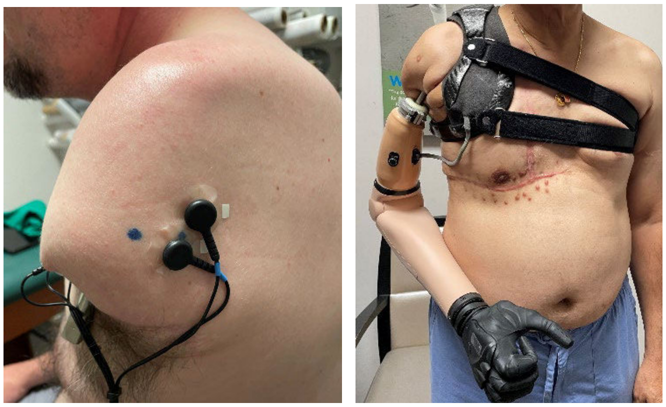

Figure 7&8: Two strategies for positioning electrodes with shorter transhumeral limbs.

CONCLUSIONS

As transhumeral osseointegration becomes more available, prosthetist will be confronted with the challenges of creating a consistent, comfortable control strategy. While our pilot observations in this space are limited, we have already encountered the need to adopt a number of strategies for both body-powered and myoelectric systems based on limb length, the complexity of the control system and the number of required inputs. Additional research is needed to understand the magnitude of the forces created by the control cables pulling against the housing retainers in the various required configurations. One solution to the challenges of maintaining elbow contact throughout an expanded range of shoulder motion is the promise of internal, surgically implanted myoelectrodes that better maintain their fidelity through shoulder movements.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the clinical creativity of the treating prosthetists, Brittany Curcio CPO, Michael Duston CPO, William Fletcher CPO and John Boldt CPO.

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