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METHODS FOR COLLECTING MYOELECTRIC SIGNALS FROM INDIVIDUALS WITH LOWER LIMB AMPUTATIONS

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ABSTRACT

Technological advancements in lower limb prostheses have resulted in actuated motors in both knees and ankles. Currently, these components are controlled by information measured from various electromechanical sensors attached to the prosthesis. Our aim is to enhance the control information provided to powered prosthetic components by including input from the user via interpreted myoelectric signals (MESs). To extract useful control information, it is imperative that consistent, high-quality MESs be collected from patients each time they don the socket. In this work, we present approaches to maintaining consistent electrode placements on individuals with transfemoral and transtibial amputations during static non-weight-bearing conditions and dynamic weight-bearing activities. Our results show that a variety of methods, similar to those used in upper limb fittings, may be used to collect high-quality MESs during static non-weight-bearing conditions. MES collection during dynamic weight-bearing activities is more challenging. The type, size, shape, and placement of electrodes must be carefully chosen to maintain contact with the skin without compromising comfort during weight-bearing activity.

INTRODUCTION

There are an estimated three million individuals in North America with major amputations [1], with an estimated 90% to 97% being lower limb amputations [2]. Most lower limb prosthetic components are passive, reacting to the external forces applied to them. Powered lower limb components consist primarily of microprocessor knees, which use input from electromechanical sensors to alter the resistance of the knee unit to compensate for different phases of the gait cycle or variations in cadence. Until recently, the only components that contained a motor-actuated joint for positioning were the Ossur Power Knee™ and Proprio Foot™ and the Power Knee was the only commercially available prosthetic component that actually generated positive power, which may reduce the user's energy expenditure and improve gait mechanics [3].

Powered lower limb components with actuated motors have been developed and tested clinically and are highly visible in the research community, with the PowerFoot BiOM™ by iWalk recently becoming commercially available. Each mode of operation of these components (e.g. stair ascent) has a kinematic profile that determines the operations of the joint. Although highly sophisticated, this variety of powered component still relies on electromechanical sensors to trigger a particular mode. Switching between modes can also be done manually. Such methods for control are not intuitive, do not provide smooth transitioning between modes, and can be cumbersome as they may involve use of the contra-lateral limb and may require donning additional hardware.

In order to enhance the performance of these lower limb prostheses, it is our goal to augment the current sensor information with user intent information. Our approach to this merger of technology is to use MESs from the surface of the individual's residual limb to provide data that will improve component responsiveness. A study by Huang et al. [4] investigated the use of advanced signal processing as a control strategy for powered lower limb prostheses. The results indicated that the combination of surface MESs and pattern recognition can provide accurate information regarding the user's intent for prosthetic control. In order to utilize user intent information, it is essential to create an interface that captures consistent, reliable, high-quality MESs from residual limb muscles during both static and dynamic situations [4].

There are standard practices regarding the incorporation of electrodes into upper extremity prostheses. Two main methods are identified; first being the *packaged electrode*, which is a combination of contacts and pre-amplifiers. These are typically rectangular-shaped packages that are mounted to the inner socket (or interface) that is in direct contact with the skin. Appropriate placement of these packaged electrodes is crucial when fabricating the interface, as these cannot be readily repositioned without creating a void in the socket and remounting the package. *Remote electrodes* are those in which the electrode contacts are separate from the pre-amplifier. A pair of contacts and a single reference is usually associated with each amplifier. These are convex or dome-shaped medical-grade stainless steel and come in different diameters and heights. Daly [5] described the use of remote electrodes with gel liners in 12 upper limb subjects. Although he reported an improvement in comfort and function, durability of the electrodes and wiring still pose challenges in this design [5]. Advantages to using remote electrodes are that the contacts can be easily placed at different locations within the socket/interface, they

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can be spaced apart from one another at varying positions and moved to another location easily without creating a large void, they can be placed at varying in depths relative to one another, and they can be mounted in irregular contours (convex or concave aspects of the socket).

METHODS

All research activities were approved by the Northwestern University Institutional Review Board.

