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Technical and Medical Problems Concerning Wider Use of Neuroprostheses in Patients with Neurologic Disorders

Problemy techniczne i medyczne w zakresie szerszego wykorzystania neuroprotez u pacjentów neurologicznych

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Abstract

Nervous system disorders may seriously impair motor, sensory or cognitive functions. Present neurorehabilitation in selected cases can cause significant functional recovery e.g. in the area of locomotor pattern generation and balance, but in the most severe cases this recovery still remains incomplete. Use of neuroprostheses broadens possibilities of rehabilitation and care.

Neuroprostheses are electronic devices substituting lost sensory, motor or cognitive functions. They significantly help to restore or replace functions lost as a result of neural damage. Clinical used neuroprostheses proved to be effective in achieving a greater patients' independence in daily activities.

Further development of neuroprostheses need for increased involvement of medical staff in the area of clinical research on clear and safe medical procedures. This progress can make another breakthrough in the therapy, rehabilitation and care of patients with nervous system deficits. **(PNN 2012;1(3):119-123)**

Key words: neurorehabilitation, care, patient with neurologic disorder, neuroprosthesis, brain-computer interface, BCI

Streszczenie

Schorzenia układu nerwowego mogą poważnie zaburzyć funkcje motoryczne, sensoryczne lub poznawcze. Współczesna rehabilitacja neurologiczna w części przypadków może przynieść znaczącą poprawę funkcjonalną, m.in. w obszarze generacji wzorców lokomocji i równowagi, lecz w najcięższych przypadkach ta poprawa jest wciąż niepełna. Wykorzystanie neuroprotez rozszerza tu możliwości rehabilitacji i opieki.

Neuroprotezy są urządzeniami elektronicznymi zastępującymi utracone funkcje sensoryczne, motoryczne lub poznawcze. Mogą one znacząco pomóc w przywróceniu lub zastąpieniu funkcji utraconych wskutek uszkodzenia układu nerwowego. Neuroprotezy wykorzystywane klinicznie udowodniły swoją efektywność w przywracaniu pacjentom większej samodzielności w codziennych czynnościach.

Dalszy rozwój neuroprotez wymaga zwiększonego zaangażowania personelu medycznego w obszarze badań klinicznych nad przejrzystymi i bezpiecznymi procedurami medycznymi. Postęp ten może spowodować kolejny przełom w terapii, rehabilitacji i opiece nad pacjentami neurologicznymi. **(PNN 2012;1(3):119-123)**

Słowa kluczowe: rehabilitacja neurologiczna, opieka, pacjent neurologiczny, neuroproteza, interfejs mózg-komputer, BCI

Introduction

Nervous system disorders may seriously impair motor, sensory or cognitive functions. Current neurorehabilitation in selected cases can cause significant functional recovery e.g. in the area of locomotor pattern generation and balance, but in the most severe cases this recovery still remains incomplete. Use of neuroprostheses broadens possibilities of neurorehabilitation, so Assistive Technology (AT) still plays an important role in it. But we should be aware that meaning of "neuroprosthesis" is much wider than "prosthesis" (artificial extension replacing a missing body part) [1]. Neuroprostheses are electronic devices substituting lost sensory, motor or cognitive functions [1]. They significantly help to restore or replace sensory or motor functions lost as a result of neural damage.

Clinical used neuroprostheses proved to be effective in achieving a greater independence in daily activities. This article aims to assess main technical and medical problems concerning wider use of neuroprostheses in patients with neurologic disorders.

Areas of implementation

Neuroprostheses (NPs) serve to "bridge the gap" of completely or partially disrupted connection(s) within human nervous system. Because of nervous system complexity, possible number of brain-computer interfaces (BCIs) and neuroprostheses seems be at least huge. Thus there is vary hard to define complete NPs classification. Current attention of scientists and clinicians in the field of neuroprosthetics is paid to:

- rather simple stimulators for spinal cord microstimulation, muscle bulk maintaining, reduce spasticity reduction and nervous system re-training [2],
- advanced sensory and motor neuroprostheses (fig. 1) for communication or control purposes (natural limbs, artificial limbs, computers) for quadriplegic patients, patients with severe communication deficits, etc. [1],
- cognitive neuroprostheses, devoted to higher order cortical processes, e.g. visuospatial attention [3].

Generations of used neuroprostheses change with each year, thus current classification can be out-of-date even tomorrow.

Improving activities of daily living

Neuroprostheses validity needs to be proved in a real-time situations. Characteristics of neuroprostheses should be fitted in the best way supporting patients' activities of daily living (ADLs), increasing independence and mobility. Thus important factors influencing everyday use of neuroprostheses seems be as follows:

- minimally invasive,
- subminiature,
- reliable,
- easy to handle application,
- correct prediction, resulting low number of incorrect trials and errors.

