Development of the system for continuous medical rehabilitation for patients with post-stroke and spinal cord injury motor disorders

O A Jafarova\textsuperscript{1}, E A Tarasov\textsuperscript{1}, R Yu Guk\textsuperscript{2}, M B Shtark\textsuperscript{1}

\textsuperscript{1}Institute for Molecular Biology and Biophysics, Russian Academy of Medical Sciences, Timakov Str., Novosibirsk, RUSSIA
\textsuperscript{2}Center for Neurorehabilitation, Siberian Clinical Center FMBA, Kolomenskaya Str., Krasnoyarsk, RUSSIA

jafarova@soramn.ru, ruslana-guk@yandex.ru

\textsuperscript{1}www.imbb.ru, \textsuperscript{2}www.skc-fmba.ru

ABSTRACT

This paper describes an experience of developing a computer system for continuous medical rehabilitation involving patients with post-stroke and spinal cord injury motor disorders. Particular focus is made on the concept of telerehabilitation for this specific group of patients. Telerehabilitation has to be continuous and regular. It is also necessary to provide the possibility of conducting treatment/communication sessions asynchronously. The empirical results of four year implementation of this system in Russia showed high efficiency and revealed some limitations of a distant network rehabilitation program based on electromyographic biofeedback.

1. INTRODUCTION

In Russia every year around 0.5 million patients after cerebral accidents and 0.5 million patients with severe brain injuries are registered. 40\% of them are in age of capacity, but their ability to move is restricted. The efficiency of medical rehabilitation for spinal cord injury (SCI) and stroke patients greatly depends on the availability of regular rehab procedures for a long-time period. Regretfully, the majority of high-tech methodologies are located in a limited number of neuro-rehab centers which are not able to provide proper medical assistance because of their farness and financial pressure. The lack of permanent medical assistance results in poor rehabilitation outcome. To increase the effectiveness of medical rehabilitation, it obviously has to be continuous and regular. The attempts to extend the care possibilities to the patient's home are so far limited, focusing mainly on tele-monitoring, tele-diagnosis, and limited tele-assistance.

The concept of telerehabilitation states that the therapy is provided remotely. Ideally, the patient should be able to receive the majority of his/her treatment at distance, at home. The advantages are clear: familiar environment ideally supported by family members, treatment accessible to those patients who either would not tolerate hospital care or are unable to commute to the specialized institutions (for a lack of mobility or financial reasons).

On the other hand, shortening the hospital staying brings non-trivial cost savings for the healthcare system as well. In this case the new possibilities emerge for delivering high quality rehabilitation services to a much larger population for much longer periods of time, resulting in significant improvements of the functional abilities of users.

Today there are some inexpensive apparatus intended for in-home use, among them Foot Mentor, Hand Mentor of Kinetic Muscles Inc. (USA), Balance Trainer of Medica Medizintechnik GmbH (Germany) which enable a large variety of exercises, and all of them provide various types of visual feedback (force, position, electric activity of muscles).

The principal aspect, which should be ensured during in-home rehabilitation is providing a total safety of a patient and securing sufficient level of professional control of the training process. Furthermore, it is necessary to provide the possibility of conducting séances (treatment/rehabilitation sessions) asynchronously, that is to separate in time a doctor’s recommendations for home training, the fulfillment of these recommendations by a patient, and the analysis of results.
Speaking of telerehabilitation where the procedure is provided remotely, it is conventionally implied that a rehab specialist and a disabled individual keep online contact all the time. If there is no need for both of them to be present in the network, then the rehabilitation, control and correction course can be organized with greater flexibility. In this way any issues related to the synchronizing of client’s and specialist’s work can be ignored. Actually, the organization of telerehabilitation online sessions for greater numbers of disabled clients may bring in the problem of scheduling the rehabilitation. Online sessions can be conducted from time to time to monitor complicated cases.

To meet these requirements we have decided to apply electromyographic biofeedback technology and implement data exchange via remote web-server. It is worth mentioning that all modern high-tech neuro-rehabilitation technologies, such as: Neuro-Robotics, Neural Prostheses, and Virtual Rehabilitation (BCI), use various types of feedback, biological feedback is among them (Chernikova, 2007).

