

## The current range of neuromodulatory devices and related technologies

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### Summary

The pace of technology dictates changes in every aspect of human life. Medical profession is not an exception. The development of sophisticated electronic devices has radically influenced diagnosis and therapy. Today neurosurgical science is revolutionized with numerous implanted and non-implanted devices that modulate and stimulate the nervous system. Physicians, patients and non-technical experts involved in this field need to understand the core mechanisms and the main differences of this technology so that they can use it effectively. It will take years until clinicians reach a “consensus” about the use of these devices, but in the course of action objective information about the current status of the methods and equipment, and the technical, biological, and financial complications that arise in practice will speed up their public approval and acceptance.

**Keywords:** Neuromodulation; neurotechnology; neurostimulation; neurodevices; neuroprostheses; brain-computer interface (BCI); assistive technology (AT); functional electrical stimulation (FES).

### From neurotechnology to neuromodulation

According to the International Neuromodulation Society, “*Neuromodulation is defined as the therapeutic alteration of activity in the central, peripheral or autonomic nervous systems, electrically or pharmacologically, by means of implanted devices*” [13]. In this usage, neuromodulation is another form of technology where the knowledge about the nervous system is used to create specially designed implantable devices to serve a therapeutic or rehabilitation purpose. On the other hand our current efforts combine technical methods, skills, processes, equipment, and information from biology (biochips, genetic engineering, and cellular implantation), neuroscience, mechanics, electronics, computing, and pharmacology in order to surpass the field of neuromodulation. This interdisciplinary nature of the fields combined is reflected in the term

“neurotechnology”, a multi-billion dollars industry that includes three sectors [17]:

1. Neurodiagnostics (neuroimaging, in vitro diagnostics, neuroinformatics).
2. Neuropharmaceutical (cognitive, emotive, sensory).
3. Neurodevices (neurostimulation, neuroprosthetics, neurosurgical).

More specifically, recent advances in the fields of neuroscience, robotics, and electronics have caused a resurgence to develop neurodevices for interaction with the impaired neuro-muscular and sensory system in order to restore or decrease the impact of a disease or injury on the individual. For example, in an attempt to bypass pathological motor or sensory nerve circuits, implantable or non-implantable devices have been invented to restore vision, hearing, motor, and sensory function.

In this review, we classify and summarize the current state of neuromodulation related technologies i.e. neurostimulation and neuroprosthetics. The third category, neurosurgical devices for navigation, radiosurgery, and endovascular intervention is beyond the scope of our review. Apart from the classification criteria in the next sections we define terms related to the technology used for the development of neurodevices and we present a short description for each type of device, an abridgment of the surgical operation required and an application example. In addition, we give a short description of the similarities of Assistive Technology (e.g. wheel chairs, artificial limbs, augmentative-alternative communication) with the neurodevices and we conclude our review with frequently met issues i.e. complications and risks, financial implications, and future prospects.

## Classifications of neurodevices

Rehabilitation is an application field for implantable neural devices. Diseases and traumatic incidents may lead to damage or lesions in the central or peripheral nervous system. When the information flow between any of the following: brain, spinal cord, nerves, biological sensors and actuators, or muscles, is interrupted, sensoric inputs are lacking and vision or hearing is lost. If motor commands from the brain do not reach the muscles, paralysis occurs. The objective of neural rehabilitation is the restoration of lost functions using therapeutic programmes and technical aids. Because of the tremendous complexity of the human nervous system, technical aids only lead to restricted restoration in function. However, what may seem to be a small improvement to a healthy person may be a great improvement in quality of life for a disabled person.

Neurodevices can be classified according to the following criteria:

- stimulation (i.e. pharmacological vs. electrical);
- application (i.e. neuroprosthesis vs. neuro-orthosis);
- purpose (i.e. therapeutic vs. assistive vs. rehabilitation);
- site (i.e. implantable vs. external);
- invasiveness (i.e. invasive vs. non-invasive);
- communication channel (i.e. unidirectional vs. bidirectional);
- effect on the nervous system (i.e. central nervous system damage vs. denervation).