Cognitive neuroprosthes need for more different decoded variables including not only basic attributes (signal presence ot not, its allocation and identity), but need for succesfull interpretation. Result of 86% correct predictions in the area of spatial allocation of endogenous attention [3] seems be high, but may be perceived insufficient - 14% of mistakes may be irritating and influence decreased efficiency of the neuroprosthesis.

Signal selection and processing

Main current possibilities of signal acquire as as follows:

1. using BCI with non-invasive electrodes placed on a scalp e.g. for motor rehabilitation (EEG P300, steady-state visual evoked potentials SSVEP, event-related desynchronization/synchronization ERD/ERS) for motor rehabilitation, devices control, and communcation using adapted PC,
2. using BCI – implantable systems (surgically implanted electrode arrays) for motor rehabilitation, devices control, and communcation using adapted PC,

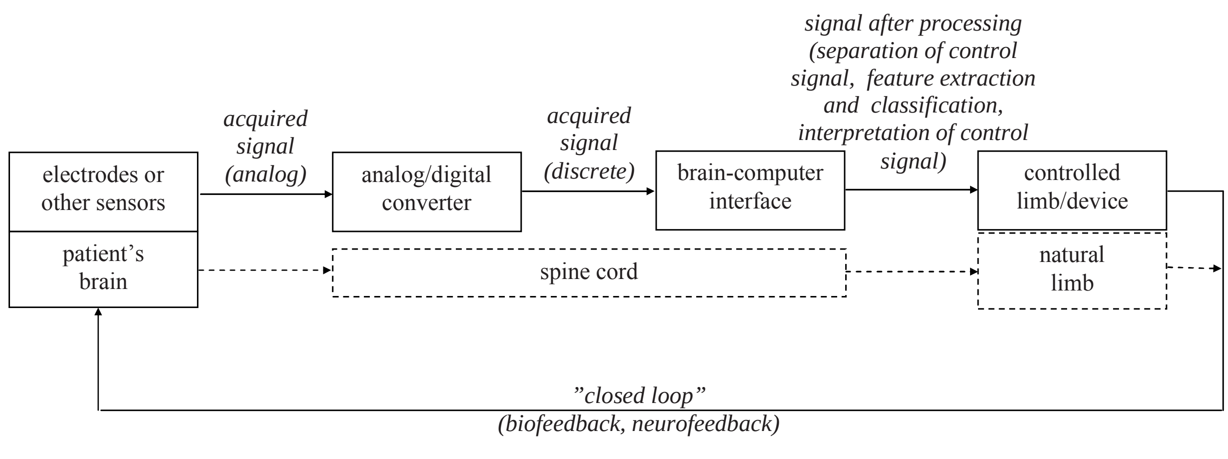

Figure 1. Conceptual schema of neuroprosthesis for people with SCI using brain-computer interface (version) [1]

3. other, e.g. by selecting command sources for triggering functional electrical stimulation (FES) with the surface electromyogram (EMG) from muscles partially paralyzed in patients with incomplete with spinal cord injury (SCI) [4] as a part of systems for enhancing or restoring:
   - standing/walking,
   - grasp function (control of hand and fingers) in tetraplegic patients [5,6].

Direct brain control of FES systems is expected to expand the application of neuroprostheses for patients with injury of the high cervical spinal cord [6]. Neuroprostheses may electrically stimulate peripheral nerves, both through electrodes implanted in close proximity to nerves or surface electrodes attached to the skin (over nerve) [2].

Clinical use

Numerous strategies to promote regeneration and restore motor function in patients with neurological deficits (e.g. after SCI) have been discussed so far. Function restoration (if possible: complete or partial) may result both in restored transmission of orders within descending pathways, and facilitated recovery of the local neuronal structures [1,2]. Neuroprostheses should not only support functions as Assistive Technology (AT), but also stimulate this function restoration, if possible. Thus clinical use of neuroprostheses should be focused on:

1. clinical research in the area of:
   - indications for use of BCI/neuroprosthesis,
   - possible contraindications, e.g. tics, tachycardia, hypertension, severe disorders of consciousness, mental diseases, use of another medical devices causing interferences, etc.
   - potiential complications,
   - possible side-effects,
   - bio-compatibility of implants, e.g. electrode arrays,
   - influence of BCI/neuroprosthesis long-term use to sensory and motor systems [7,8], personality, etc.,
   - possible long-term effects of BCIs used e.g. in entertainment,
2. widely approved technical standards, including:
   - safety: resistance to interferences, electrode stability, component survivability, long-term stability,
   - more comfortable use with reduced size, and power consumption,
   - BCIs/neuroprostheses adjustment to the patient,
   - improved data acquiring, processing and interpretation providing better coordination of more natural, smooth and precise movements [9],
   - cooperation with other Assistive Technology (AT) systems: wheelchairs, assistive robots, future Ambient Intelligence systems and integrated environment of disabled people: e.g. MUNDUS assistive platform for recovering integrating multimodal information (EMG, eye tracking, brain computer interface) to control different actuators (exoskelton, neuroprostheses, etc.) [10],
3. common accepted clinical guidelines/recommendations regarding:
   - (neuro)physiological research over mechanisms underlying interactions between neuroprosthesis and nervous system, including their long-term effects,
   - acceptance of neuroprostheses among medical staff and patients,
   - shared responsibility within therapeutic multidisciplinary team, including co-operation with specialists in medical IT and biomedical engineers,
   - BCIs and neuroprostheses selection, beacause according to current knowledge and experience people need various types of BCIs/neuroprostheses because of their abilities,
   - preoperative patients' therapy, rehabilitation and preparation to BCIs and neuroprostheses,
   - implantation procedures,
   - postoperative patients' therapy, rehabilitation and care, including functional tasks re-learning, ADLs training, etc.,
   - patients' family/caregivers training,
   - wider use of neuroprostheses, e.g. in amputees [1],
4. troubleshooting and emergency procedures, including neurosecurity [1],
5. future efforts toward commercialization of the most effective and safe solutions.