Transfemoral Fittings

The advantages of remote electrodes and the amount/type of soft tissue present in most transfemoral limbs provided an ideal combination for collection of surface MESs with transfemoral sockets. However, early in our research the results using remote electrodes were suboptimal. In the study by Huang et al. [4], dome-style contacts (Liberating Technologies, Inc.) were incorporated into a transfemoral diagnostic suction socket by drilling holes precisely 18 mm apart—the spacing of the MA-411-002 electrode (Motion Lab System, Inc.)—as the electrodes were mounted directly onto the threads of the contacts [4]. The threads of the contacts had to be parallel to one another and spaced at a distance to allow them to screw into the socket-mounted electrodes. If this constraint was not precisely met, the holes had to be re-countered. This resulted in oversized holes that compromised suction. We attempted to remedy this by applying silicone putty between the contact and electrode in order to re-establish suction. This was found to be time-consuming and tedious.

Later, we established a different protocol for collecting MESs from subjects with transfemoral amputations [6]. MESs were first collected during a static, non-weight-bearing condition without a prosthesis or socket. Nine muscles were identified on the residual limb, including sartorius, rectus femoris, vastus lateralis, vastus medialis, gracilis, adductor magnus, semitendinosus, biceps femoris, and tensor fascia latae. Self-adhesive Ag/AgCl contacts were applied over these sites and were snapped to modified surface MES sensors (DelSys). In an attempt to keep electrode locations relatively consistent between static and dynamic conditions, the positions of these electrodes needed to be re-located onto a test socket. If a well-fitting diagnostic socket had been previously fabricated, the subject was asked to don the socket multiple times and the muscle sites were marked on the socket. The average muscle location during these donning attempts was then used to locate the socket-mounted contacts. If a diagnostic socket was not available, an impression was taken with fibreglass bandage and the electrode locations were later transferred to the test socket.

With the DelSys electrodes, it was possible to use a different style of stainless steel dome contact (Motion Control, Inc.) within the socket. These contacts permitted a snap, analogous to those on the self-adhesive Ag/AgCl contacts, to be mounted on the outside of the socket. Domes were then threaded through the diagnostic socket and into the back of the snap (Figure 1). This greatly decreased the time and complexity of the diagnostic socket set-up. Data with the socket could then be collected in either static or dynamic conditions.

Figure 1: Transfemoral test socket with domes and snaps mounted for MES collection.

Transtibial Fittings

Transtibial sockets present a different challenge due to anatomical contours and minimal soft tissue coverage. Typically, a soft interface (i.e. sock and/or liner) exists between the skin and hard socket to provide comfort and/or a means of suspension. Our team did not feel it was plausible to attempt to fit individuals with transtibial sockets that were similar to the transfemoral designs, as the residual limb would need to be in direct contact with the hard socket and stainless steel domes, compromising comfort and electrode-skin contact. Two alternative approaches were (1) to place contacts on the skin prior to donning the soft interface and socket, or (2) to embed contacts into the soft interface itself. We chose to examine the latter, as many individuals with transtibial amputations utilize gel liners and this approach is in line with our group's ongoing research into gel liners.

The method that we chose to employ was different from that described by Salam [7], who cut holes in the liner for residual limb/electrode contact, or Daly [5], who used snap electrodes through the interface along with a pre-amplifier wire harness. Incorporating DelSys electrodes permitted us to design a liner that would contact the residual limb at the required muscle locations and then carry this information to a remote location where snaps could be used to connect to the DelSys electrodes. As in our previous designs, requirements for the interface were that it (1) was easily donned and doffed, (2) was comfortable, and (3) contained flexible leads to permit bending and rolling without fear of fatigue or damage.