### *Pharmacological vs. electrical*

This distinction fits with the definition of neuromodulation and leads to two of the main categories for neurodevices namely “stimulators” and “pumps”. In particular, stimulators are devices that use electricity to stimulate the brain, the cord, and the peripheral nerves, whereas pumps refer to implantable devices that inject a pharmacological substance into the nervous system (e.g. baclofen for spasticity or morphine for pain).

### *Neuroprosthesis vs. neuro-orthosis*

In terms of the application of neurotechnology, devices can be categorized to those that couple an artificial system with the physiological system in order to replace or supplement a neuromuscular or sensory function (vision, hearing, tactile), i.e. “neuroprosthesis”, and are contrasted to those that influence/modulate the neural controller to achieve an ample relief of symptoms of a disease and/or to train the physiological system until the

function is performed adequately without any support, i.e. “neuro-orthosis”. Characteristic type for this kind of devices is the neurostimulation devices.

### *Therapeutic vs. assistive vs. rehabilitation*

Perhaps the most important criterion for distinguishing neurodevices is the purpose of their development, i.e. neurostimulation may be used for muscle contraction to assist in breathing, grasping, reaching, bladder and bowel function. On the other hand TENS (transcutaneous electrical nerve stimulation), does not involve moving muscles, but prevents secondary complications and is aiming at a relief of symptoms (i.e. spasticity, tremor, atrophy).

Yet other devices are applied for rehabilitation, usually after the therapy, and their objective is full restoration or improvement of recovery with some form of training. A third type of device may be complementary to the other two or self-contained and is targeted to supplement, replace or even enhance a function. This type is commonly referred in the literature as an *assistive technology device*. Therapeutic and assistive technology devices may permanently accompany the patient for the rest of his life.

### *Implantable vs. external*

There are two types of implantable devices: one that is completely internal and one with both internal and external components. In the first, the power source (battery) and lead(s) are surgically implanted, whereas in the second a receiver is implanted and detects radio-frequency signals through the skin from an external power source [17]. On the other hand external devices may be “worn”, e.g. electrodes are attached on the skin and have either a wired or wireless connection to the device [24].

### *Invasive vs. non-invasive*

Devices that require surgery can be implanted at some point in the body and are considered invasive (e.g. deep brain stimulation, DBS) in contrast to those that may operate externally with surface electrodes attached on the surface of the body (e.g. peripheral nerve stimulation, PNS).

### *Unidirectional vs. bidirectional communication*

The human nervous system is a two-way communication system. It has two main types of signals, those that

travel from the brain to the limbs (motor signals) and other signals that go in the opposite direction and carry electrical messages from the limb, trunk, or the head, to the brain (sensory signals). Similarly, there are devices that they have controller units that are able both to send and receive signals. Coupling the human nervous system with electronic and/or robotic prostheses by means of appropriate electrodes ought to permit a bidirectional travelling of signals; from the nervous system to the artificial one (i.e. stimulation) or the opposite (i.e. electrophysiological signal recording). Most important, the user of these devices must be aware of their status and the level of performance, likewise proprioception. Then it is possible to regulate the controller and adjust the parameters to meet the changing conditions. This type of information that the user receives back about the functioning of the device is called biofeedback.

#### *Central nervous system damage vs. denervation*

When there is an injury or disease in central nervous system the muscle and its nerve supply remain healthy. In such cases we may replace the natural electrical command signals that originate from the brain with artificial electrical signals that come from a device. External PNS also known as functional electrical stimulation (FES) or functional neuromuscular stimulation (FNS) is a characteristic type of stimulation applied in those cases. For example, peroneal nerve stimulation helps clear the toes during the gait cycle when we have a dropped foot problem in hemiparesis.

