A new Method for Myoelectric Signal Acquisition: 
Preparing the Patients to Efficiently Use an 
Artificial Arm

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Abstract. This paper presents a new methodology in amputation surgery that is dedicated to patients who intend to use a myoelectric forearm prosthesis. The control signals for a myoelectric prosthesis are the surface EMG signals. In the case of an amputation stump, these signals are weak and difficult to use for effective control, due to the amputation methodology and the lack of activity after amputation. The proposed method aims the osteomyoplastic suturing of the muscles in circumferentially offset positions in order to obtain clear myoelectric signals, non-overlapping and with less correlated information. Following the surgery, a specific training is used, based on a biofeedback device, in order to help the patient to gradually obtain better control of stump’s muscles. The proposed methodology was evaluated experimentally at CMH, in a stump retouch surgery (on a patient who lost his hand almost 20 years ago), allowing comparison of the signals before surgery with ones after surgery and also with ones obtained after completing the post-surgery training. While going through these stages, a constant improvement of amplitude and independence of EMG signals collected from the stump was found. In the end, the patient was able to control an experimental model of artificial hand, by five different EMG signals, collected from stump’s muscles. The results appear to validate, in this case, the working hypotheses used as the base for the surgical method and biofeedback training.

Key-words: amputation, CONM, artificial hand, prosthesis, myoelectric control.
1. Introduction

Coordinated by half of the brain motor centers, for a healthy man, hands are indispensable for most of his activities. Total or partial amputation of one or both hands is one of the most devastating situations that a human being could experience [2]. Statistics in recent years show that, globally, the number of people with amputated hands is alarmingly high and continually growing: 450,000 people in 2010 in the USA [3], 11,000 registered people in the UK [4] and 35,000 registered people in Romania [5]. Traumatic injuries, cardiovascular diseases, malignant diseases and birth defects are the most common causes that lead to hands amputation. The only chance for these patients to be able to recover at least some of the functions lost during amputation is the acquisition and use of an artificial hand. In this context, it should be taken into account that most of them have a modest financial condition [6] and, because the artificial hand market price is high or very high, the real situation of these millions of people is worryingly difficult [7]. Neural control prostheses offer high-performance functions, but are inaccessible due to high purchase price. The only solution more accessible in terms of price/performance ratio is the use of myoelectric control prostheses, even if they have technological limitations.

One of the main limitations of myoelectric prostheses is the reduced number of movements that the patient can do, because of the small number of EMG control signals which can be collected from the patient stump [8]. Due to the difficulty (or even the impossibility) to collect from the forearm stump enough quality EMG surface signals (sEMG) to control the functions of the prosthesis, control signals from the arm or even shoulder muscles are often used, which greatly hamper the development of skills by the patient [9].

Measurements that have been made in order to collect sEMG signals through various contractions of the stump’s muscle showed that not all the contractions from the stump were leading to quality sEMG signals. According to intelligent prostheses theory, because the sEMG control signals are “mixed”, there were revealed two main ways of diversifying the commands that the patient can give to an artificial hand: recognition of signals/patterns of movement and their use for making complex movements, respectively using “unnatural” muscles to control the prosthesis movements [10]. sEMG measurements performed on the patient showed strong attenuation of sEMG signals collected from the amputation stump compared to signals collected in similar positions from the healthy hand. Possible causes leading to the attenuation of sEMG signals were set as working hypotheses as follows:

1. Retraction of the muscles that were not appropriate sutured during the amputation;

2. Shrinking of transmission area of the nervous impulse to muscle fibers through motor end plates, due to the reduction of muscle mass after amputation;

3. Muscle atrophy due to their disuse;

4. Reduction of motor memory.

To remedy or at least reduce these causes or their effects, there were suggested solutions for surgical correction of the first two and individual training and biofeedback for the other two. In the following we present the methodology that includes all.
2. Methods

2.1. Classical methodology of amputation

The usual medical methodology for forearm amputation involves suturing the muscles over the bone stumps, without explicitly specifying a particular individual disposition of them. Although it is medically correct, the usual procedure makes the acquisition of surface EMG signals (sEMG) from different groups of muscles of the stump very difficult after amputation. Patients undergoing a specific post-surgery training, even if they manage (with difficulty) to contract each muscle group from the stump separately, this success does not lead to the collection of distinct sEMG signals, due to the existence of four volar muscle plates. Thus, the number of commands to control an artificial hand is limited to the small number of distinct sEMG signals.