The most important issue is perceived fact that attachment of the neuroprosthesis to the body is only the first stage of the whole therapy. This therapy requires close collaboration of users (patients and their families/caregivers), medical staff (physicians, nurses, physiotherapists, occupational therapists, psychologists, etc.), and engineers. Success of the therapy depends on synergy of common efforts. Training can be long-lasting (from approximately half an hour to months depend on used BCI and neuroprosthesis) and exhausting, especially for elderly people. What more simultaneous therapy of other diseases may be necessary. Role of the nurse within multidisciplinary team seems be very important, and need for additional research due to lack of valuable evidences and guidelines.

Number of BCIs and neuroprostheses used in medical applications increases with each year. It seems nothing can stop this tendency. No doubts medical staff should control and shape it in the required direction. Wider use of BCIs in entertainment (e.g. computer games) can provide additional threats in the area of neurologic syndromes.

Ethical considerations

Novel technologies can cause severe ethical problems. BCIs/neuroprostheses are devices influencing human nervous system, thus main ethical issues in the area of BCIs/NPs use are as follows:

- possibility of the alteration of patients' personality,
- user approval and procedures of the patients' informed consent, e.g. in patients with disorders of consciousness,
- scope of use and possiblity of abuse neuroprostheses to "brain upgrading", based on Prof. Kevin Warvick brain enhancement, its individual and societal results [11,12].
- issue of balance between user intent (and independence), and autonomy of the device (BCI, neuroprosthesis), including emergency situations [1],
- animal experimentation and human trials [12].

There is need for continuous threats identification. Technical development causes that some emerging techniques (e.g. artificial intelligence) can be partially out of control because of their computational complexity and/or heuristic principles of operation.

Discussion

Current neuroprosteses are usually technical devices acquiring and interpreting (even: predicting) movements or other users' activities, and then supporting them. Some of them are still under research, but several is in commercial use, e.g. EEG-based Wadsworth BCI system provided by Wadsworth Center and Helen Hayes Hospital (USA). Significant role may play two nowel technologies:

–nanotechnology, e.g. use carbon nanotubes (CNT) in neuroprostheses [13],

–computational neuroscience, providing more detailed computer models of CNS and optimization of CNS-BCIs co-operation.

Novel technology seems be electrochemical neuroprostheses and robotic postural interfaces described recently by van den Brandt et al. [14]. This recovery relies on remodeling of cortical projections (brainstem and intraspinal) and restoration of control over electrochemically enabled lumbosacral structures [14]. Research in rats with lesions seems be promising. Rats' cortex regained the capacity to transform contextual information into task-specific commands to provide locomotion despite interruption of direct supraspinal pathways. What more treadmill exercises did not supported plasticity and associated recovery within cortical projections [14]. Versatile robotic interface associated with epidural electrical stimulation and monoamine agonists seem be promissing too – as a result of their use coordinated steering and balance in rats with a paralyzing SCI was restored [15].

There is strong belief of scientists that reported progress allowing bypass the spinal cord and/or other lesioned parts of nervous system. This possibly provide more flexible and dexterous movements or other activity.

Wider application of neuroprostheses can significantly lower costs of care over disabled people [16,17], reduce the burden to medical staff, including nurses, and make possible e.g. traditional exercise therapy combined with interventions such as FES using telerehabilitation (e.g. supervised over the Internet) [18].

Conclusions

Neuroprostheses seem be very promising solution for patients with severe nervous system damages. They can significantly improve independence, mobility and communication abilities, breaking down another limitation of disabled, severe ill and elderly people.

Research over neuroprostheses are interdisciplinary and need for cooperation specialists in medical sciences, technical sciences, psychology, cognitive science, etc. Based on current research further development of neuroprostheses need for increased involvement of medical staff in the area of clinical research over clear and safe medical procedures. This progress can make another breakthrough in therapy and rehabilitation of patients with nervous system deficits.

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