When the peripheral nervous system is affected the nerve-muscle connection is broken. This happens in peripheral nerve disorders or injuries and in nerve-muscle diseases. In this case, the central nervous system remains intact but access to the periphery is blocked. Researchers have developed special stimulation equipment to activate denervated muscle directly bypassing the damaged peripheral nerve.

#### **Functional electrical stimulation (FES)**

The concept of FES was put forward by Liberson in 1960 for the correction of dropped foot in hemiplegic subjects [15]. Liberson applied FES as an alternative to an ankle foot-orthosis (AFO) to restore functional movement of paralysed muscles. A development of his device the Odstock Dropped Foot Stimulator (ODFS) consisting of “*a single channel, foot switch triggered stimulator*

*designed to elicit dorsiflexion and eversion of the foot by stimulation of the common peroneal nerve”* [24], is widely used in Europe and it started becoming popular in United States [4]. Every FES device is composed by four main components, the electrodes, the stimulator, the sensors or switches, and the leads that connect the electrodes to the stimulator. Currents in the electrodes cause either the weakened or paralyzed muscles to contract or stimulate the tissues without muscle movement. The sensors or switches constitute the interface with the stimulator that controls the strength and timing of the electrical pulses that flow to the electrodes. In FES low level electrical current is applied at specific points of the body to restore or improve function (cardiovascular, bladder and bowel, breathing, grasping and reaching, transfer and standing, stepping and walking, erection and ejaculation, circulation), to prevent or treat pressure sores, contractures, osteoporosis, weak muscles, to control spasticity, tremor, to restore sensation, to regain voluntary function or improve movement control [17]. Apparently FES is not limited to the stimulation of the central or peripheral nervous system, but it is extended to a direct stimulation of muscles (i.e. cardiac pacemaker). In the following paragraphs we describe other subcategories of FES devices according to their primary purpose and effect they have on the nervous system.

#### *Functional neuromuscular stimulation (FNS)*

When FES is used to move parts of the body we call it functional neuromuscular stimulation (FNS). FNS operates by stimulating motor nerves as they enter muscles by injecting automated control signals. The contraction of the muscles restores either movement such as limb function, hand grasp, or improves function, such as bowel and bladder operation. Neuromuscular electrical stimulation is also known with the abbreviation NMES. It has shown promise in promoting motor relearning in cases where previously learned motor skills are lost following brain injury, in a stroke for example, by encouraging movement repetition and possibly by promoting cortical reorganization. There are two types of FNS, automatic or synchronous FNS, in which muscles are stimulated to move without conscious effort and EMG-EEG triggered FNS, where the user supplies commands asynchronously. In present days FES systems rely on automated control signals. A neuroprosthetic arm developed in Cleveland FES center [17] is driven by an externally worn joystick on the contralateral shoulder [7].

### Neurostimulation devices

The heart pacemaker is considered the first and most renowned application of electrical stimulation. This device applies low level electrical currents to the muscles of the heart to restore the beat rate or improve the beat rhythm. Neurostimulators evolved from cardiac pacemaker technology and use the same principle. In 1963, scientists managed to electrically stimulate and activate the phrenic nerve for long-term artificial respiration [8]. In neurostimulation, electrical stimulation is applied to nociceptive pathways of the central nervous system to modulate pain, spasticity, abnormal movements and seizures in patients suffering from spinal cord and brain injury, cerebral palsy, stroke, epilepsy, and multiple sclerosis. Peripheral nerve stimulation is also used to treat upper/lower extremity nerve problems.

#### *Transcutaneous electrical nerve stimulation (TENS)*

If the primary aim of FES does not involve moving muscles, then it may be called simply electrical stimulation (ES), transcutaneous electrical nerve stimulation (TENS), or electrotherapy. In such cases, the primary purpose is to treat the sequellae of spinal cord injury or multiple sclerosis. These include pain, deep venous thrombosis, pressure sores, spasticity, contractures, osteoporosis, atrophy, and tremor.