Our first transtibial subject had been using an Iceross Synergy Liner^{TM} by Ossur and was therefore accustomed to donning and doffing techniques. We modified this liner for MES collection at eight desired electrode sites: over the rectus femoris, biceps femoris, vastus medialis, vastus lateralis, gastrocnemius (lateral head), gastrocnemius

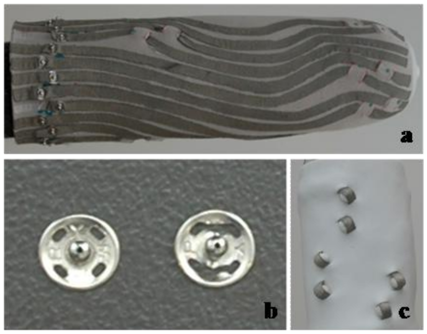

Figure 2: a) Modified Liner; b) Snaps; c) Inner Contacts with Domes

(medial head), tibialis anterior, and the peroneus longus. These muscles were palpated and marked, and marks were transferred onto the roll-on gel liner. Two contacts were required for each bipolar electrode, and slits were cut in the liner to weave conductive fabric through to the inside and back out. Each contact site was 1 cm wide and 2 cm long with a 3 cm center-to-center distance between contact sites for each bipolar pair. Contacts were made on a slight angle to allow the fabric to travel up and down the liner without touching adjacent fabric strips. The conductive fabric was secured to the outside of the liner, terminating in snaps (Figure 2).

On the subject's first visit, we identified muscle sites and performed non-weight-bearing MES testing. Self-adhesive Ag/AgCl contacts were used for this experiment. The subject was familiarized with the protocol and MESs were collected while he visualized performing different movements with his missing limb in a static, non-weight-bearing condition.

The subject came in on three additional days to test MES collection with the modified liner. At each visit, the subject was asked to perform muscle contractions for the same motions introduced on the first day. MESs were collected under three conditions: (1) with the liner and no socket, (2) with the liner and socket but non-weight-bearing, and (3) with liner and socket during walking trials. At the first visit, the liner was tested without anything under the fabric to raise the contact sites (the fabric was flush with the gel liner). At the second visit, small leather discs were glued under the fabric inside the liner to raise the contact site from the surface of the gel liner in order to improve contact with the subject's residual limb. For the third visit, we used higher silicone domes instead of the leather discs; again the goal was to achieve and maintain good contact with the subject's limb without compromising comfort.

RESULTS

Transfemoral Fittings

The results of data collection have shown promise for the new socket design both statically, in a seated position, and dynamically, with both a passive and powered prosthesis. Only minor modifications, typical in prosthetic fittings, were necessary to the socket/contact interface. There were minimal differences between the myoelectric signals recorded from the Ag/AgCl electrodes without a socket and the stainless steel dome electrodes embedded into the socket (Figure 3). These data were recorded on separate days so small differences in signal amplitude can be attributed to differences in electrode position (i.e. donning the socket) and muscle contraction intensity.

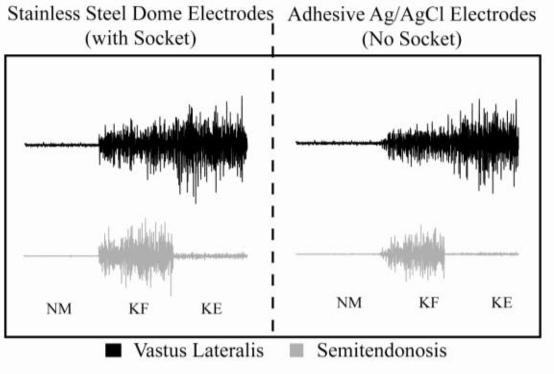

Figure 3: MESs from a transfemoral amputee during non-weight-bearing activities: no motion (NM), knee flexion (KF), and knee extension (KE).

Each electrode setup was used to train a pattern recognition system for both knee and ankle motions in the sagittal plane. The system was 93% accurate using the Ag/AgCl electrodes without a socket and 92% accurate using the stainless steel dome electrodes embedded into the socket.

During weight-bearing activities, increasing the depth of the contacts decreased motion artefact and potential lift-off within the socket. Lift-off is most often characterized by large signal amplitudes with a 60 Hz frequency component and usually occurs during heel strike and/or toe off. The addition of spacers behind the convex dome or aggressive modification of the positive model and/or diagnostic socket has reduced the likelihood of lift-off. Using these modifications, we were able to use stainless steel dome electrodes to collect high-quality myoelectric signals during walking (Figure 4).