2. METHODS

2.1 EMG Biofeedback

The biofeedback method uses signal processing devices to provide a patient in real time with meaningful information (auditory or visual) about the changes of a certain physiological signal, such as heart rate, temperature, muscle tension and brain rhythms. With this information, and guided by the biofeedback therapist, the subject has the possibility of altering these physiological signals, changing them to a more desirable level by practicing special self-regulation techniques. The aim of biofeedback-based training is to increase awareness and to facilitate voluntary control of physiological processes that a person is not aware of. Additionally, the aim is to motivate learning of effective behavioral patterns that would prevent, eliminate or reduce symptoms. According to the principles of biofeedback technology, instead of being a passive object of the rehab procedures a patient becomes an active participant of treatment (Shtrak and Shwartz, 2002).

The electromyographic (EMG) biofeedback involves measuring the electric activity of the muscles which expresses their degree of contraction/relaxation. EMG biofeedback is used in many clinical and biomedical applications as a diagnostic tool for identifying neuromuscular diseases and is targeted as a control of muscle activity in motor disorders rehabilitation.

The use of the biofeedback computer system allows registering and monitoring the muscle tone. The dynamics of the EMG signal is viewed on a computer screen so that the patient is able to assess his/her own muscle tension and increase/reduce muscle efforts to achieve the goal of training or “threshold” (Fig. 1, 2). Consequently EMG biofeedback helps improve motor functioning.

The advantages of biofeedback-based rehabilitation include: quantitative evaluation of the results, monitoring of the signal dynamics, supervising of training progress, control of pathological deviations of physiological functioning and automatic session break if a patient has got tired, independently of rehab specialist presence.

![Figure 1. The biofeedback loop. An example of EMG biofeedback session [Guk et al, 2010a].](image-url)
Fig. 2. EMG biofeedback training screenshot. When integrated EMG (calculated from raw EMG signal) is above the threshold audio feedback signal sounds, for each channel its own.

The following biofeedback equipment was used: computer system BOSLAB with BI-12 module of 2 EMG and 2 temperature channels (EC conformity declaration CE № 01052008/K, Russian Registration Certificate №FSR 2011/11236 and Russian conformity certificate №POCC RU.AЯ79.B15475) and PC Windows XP/Vista with Internet connection.

Monitoring a fatigue during biofeedback sessions was carried out by monitoring the skin temperature of the trained limb ("target"). As the decrease of temperature means there is an increase of fatigue, so the patient takes a short rest.

The average training session consisted of 2-3 sessions of working with various muscle groups, the total duration was 20-30 minutes.

The use of the game forms of biofeedback EMG training (Fig. 3) featuring players’ ratings, morphing, augmented reality (Fig. 4) and other modern media does indeed enhance motivation of the patient and actively involves the mechanisms of individual’s self-improvement.

Fig. 3. Screenshot of a game form of EMG biofeedback. If both signals (EMG1 and EMG2) lie in the range between the thresholds in so called target zone a flower grows and blooms.

2.2 Network Neuro-Rehabilitation System

To provide the system of continuous distant medical rehabilitation the following structure of network rehab has been applied (Guk et al. 2010a):

- While in a hospital or in a rehab center, a patient masters the required program of rehabilitation and gets the necessary skills and further instructions to continue practicing at home.
In particular, the doctor defines in what muscle group the decrease of strength resulted in a considerable impairment of patient’s motion (e.g., if a patient had a decrease of strength of the hand’s extensor muscles, the electrodes were attached to the motor points of the hand’s extensor muscles; if the decrease of strength was determined at the knee extensor, the electrodes were attached to the motor points of the quadriceps muscle, etc.) The doctor uses BOSLAB program to create a treating session that consisted of set of sessions. After the session has started, the patient alternately tenses and relaxes target muscles trying to perform the movement which is typical for this muscle group.

- At home a patient continues practicing rehab procedures independently or with the help of family members, regularly sending out training reports and data to the server via Internet, where the therapist (neurologist, rehab specialist) views and analyzes them, and come up with the task for the next training session (Fig. 5).

![Figure 4](image1.png)

**Figure 4.** Movements’ coordination in physical space realized in virtual reality software based on EMG biofeedback. To improve the muscle sensitivity of a hand it is necessary to maintain a certain level of muscle tension precisely in forearm and hand to take and hold a cup or a pen, not too hard and not too loose.

![Figure 5](image2.png)

**Figure 5.** Doctor-patient interaction. 1 – A doctor creates a task and uploads it to the server. 2 – A patient at home receives a task. 3 – EMG biofeedback session. 4 – The patient sends the results of the training session to a data storage. 5 – The doctor receives and analyzes the patients’ data.
All system components of the system divided into the following three levels:

- **The first level** (patient’s computer) is represented by the sources of data: Internal recording systems: hardware and software complexes for multichannel monitoring and biofeedback; applications for primary analysis, purification and compression of the data.