#### *Peripheral nerve stimulation (PNS)*

In PNS, depolarization with electrical current pulses on the surface of the nerve are generated to treat painful paresthesias. PNS has been suggested for the control of chronic intractable neuropathic pain. The most common nerves treated with PNS are ulnar, median, radial, tibial, and common peroneal nerves [23].

#### *Spinal cord stimulation (SCS)*

SCS is based on the “gate-control theory” of pain. Ionic activity in the cell membranes either opens or closes the pain “gate”. Accordingly, strategically placed epidural electrodes stimulate the dorsal horns of the spinal column to regulate the flow of nerve impulses from peripherally to the central nervous system (CNS). Implanted spinal cord electrical stimulation was introduced in 1967 by Shealy *et al.* [22]. Therefore, SCS is the oldest and most frequently applied neurostimulation method. There is a significant body of literature on clin-

ical efficacy studies, and the effectiveness has been cross-examined internationally [14, 25].

#### *Sacral nerve stimulation (SNS)*

SNS is a surgical procedure in which electrodes are implanted surgically through the sacrum. A small generator device, implanted in the lower abdomen, sends electric pulses that stimulate the sacral nerve, which in turn, stimulates bladder and bowel function. SNS is applied only after less invasive treatments of urge continence have failed. FDA approved SNS device for treatment of refractory urinary urge continence in September 1997. Ontario Health Technology Advisory Committee reports that “*since 2000, 5 international health and technology assessments (HTA) have been conducted to evaluate SNS. All 5 HTAs reported that SNS was effective*” [20].

#### *Vagus nerve stimulation (VNS)*

In 1997, FDA approved VNS to assist in controlling epilepsy related seizures that are intractable to drug or surgical therapies. In VNS, an electrode is implanted and connected to the left vagus nerve. A generator is placed under the collarbone and is programmed to deliver stimulation of the vagus nerve at set intervals [9].

#### *Deep brain stimulation (DBS)*

DBS involves surgical implantation of a multiple electrode lead in the thalamic, pallidal or subthalamic areas of the brain. The leads are connected to an implantable pulse generator (IPG) that is activated by the patient to send a constant stream of electrical pulses to the brain in order to block the tremor [27]. This surgical procedure is used to treat severe essential tremor, rigidity and bradykinesia associated with Parkinson’s disease, as well as dystonia and other conditions like depression and obsessive-compulsive disorder. A DBS device designed to control tremors in patients with Parkinson’s disease (PD) or essential tremor (ET) was the third type of device approved by the Food and Drug Administration (FDA) in 1997.

### Neuropharmaceutical devices

Oral or intravenous medication has the drawback that is diffused throughout the entire body and only a small percentage of the digested substance reaches eventually its final target. By surgically implanting a pump at the precise location where the problem exists, we can pump

medication directly. This drastically cuts down the dose needed, it is often more effective, and it has fewer side effects. There are a lot of alternate infusion routes for certain treatments. Such are intrathecal or epidural spinal pumps that deliver small doses of morphine in the subarachnoid or epidural space [11]. Other types of pumps include intravenous, intra-arterial, subcutaneous, intraperitoneal and intraventricular. The device is surgically positioned in a subcutaneous pocket in the abdominal wall, and a catheter is threaded into the desired position. The period and the volume of the infusion can be adjusted by the physician and the reservoir can be easily refilled with an external needle injection through a self-sealing septum in the pump.

### Neuroprosthetic devices

In all aforementioned devices their main distinctive characteristics refer to the type of stimulation (electrical or pharmacological) and the exact position they are inserted. Nevertheless, according to the classification criteria we listed in previously there are other ways we can differentiate neurodevices. Such systems augment, supplement, or complement the nervous system. The term neuroprosthesis was coined to accentuate the interaction and the coupling of the two systems; the nervous and the artificial one. Neural prostheses are devices, which can restore very successfully lost functions resulting from damage to the nervous system. They can take the form of both implanted and externally worn aids to restore many different functions in spinal cord injury and provide patients with remarkable improvements to their quality of life. These devices can be powered and controlled through radio links or have their own in-built power and control. The range of such devices now available to patients is considerable, from vital assistive devices such as heart pacemakers and phrenic nerve stimulators for breathing to multi-channel stimulators capable of restoring useful movements. A neuroprosthetic device shares a lot of common features with neurostimulation devices. They are both considered as artificial control systems with a controller, actuators, mechanics and sensors. This system operates in parallel with the affected part of nervous system. It is mainly the signal acquisition, the type of control, and the interaction that distinguishes neuroprosthesis from neurostimulation. To make a solid point on that terminology issue another frequently term met in the literature review, “biomechatronics”, is closely related to neuroprosthesis. Biomechatronics focuses on the interactivity of biological organs with