2.2. The method of amputation/retouch of stump by circumferential osteoneuromyoplasty (CONM)

The improvement of the methodology of amputation was aimed by suturing muscle groups in appropriate positions in order to get clean and distinct myoelectrical signals, with independent information (low correlation) after the distinct contraction of each muscle groups. This method aims to bring deep muscle plans to the surface, preserving the nervous distribution area in order to obtain distinct EMG signals with low correlation. This methodology involves placing and suturing the stump muscles by muscle groups and categories of motor functions, in order to allow collection of several uncorrelated sEMG signals from the stump. This allows distinct and more natural control (with signals from muscles that would have produced the same movements to a healthy hand) of movement of the prosthesis components. Thereby it becomes justified to equip the intelligent prosthesis with larger motor functions that the patient could use. The eligibility criteria for participants are: forearm amputees which needs forearm’s stump reshape and who are also interested in using a noninvasive intelligent prostheses. Elbow disarticulation amputees are excluded. During the surgery it is aimed to identify all muscle groups and each muscle with their circumferential transosseous reinsertion, in order to avoid muscle retraction and increase the surface of muscle exposed to EMG measurements. Muscles will be well individualized, yet keeping the topography of the main muscle groups: ventral muscles into ventral horn and dorsal muscles into dorsal horn. In the classical method of amputation (Figure 1a) it can be observed that some muscles of the stump, which might provide useful sEMG signals are superimposed on others, due to natural anatomical distribution. The osteoneuromyoplastic circumferential methodology (CONM) that was proposed (Figure 1b) aims to bring muscle groups in the stump to the surface circumferentially before anchoring. This placement of muscle groups in the stump allows also collection of sEMG signals from deep muscle groups with surface EMG electrodes. The CONM methodology also involves the forearm fasciotomy at the amputation stump in order to reduce the electrical resistance of the tissue layer between muscles and electrodes, for increasing the level of collected sEMG signal. To improve the nervous impulse transmission to muscle fibers, the methodology involves nerves neurolysis followed by increasing the length of the motor nerve branches entering each muscle group.
3. Training methods and techniques for increasing sEMG signal

The main training method begins with isometric contractions of stump’s muscles in order to increase both the patient’s ability to control these muscles, and muscle’s strength. In the next stage, different movements are performed with stump’s muscles and healthy arm’s muscles successively and then simultaneously. Thus, certain movements made symmetrically and simultaneously with both hands help to rehabilitate some affected features of the partially amputated hand because the patient with an amputated hand and a healthy hand has an active brain map of the healthy hand’s muscles and a brain map that is intended to be reactivated for the amputated hand. Finally, the patient learns again to use certain muscle groups on the stump by contracting them separately. This training is supported by biofeedback techniques but also by solutions for reactivating the psychomotor representation of the amputated forearm in the patient’s motor cortex. During the training workout, the patient is connected with the electrodes on the stump to biofeedback device, first with each muscle separately, in order to improve his control over it, then with more muscles, in order to simulate the complex control contractions of a prosthesis. Thus, the patient sees directly on the biofeedback model, the straining effects of certain muscles from the stump. The patient will be able to command gradually the moving parts of prosthesis.

3.1. Evaluation equipment and biofeedback devices used

The EMG devices that was used were Contec CMS6600 (PUB) and Nicolet EDX (UEH), together with their dedicated EMG software. There were also developed a portable biofeedback device and a model of intelligent prosthesis with independently actionable fingers, that were used as a support for patient’s training. The biofeedback device is hand shaped and each finger can light LEDs in three colors, depending on the control signal amplitude generated by the patient. The most complex device, developed in collaboration by UPB and IMT is an artificial hand model that allows independent movements of the five fingers.
4. Discussion

Methodology and training techniques were experimentally evaluated on a patient with trans-radial amputation of the right hand, who needed surgery to retouch the stump. Experimental evaluation of CONM methodology for a retouching surgery allowed comparison of the myoelectrical effects of the two methods of amputation.

4.1. Case presentation

The 37 year old patient had a post-traumatic amputation at the age of 9 and, due to muscle atrophy and retraction, experienced pain on amputation stump. Thus, the retouch surgery of the stump became necessary and the patient subscribed to the CONM method by self-selection (on 04.04.2013). The recruitment was based on the patient’s interest in buying forearm prosthesis with myoelectrical command.

Measurements done before surgery showed the fact that the sEMG signals collected from the patient’s stump at alternate contractions of different muscle groups had a low amplitude and also were strongly correlated, thus being not useful for obtaining different commands of a prosthesis. Figure 2 shows such typical results (on the display in the background): sEMG signal are monitored on two different channels for two distinct muscle groups. Although the patient intends to contract only one group, the signals or both channels are similar (or, in mathematical terms, are highly correlated). The amplitude of the signals has a mean value of around $10\mu V$ with a statistical variance of about 15% (from 5 different measurements) and comparable with the noise.