- **The second level** is represented by distributed data warehouse that also contains the operational management and analysis. It involves either a single server or a local high-speed network of servers with installed software packages for database management.

- **The third level** is represented by a set of applications for data analysis and reports, for remote monitoring of the rehabilitation process by a rehab specialist: statistical comparison of training effectiveness.

In the structure described above, there is no need shown for a rehab specialist and a patient to conduct the training sessions in a teleconference regime, therefore the schedule of the process is assumed to be more convenient for both a doctor and a patient. The network rehabilitation system may involve unlimited number of users, considering the sensible organization of the work of rehabilitation specialist. Teleconferences with patients can be conducted if needed (to control placement of the electrodes and quality of oscillatory process during training session, to eliminate interference and to control exercise performing) (Fig. 6).

### 2.3 Experimental Group and Procedure

Since 2007 the Siberian Clinical Centre FMBA (Krasnoyarsk) has been a clinical base of the project. There were 30 post-stroke patients, 43 patients with SCI consequences who manifested severe motor disorders. They took part in the study. The participant requirements for the project were: normal cognitive functioning and ability to learn. Control group consisted of 35 disabled in-patients of the Siberian Clinical Centre FMBA with motor disorders of the same origin who were examined in 2011-2012.

At the first stage the patients underwent 5 to 10 sessions of EMG biofeedback at the hospital to get the required training skills. The choice of training type depended on the clinical picture of the disease. Patients with high muscle tone underwent the treatment of excessive spasticity, mainly aimed at spastic muscles’ relaxation and the rest practiced increasing muscle strength.

Later at home they continued practicing muscle activation and relaxation exercise 3 to 5 times a week during 2 to 4 months, depending on the severity of the cases and the level of affection, using distant network neuro-rehabilitation.

Testing was conducted at the end of staying in a rehabilitation center and after the distant rehabilitation, which usually coincided with the rehospitalization. For the control group the testing was performed at the end of the period of staying in a rehabilitation center and before the next hospitalization. We used the following scales: Modified Ashworth Scale for Grading Spasticity, Barthel ADL Index, Motor and Sensory Examination of ISCSCI-92.
3. RESULTS

The research conducted in 2007-2011 has demonstrated improvements in the dynamics of EMG such as stable increase in EMG amplitude of the trained muscle group during biofeedback sessions that resulted in the higher muscle strength, increased limbs’ circumference and joint range of motions. Additionally, it resulted in improvement (recovery) of the superficial sensitivity at 2-4 segments, and change of the deep sensitivity (sense of pressure, muscular sense) (Guk et al, 2010a,b).

Average duration of the distant rehabilitation course was 3 months for post-stroke patients and 4.5 months for SCI. The example of the dynamics of EMG of a post-stroke patient is shown on Fig. 7A. The distant rehabilitation course lasted 2 months. The motor dysfunction of the case shown at Fig.76B was more severe (L1, lower paraparesis) and the duration of rehabilitation was more than 5 months.

![Figures 7A and 7B](image_url)

**Figure 7. Examples of network rehabilitation dynamics:** A - Patient V., 50 years. Post-stroke. Left-side hemiparesis; B - Patient M., 21 years. L1. Lower paraparesis.

It was discovered that stable increase in the amplitude of EMG registered at the trained muscle group during the first 10-20 training sessions can be regarded as positively prognostic.

The results of patients’ examination before and after distant rehab showed that for the patients with increased spasticity the efficiency of biofeedback training was less pronounced (Table 1). This could be due to their low motivation related to the relaxation training, as these patients wanted to improve their movement ability and increase self-service, for which purpose they thought it was expedient to practice muscle activation, not relaxation. Therefore we believe that for patients with increased muscle tone the biofeedback relaxation training at home should be more exciting, with a sufficient motivational component.

In our study, during the relaxation training, the patient tried to relax muscles and increase the skin temperature, at the same time trying to keep the EMG signal on the monitor lower than the threshold set by the program. Upon reaching the required level of muscle relaxation a movie or slide show could be viewed without distortion, the flowers were growing, the mosaic pictures were opening. Unfortunately, the authors of the project do not have other options to offer for this target group.
Table 1. Dynamics of patients’ condition during network neuro-rehabilitation course (M, scores).