electromechanical devices and systems [4]. The primary aim on this field concerns the development and study of artificial hybrid bionic systems and therefore it is not limited to applications such as prosthetic devices. In the sections to follow we summarize systems that have been developed to artificially replace, restore, or augment central sensorimotor control and communication. These can be categorized as artificial prostheses aiming at augmenting functions or substituting parts of the body (e.g. vision, hearing, movement and exoskeletons).

### Neurosensor prosthesis (NSP)

#### *Retinal implants*

Retinal implants are neuroprosthetic devices that have the ability to restore vision to some extent by converting the light signals to electrical current stimulation on functional neurons in the retina of the eye. Retinal implants are discerned to subretinal, designed to replace photoreceptors in the retina, and epiretinal, designed to communicate directly with the ganglion and bipolar cells. People with degenerative diseases of the retina such as retinitis pigmentosa and macular degeneration may be suitable for treatment. All retinal implants require an intact optic nerve pathway to allow them to function [21].

#### *Auditory brainstem implants*

An auditory brainstem implant (ABI) is an implanted electronic hearing aid, designed to generate hearing perception, to a person with severe deafness, by electrically stimulating the cochlear nucleus in the brainstem. The device is composed by an external microphone, a sound processor and an implanted electrode system. The system mimics the inner ear by detecting ambient sounds, digitalizing them and sending them in the form of electrical current through the implanted electrodes a membrane, which contains the electrode contacts and is inserted surgically and applied on the cochlear nucleus surface in the brainstem. Hearing through an implant may sound different from normal hearing, but it allows many impaired people to communicate with oral communication and over the phone [5, 26].

### Neuromotor prosthesis (NMP)

The core mechanism of this type of devices is the recording of bioelectrical signals (e.g. EEG, EMG) from the central or peripheral nervous system, and the processing – translation of them into commands for the prosthesis

or other environmental control device. Neuromotor prostheses are now being developed to provide a new pathway or effector between the brain that remains intact and able to generate motor plan, and external devices or paralyzed muscles. There are two types of movement which neuromotor prosthetics must restore: those related to physical movement and those related to communication. The requirements for effective operation are the ability to sense neural activity related to motor plans or actions, the transformation or decoding of this activity into an output signal, and then the coupling of that output to assistive devices or to the muscles as quickly and accurately, as the intact nervous system [6, 7].

In Cyberkinetics, a team of surgeons implanted a  $4 \times 4$  mm, 100-channel electrode array on the surface of the primary motor cortex (MI) of a 25 year-old quadriplegic ventilator-dependent male. [18]. The surgical procedure consisted of an incision and 3 cm diameter craniotomy to place the sensor in the precentral gyrus immediately posterior to the superior frontal sulcus. Using the BrainGate system the patient gained control of a brain-computer interface and was able to operate the cursor on a computer screen while performing other voluntary motor tasks. NMP relies on the same principle as FNS, both systems attempt to reconnect the brain to the intact neuromuscular system by stimulating motor nerves as they enter muscles, causing the latter to contract. The difference is on the control mechanism of stimulation. FNS is using automated control, thus, it usually sends continuously a signal to the motor nerve while NMP is recording a sufficient residual voluntary movement and transforms it asynchronously into an electrical signal that is fed into the motor nerve for stimulation [19].

