EMG-ELECTRODES FOR MYOPROSTHETICS: DESIGN PRINCIPLES AND APPLICATION TIPS
By Gerald Haslinger, Otto Bock Austria GesmbH

SUMMARY: The myoelectrodes for the detection of myoelectric activity play a paramount role in myoelectric upper extremity prosthetics. This presentation explains the procedures which should be employed for the optimal use of myoelectrodes and introduces a new myoelectrode.

1 INTRODUCTION

Myoelectric control of externally-powered prostheses has proven to be state-of-the-art technology in upper extremity fitting. In contrast to body-powered prostheses, the control of myoelectric prostheses generally does not interfere with other motions, since the muscles of the residual limb can be used to the control the prosthesis. In addition, the maximum grip-force is only limited by the external power source. Myoelectric (externally-powered) prostheses are more comfortable and cosmetically attractive than body-powered ones. Another positive note is that reduced phantom limb pain has also been reported [1].

The proportional control scheme improved the rehabilitation with myoelectric prostheses using the strength of the muscle signal for precise control of grip-speed and grip-force [3]. In particular, proportional control makes high demands on the quality and stability of the control signals.

With all the positive attributes of myoelectric control, myoelectrodes for the acquisition of the myoelectric signal are the “weak link” in myoelectric fittings. On the one hand, they reduce the variety of muscle signals in their pickup area to a single control signal and therefore limit the possibility of multi-degree of freedom control of prosthetic hands or arms. On the other hand, they are very sensitive and therefore prone to disturbances. The performance of the myoelectrodes is essential for patient satisfaction.

The basic function of myoelectrodes is the reliable acquisition of the myoelectric signal and the rejection of interference. In this presentation we will disclose the optimal use of myoelectrodes while also introducing a new myoelectrode which is currently in development.

2 TECHNICAL PRINCIPLES OF ELECTROMYOGRAPHY

The myoelectric signal is a very low-level signal with high resistance and therefore very sensitive to disturbances [2].

2.1 Disturbances

The disturbances can be classified in the following two groups:

2.1.1 Low frequency disturbances

In definition low frequency disturbances reflect disturbances in the frequency range of the myoelectric signal. They originate from motion artefacts and electrical interference e.g. from power lines. As they are in the same frequency range as the myoelectric signal they cannot be filtered since that would also eliminate the myoelectric signal. They can only be suppressed by the input characteristics of the
amplifier (as explained below) or by notch filters which eliminate just a small band of frequency but also cause a loss of myoelectric signal-power.

### 2.1.2 High frequency disturbances

High frequency disturbances have recently become more problematic by the ever increasing number of mobile phones and other devices. They can be suppressed by low-pass filtering which cuts off the high frequency band. Additional shielding of the myoelectrodes may be necessary.

### 2.2 Amplifier technology

Ranging from 5 to 300 $\mu$VRMS the EMG is a very low level signal superimposed by disturbances that are up to 100,000 times stronger. The need for high amplification as well as simultaneous rejection of interference demands sophisticated electronic amplifier technology. The differential amplifier concept helps to reject interference while it amplifies the myoelectric signal.

Low frequency interference can be regarded as a constant potential in the pickup area of the myoelectrode (common mode interference – n in figure 1). The amplifier eliminates this constant potential by subtracting one input from the other. In contrast, the myoelectric signal produces different potentials (m1 and m2) that are superimposed on the constant interference potential. These differences remain after subtraction by the amplifier. The *differential amplifier* is therefore able to separate the EMG from the common mode interference.

\[
\text{differential amplifier} \quad \begin{array}{c}
+ \\
- \\
\end{array} \quad (m1+n)-(m2+n)=m1-m2
\]

**Figure 1: Differential amplifier (schematic drawing)**

In practice some of the interference will always remain after subtraction since the two differential inputs are never perfectly equal. To reject interference that is up to 100,000 times stronger than the myoelectric signal, the gains of the two differential inputs must not differ by $1/100,000^{th}$. The ability of a differential amplifier to reject common mode interference is called common mode rejection ratio (CMRR).
2.3 Skin electrode interface
Unfortunately the CMRR is also influenced by asymmetries in skin resistance of the differential inputs, due to the fact that the two input signals are affected by the skin resistance. This is because the signals are divided by the ratio between skin interface resistance and the input resistance of the amplifier. The effect of the skin interface resistance lessens with higher input resistances. Therefore a high CMRR and a high input resistance is required.

One should be aware that while exhausting technical possibilities of high input resistances, the skin interface will always have a negative effect. For this reason it is vital to keep a balanced resistance of the skin interfaces at the two differential inputs.

![Figure 2: Inputs of a myoelectrode](image)

That can be achieved by:
- equal pressure on the two differential inputs and
- a skin patch with uniform characteristics.

Therefore the myoelectrodes have to be mounted flat onto the skin and the differential inputs must avoid any scarred areas or amputation flaps as much as possible.

2.4 Gain adjustment
Another important detail regarding the application of the myoelectrode is the gain adjustment. It should be adjusted so that the patient can maintain the signal for approx. two seconds over the maximum control value of his prosthetic device.

Setting the gain too high will result in three drawbacks:
1. a loss in control-efficiency as only a small part of the signals’ dynamic range is actually used for controlling
2. It causes higher disturbance susceptibility when the disturbances are over-amplified and
3. The training-effect of the muscles in the residual limb is also reduced.

3 RECOMMENDATIONS FOR FITTINGS
For the placement of the electrode one has to find suitable muscles for the control of the myoelectric prosthesis.
The muscles should:
- produce a strong signal, i.e. should be big enough and located just beneath the skin's surface,
- be voluntarily contractable by the patient,
- be selected so as not to be influenced by myoelectric signals from other motions,
- be used as per their original intention and
- be located in an area of the residual limb that offers good contact with the myoelectrodes.
- If two or more myoelectrodes are used, the involved muscles should be apart far enough to be able to produce distinguishable signals.

In order to find a good myoelectrode position, the use of an EMG monitor is recommended. The myoelectrode should remain in one position for a longer period of time until its contact has stabilised. To create good conditions for fitting, it is helpful to clean and/or to moisten the skin prior to attaching the myoelectrodes (e.g. with saliva of the patient, disinfectant [clear Kodan spray], or Dermaclean from Otto Bock). The skin should not be cleaned with fluids like alcohol which dry out the skin too much and therefore impair conductivity.

A well-fitted socket avoids movements between the skin and the myoelectrodes. Loose fittings result in motion artefacts that can by far exceed the EMG signal strength. Elastic myoelectrode suspensions also hinder motion artefacts by making up for volume differences during movement.

Therapeutic care: To achieve the optimum of the patients' potential an experienced therapist will ensure that breaks during the process of fitting are strictly upheld. This will avoid muscle fatigue which leads to severe fading of muscle signals. It is therefore strongly advised that short sessions are spread over the whole day instead of holding a single intensive training session.

4 INTRODUCING A NEW MYOELECTRODE

Due to our past experiences and the necessities stated in this article we are developing a more sensitive electrode which is less disturbance susceptible due to higher CMRR and higher input resistance. We have improved on gain adjustment with a more precise logarithmic adjustment scale and have upheld patient safety by keeping the myoelectrode DC decoupled. The first results from a field study will be presented during the presentation since these results were not yet completed by submission.

5 CONCLUSIONS

Myoelectric fitting is state of the art for upper extremity fitting and offers many advantages in rehabilitation. To overcome existing practical needs a new electrode is being developed. Nonetheless, careful application of the myoelectrodes is imperative for achieving optimal patient satisfaction.