Fig. 2. sEMG measurements before retouch surgery.
5. The retouch of the stump surgery performed by the CONM method

The surgery involved the excision of bone ends, the identification of all muscles followed by bringing muscles to the surface circumferentially, according to the presented methodology, in order to increase muscle surface exposed to EMG measurements and to avoid muscle retraction. The intervention was done at Central Military Emergency Univeristary Hospital by Prof. Adrian Barbilian and his medical team.

Muscles were placed individually, yet keeping the topography of the main muscle groups: ventral muscles into ventral horn and dorsal muscles into dorsal horn (see Figure 3).

Additionally, in order to reduce the electrical resistance of the layer of tissue between muscle and EMG electrodes, the forearm fasciotomy was also performed near the amputation stump. In order to enhance nerve inflows transmission to muscles, motor nerves neurolysis was conducted as well. There were found residual nerve items: posterior interosseous nerve, median nerve-motor nerves, which were neurolysed.

5.1. The results achieved immediately after surgery

Post-surgery evolution was favorable with complete disappearance of painful symptoms within two weeks. Then, after other two weeks, sEMG signals was collected from the stump. The new signals had 20% higher amplitude (under the same statistical conditions) compared with those obtained from pre-surgery measurements.
5.2. Training program and results

In order to improve the capability to control a prosthetic device with myoelectric stimuli, the patient followed a specific training program that aimed the development of specific abilities. The program started one month after surgery, with a daily basic training, consisting in 4 hours sessions of isometric contractions of stump’s muscles. The sEMG signals collected after these sessions showed a slight improvement in amplitude (10%) and control capability.

In the next stage, for a month, the patient conducted sessions of successive movements and then synchronous with both hands performing contractions of the same muscle. Stump’s muscles have generated sharper sEMG signals and with 80% higher amplitude for synchronous movements made by the patient, showing a better control (same statistical conditions).

The results achieved in the post-surgery training phase were highlighted by simultaneous measurements of sEMG signals with two EMG devices. For the measurements pictured in figure 4, the electrodes are placed on the stump on different muscle groups.

![Fig. 4. Simultaneous measurements with two EMG devices.](image)

The measurements have shown the fact that sEMG signals corresponding to different muscle groups’ contractions was distinct and less correlated than the previous ones. This was a significant improvement related to the initial situation and was due to the CONM retouch surgery. The two EMG devices were used in order to certify that there are low or no interferences between different signals’ envelopes.

![Fig. 5. Training by biofeedback using: the "intuitive" device a), the artificial hand model b).](image)

The patient was trained for one month by biofeedback sessions for each relevant muscle group (Figure 5a) until he obtained five distinct (less correlated) signals. After this stage, the patient was able to control the fingers of the experimental artificial hand (Figure 5b).

One of the objectives of the training was that the patient reactivates the neuronal commands prior the amputation, when the hand was healthy. Thus, the distinct sEMG signals obtained
correspond to commands already existing in the neuronal map of the patient. As the experiments proved, this helps the patient to reactivate some motion reflexes at the level of the stump muscles. The results appear to validate, in this case, the working hypotheses used as the base for the surgical method and biofeedback training. The interdisciplinary team continues the CONM study on other cases and also the work to develop a new sEMG controlled artificial hand [11, 12].

6. Conclusions

The proposed methodology (CONM) was evaluated experimentally on a patient with transradial amputation of the right hand. He received a retouch surgery of stump that removed the painful symptoms on this level and brought deep muscles of the stump to the surface, in order to better highlight their EMG signals. After surgery and recovery period, the collection of sEMG signals from the stump allowed the highlight of a better control and higher amplitude. The retouch surgery of stump that was conducted in this case allowed the comparison of myoelectrical effects of the two methods of amputation, and the highlight of the CONM method’s advantages. The CONM method allowed the non-invasive collection of sEMG signals from all muscle groups of the stump. The access with surfaces non-invasive electrodes at muscle groups that were brought to surface with CONM method made possible the collection of five different signals with low statistical inter-correlation. The training program helped the patient to improve both the amplitude of sEMG signals on the stump and his ability to control them. The training was assisted by biofeedback, allowing the patient to improve his performance and to evaluate his progress constantly. This led him to the individual control five different signals, allowing its connection to the experimental model of artificial hand. Taking into account the fact that the patient lost his hand almost 20 years ago, the results obtained are already impressive. The results are under discussion and generalization and are to be updated following other patients enrollments into the CONM trial and subsequent training.

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References