#### *Biohybrid systems*

The combination of microsystems with biological cells and tissues, known as biohybrid systems, are offering completely new product possibilities for diagnosis and therapy. Microsystem technology is quite new in the field of neural prostheses and will offer solutions where anatomical restrictions in space and the application itself needs a high technical complexity to deliver the adequate performance as it is necessary in a retinal vision prostheses, for example.

#### **Brain computer interfaces (BCI)**

Restoring function to those with motor impairments with NMP devices involves providing the brain with a new, non-muscular communication and control channel,

to convey commands and messages to the external environment [2, 28]. In the 1970s, Jacques Vidal used the term ‘brain-computer interface’ to describe any computer-based system that can ‘wire-tap’ brain activity. Present usage of the term denotes systems that support alternative or augmentative communication and control. BCI is coupling the brain. Instead of the nerves and the motor plan we have computer hardware and software. Electrophysiological signals are the input of BCI and output depends on the type of application (e.g. computer access, environmental control, neuromotor prosthesis control). The two systems, the user and the BCI, interact in a closed loop fashion. During the training cycle, BCI transmits a cue to the user, then it acquires the response as an electrophysiological input from the user, next it translates the signal into output to control a device. When user-intended command is executed the individual receives a type of feedback through the sensors about the resulted action. The consequence of this is that the user in turn adapts to the BCI by modifying the response and the BCI should adapt according to the learning ability of the user by increasing the level of practice. Successful operation of the BCI is the result of adequate adaptation of each system through the use of feedback.

#### **Similarities of assistive technology with the neurodevices**

Assistive technology is defined in the Technology-Related Assistance Act (Tech Act, 1988) as “*any item piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities*”. AT may improve the physical or mental functioning of the disabled, enable them to accomplish daily living tasks, assist them in communication, education, work or recreation activities. In other words help them achieve greater independence and enhance their quality of life. One can immediately realize that AT and Neurotechnology share a common objective which is to help the individual to overcome a disability or impairment.

When AT is divided into categories or product families, one can notice the similarities with neurodevices taxonomy. In particular prosthetics and orthotics, vision and reading aids, hearing and listening aids, include both neurotechnology and non-electronic equipment that assist the disabled. More specifically Augmentative Alternative Communication (AAC) is built around the concept of communication of the impaired individual

with the environment. AAC involves alternate methods of communication through the use of electronic and non-electronic devices for the disabled. It includes communication boards, text-to-speech software, speech recognition software, head wands, mouth sticks, signal systems, and others.

In two other categories of AT namely environmental control systems (ECS), and computer access aids, applications of the brain computer interface are commonly included. ECS enable someone with limited mobility to control various electrical appliances. Computer access aids include alternative input and output devices together with adapted software applications that enable persons with disabilities to access, interact with, and use computers.

### Technical and biological complications

Three decades of continuous development of implanted devices and technological progress make operative techniques safer, and the equipment implanted more robust. Nevertheless there are both technical and biological complications that arise from their use. For instance, spinal cord stimulation devices have been examined and studied extensively for more than thirty years. In a recent literature review, researchers report that the most common problems with the operation of the device are: lead migration, lead breakage, over- or understimulation, loose connection, battery failure, hardware malfunction. In addition, biological complications include infection in the tissues surrounding the implant, cerebrospinal fluid leakage, and pain at the incision electrode or receiver site [3]. In the same review, it is most encouraging to notice that the percentage of incidence of these cases is very small compared to the total number of patients with an implanted device.

Another characteristic example of technical complication is the type of interaction of the user with the neurodevice. In certain functional electrical stimulation operated devices the stimulation is handled automatically for safety reasons. Conscious intervention from the user to handle the operation of the device is a highly complex task. *“To accomplish this, the device must be able to detect specific brain activity at any time a command is intended, and disregard all other brain activity that arises when the user is performing other tasks”* [1].