<table>
<thead>
<tr>
<th>Group of low spasticity (N=56)</th>
<th>ISCSCI-92 Motor Examination</th>
<th>ISCSCI-92 Sensory Examination</th>
<th>Barthel ADL Index</th>
<th>Ashworth Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>p=0.000</td>
<td>75.12</td>
<td>78.00</td>
<td>190.46</td>
<td>192.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Control subgroup of low spasticity (N=27)</th>
<th>ISCSCI-92 Motor Examination</th>
<th>ISCSCI-92 Sensory Examination</th>
<th>Barthel ADL Index</th>
<th>Ashworth Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>p=0.361</td>
<td>76.24</td>
<td>76.16</td>
<td>185.61</td>
<td>187.13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group of high spasticity (N=17)</th>
<th>ISCSCI-92 Motor Examination</th>
<th>ISCSCI-92 Sensory Examination</th>
<th>Barthel ADL Index</th>
<th>Ashworth Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>p=0.109</td>
<td>50.71</td>
<td>52.00</td>
<td>151.14</td>
<td>152.86</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Control subgroup of high spasticity (N=8)</th>
<th>ISCSCI-92 Motor Examination</th>
<th>ISCSCI-92 Sensory Examination</th>
<th>Barthel ADL Index</th>
<th>Ashworth Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>p=0.004 decline</td>
<td>61.43</td>
<td>55.72</td>
<td>168.00</td>
<td>169.13</td>
</tr>
</tbody>
</table>

\( p \) – level of significance, Wilcoxon matched pairs test.

The use of the immersive virtual / augmented reality (i.e. traveling in a virtual world like "Second Life") that allows to control the game using physiological functions aiming to relax muscle, is still a challenge. The most famous training set to develop the skills of self-control, «The Journey to the Wild Divine», «Wisdom Quest», implemented as a classical 3D computer game, uses cardio intervals and skin conductance, but not muscle characteristics, to control the Oriental mystical themes of the games.

It should be noted that the participants of the project in addition to the main myographic biofeedback training also conducted the biofeedback training based on cardio intervals control that involved competitive game subjects using Russian complex "BOS-Pulse". The training was aimed to improve the emotional condition, reduce anxiety, learn self-control, but these data are not included into the present study.

Figure 8. Functional Independence Assessment using FIM™ scale with and without network neuro-rehabilitation. Rehab1 and Rehab2 – two subsequent courses of rehabilitation in specialized center.

We studied the results of the network rehab course of the subgroup of 12 SCI patients during their secondary hospitalization (NNR Group). We have compared them to the control group with similar diagnosis and disease severity using the FIM (Functional Independence Measure) scale. The results shown in Fig. 8 confirmed the effectiveness of the distant medical rehabilitation program.
4. CONCLUSIONS

The project was implemented for the first time in Russia by the Institute for Molecular Biology and Biophysics of the Russian Academy of Medical Sciences (RAMS) jointly with Siberian Clinical Centre FMBA and the “Biofeedback Computer Systems Ltd.” company. The project brought to reality the possibility of providing a continuous course of medical rehab of the patients with post-stroke and spinal injury disorders. As a result, the system for acquisition, management, and storage of physiologic data and other parameters obtained during the biofeedback training has been created, including software and hardware “BOSLAB-Patient” and "BOSLAB-Doctor” that provided advanced analytical processing of data and presenting the results of processing using a detailed and comprehensive analysis of information at both regional and national levels.

The system can provide benefit for the patients with severe motor disorders as regular treatment and rehab procedures can be conducted not only in hospitals, but also at home to secure a constant contact between patients and rehab specialist who organizes and controls the process of rehabilitation, which is very important to increase its efficiency.

Acknowledgements: The authors would like to thank Prof. Lyudmila Chernikova, Head of Neuro-rehabilitation department of the Neurology Scientific Center of RAMS and Dr. George Tzirkin, neurologist, who works with the authors at the same research laboratory for their contribution to scientific part of the project. The authors would like to thank also Ms.Olga Lazareva and Mr.Aleksandr Terleev for their contribution to the paper concept. This work was jointly supported by the “Biofeedback Computer Systems Ltd.” company (Novosibirsk) and Foundation “SM Charity” (Krasnoyarsk).

5. REFERENCES


R Yu Guk, M M Sklyar, E A Tarasov (2010), Neuro-rehabilitation (neurobiofeedback) in virtual network, Bulletin of Siberian Medicine, 9, 2, pp. 17-23.