Transtibial Fittings

Transtibial data collection has also proven comparable to other methods of obtaining myoelectric signals during non-weight-bearing conditions. When compared to signals obtained using Ag/AgCl contacts, the myoelectric signals displayed from the medial gastrocnemius and tibialis anterior show similar characteristics (Figure 5). When used to train a pattern recognition system for ankle motions in the sagittal plane, the system was 100% accurate using the Ag/AgCl electrodes and 100% accurate using the fabric electrodes with a socket.

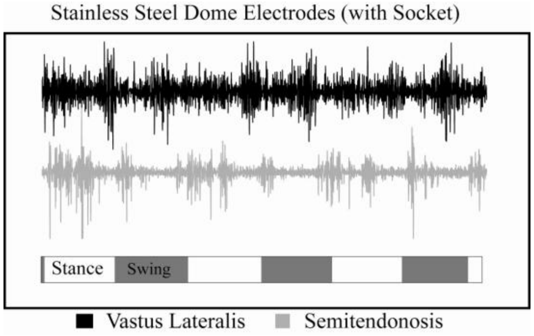

Figure 4. MESs from a transfemoral amputee while walking.

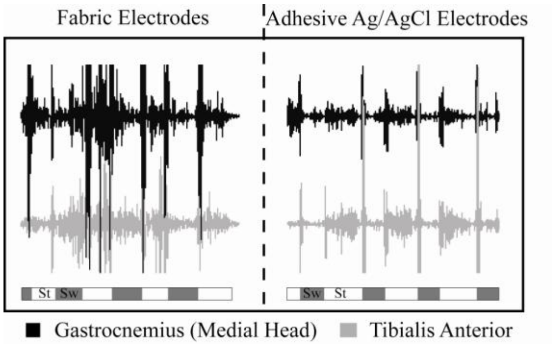

Figure 6. Myoelectric signals from a transtibial amputee while walking. St = stance; Sw = swing.

In dynamic weight-bearing conditions, myoelectric signals were not as clean, with a movement artifact present during peak periods of loading and unloading (Figure 6).

DISCUSSION

For our current research with transfemoral subjects, it is plausible to use a test socket with dome-style electrodes and snaps. However, in future developments, it may be necessary to alter the configuration to permit the inner socket and/or frame to contain the wire harness, or to use a liner in conjunction with transfemoral fittings and house the electronics somewhere within the prosthesis itself. However, this may compromise the fit and control of the prosthesis. We feel that fitting liners to individuals with transfemoral amputations is less optimal than fitting traditional suction sockets.

Within the transtibial MES recordings it is difficult to surmise exactly what is occurring inside the socket and interface, although the data appears to suggest a lift-off of one or more of the contacts from the skin. Pistoning (translational movement of the limb within the socket) or movement of subcutaneous tissue may also be the cause of such artefacts. Deepening the contacts on the muscle bellies proved effective in the collection of MES, however, this was done at the expense of comfort. New style contacts are being investigated to improve the reliability of the signals as well as the comfort for the user.

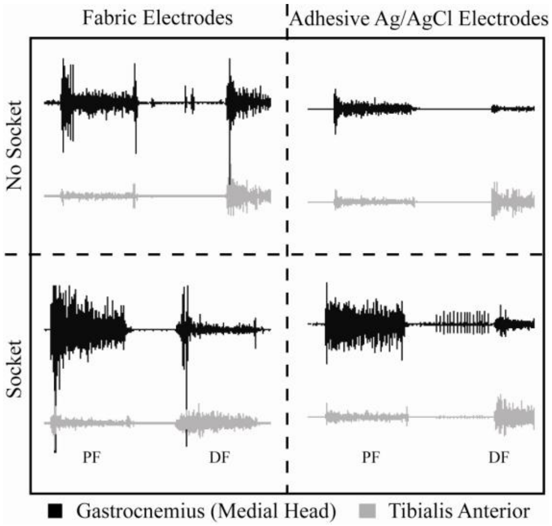

Figure 5. MES from a transtibial amputee during a non-weight-bearing session performing ankle plantar flexion (PF) and dorsiflexion (DF) muscle contractions.

ACKLOWEDGEMENTS

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