Many devices need adjustments; if the surgeon or the clinician is new to the device she/he must receive guidance from a qualified engineer for this type of devices. That simply means that the surgeon must be interested

and even skilled at implanting and using the device [5]. Another complication regards insurance and indemnification. In feasibility and/or clinical trial studies, the physician has to examine whether the patient is covered by his or her insurance for injury claims, device malfunction, or even death resulting from faulty equipment and the extent of liability of the manufacturer [5].

### Embracement of neurotechnology in the medical profession

In 1998, Health Technology Advisory Committee (HTAC), reviewed neurostimulation devices and found that [12]:

- i. There are not large-scale clinical trials published in medical literature.
- ii. Devices are appropriate for a small number of patients compared to the total number of patients with a disorder. This is due to the fact that there are strict criteria based on various assessment tests that include or exclude a patient from a clinical trial.

In United States gaining FDA approval may take years. Safety and effectiveness of the device is tested on a large group of subjects in order to gather sufficient information from multicenter clinical trials. This is one of the main reasons that today many neurotechnology devices are investigational. Moreover, even if it is approved by FDA, clinicians will reach a “consensus” in many years to accept them in their practice. That means the clinical availability of the device may be restricted or limited in only a few clinical research centers around the world [17]. Other reasons that prohibit the embrace of this technology in the medical profession include technical problems, poor documentation and training for the practitioners and absence of continuous development [24].

### Financial implications

Neurotechnology is an expensive complex technology for many reasons; treatment is usually very specialized, it is a new technology in the medical marketplace and the cost of the components of the devices is substantial. The battle for dominance of neurodevices over neuropharmaceuticals is enduring. Evidence presented in the review from Taylor *et al.* showed that the actual cumulative cost for SCS treatment of chronic pain incurred in diagnostic imaging, implantation, hospitalization, physiotherapy, maintenance of the stimulator, for a 5-year period is economically favorable in comparison to best conventional pain therapy method but in the first two

years the cost is significantly more for SCS [25]. More important, in a similar study by Kumar *et al.* an assessment of the SCS group indicated a 27% improvement in quality of life compared with 12% improvement for the control group. In addition, 15% of SCS-treated patients were able to return to employment but none was able to return to employment from the control group [14].

### Future prospects

There are 1.5 billion people worldwide that suffer from neurological diseases and psychiatric illnesses, the largest and fastest growing medical sector [16]. Until recently, stimulation methods were usually the last resort, when patients were intractable to medical and other non-invasive treatments or when other more conservative therapies had proved ineffective in addressing a particular condition. As the technology advances, implantation technique is simplified, devices are miniaturized, durability and reliability is prolonged, and effectiveness is increased while side-effects are decreased. Despite all these improvements, Neurotechnology is still at an infancy stage and progress resembles the adoption and development path of cardiac pacemakers. “*Systems now in use rely on rather gross levels of electrical stimulation, placement is relatively imprecise, and control parameters are empirically derived*” [3]. In the same article, the authors report that “*these devices are not modulated by feedback sensed by the system, are always “running” and require subjective human intervention for calibration due to changes in the patients state*”. Neurostimulation or neuroprosthetic devices will become more practical when their operation will be adjusted automatically according to changes in the environment or in the user’s body. One can arguably say that the perfect device is the one that the user will feel like any other part of his body. At the present the main reason that stimulation is optimized empirically by trial-and-error is due to our limited knowledge about the underlying biophysical mechanisms. The development of new generation devices will require computer modeling of electrical stimulation of nerve fibers, the neuronal target area, and the surrounding anatomical structures.

### Conclusion

Man is the undisputable ruler of planet earth. We survived and we evolved thanks to the technology we developed. Nevertheless the ever-lasting battle on human mortality and diseases has not been conquered yet. Neurotechnology is our latest weapon to fight against

the suffering from our bodily weakness, to prolong our life, and to expand our physical or mental ability. This is the time where science fiction has started to become reality. But there is always this tormenting question that emerges when we compare ourselves against other artificial or physical forms of life. What makes us humans? Is it our brain – mind or perhaps is it our body – soul?

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