Ethics of Functional Neurosurgery

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Abstract

Functional neurosurgery became one of the most dynamic fields in surgery developing from a subdiscipline to a major driver of innovations and novel therapeutic interventions. Despite an inglorious history rooted in unspecific psychosurgical lesioning techniques, functional neurosurgery has evolved to a

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highly precise intervention based on cutting edge imaging, image guidance, and physiological technology offering the last treatment resort for a growing number of neurological and psychiatric indications. Novel devices including closed-loop systems for neuromodulation and prosthetic control promise further new treatment options in the near future.

These dynamic developments are changing the traditional field of related ethical issues significantly. This necessitates that functional neurosurgeons, patients, and society in general will have to deal with new ethical issues in the areas of neuroenhancement, privacy of brain-related information, and patient autonomy regarding control of implanted devices. These issues add to those already inherent to this discipline, e.g., challenges to neurosurgeons from the perspective of professional ethics in the specific context of brain intervention or adequate patient information about the increasing unpredictability of risks and benefits.

Functional neurosurgery will continue to open new doors of modulating brain function; concurrently arising ethical issues need to be addressed by ethicists and physicians jointly and ahead of time.

Introduction

This article on "ethics of functional neurosurgery" is divided in three chapters: core characteristics of functional neurosurgery, specific aspects of functional neurosurgery with ethical relevance, and discussion on general ethical questions.

The current focus of the ethical discussion about functional neurosurgery in literature is the stereotactic implantation of electrodes for deep brain stimulation (DBS). In the last decade more than 130 publications have been written on this topic, in contrast to only six publications on the ethics of functional neurosurgery (according to the data bank PubMed for the search terms "ethic*" $\wedge$ "deep brain stimulation" versus "ethic*" $\wedge$ "functional neurosurgery"). But functional neurosurgery is more than DBS. Although DBS is the most common intervention in functional neurosurgery, it is only one of many techniques used in this field. Thus, the current perspective might mask fundamental anthropological and ethical issues which need to be addressed.

What Is Functional Neurosurgery?

The field of neurosurgery addresses diseases of the central and peripheral nervous system with a large variety of surgical techniques. In the majority of cases, neurosurgical interventions aim at removing pathologies such as brain tumors, vascular lesions, or degenerative tissue of the spinal cord. These "morphological" approaches to diseases of the nervous system have been extended especially in the last two decades by "functional" approaches. Due to neurotechnological developments and a deeper understanding of the neurophysiology of diseases, many new approaches arose modulating "functionally" the nervous system, e.g., in movement disorders

(Elder et al. 2008; Sachdev and Chen 2009; Missios 2007). Hence, these new approaches have to be addressed from an ethical perspective as well.

The term *functional neurosurgery* was coined by Lériche and Wertheimer around 1950, stressing the importance of exploiting neurophysiological knowledge for interventions aimed at changing the dynamics of a system. According to this concept, the "aim and objective of functional neurosurgery are to treat, correct, or balance the functions of the brain that are altered toward either hyperfunctional or hypofunctional states." (Marino 1979). This can result in "positive" or "negative" symptoms and is closely linked to a functional account of disease as exemplified by Boorse. He defined a disease as a "type of internal state which [. . .] reduces one or more functional abilities below typical efficiency," (Boorse 1977) relating functional abilities to the concepts of reference class and normality: "The reference class is a natural class of organisms of uniform functional design; specifically, an age group of a sex of a species," while "a normal function of a part or process within members of the reference class is a statistically typical contribution by it to their individual survival and reproduction" (Boorse 1977). This approach to the design of neurosurgical interventions necessitates an explicit view of the central and peripheral nervous system as a *dynamical system*. In the same way as the "origin of disequilibrium may be vascular, tumoral, degenerative, or infectious and it may or may not require specific treatment," (Marino 1979) the actual intervention might be targeting a different function located at a different brain area to reestablish normality. In that regard, functional neurosurgery is not a specific technique but a family of methods to modulate functionality with implants in the central or peripheral nervous system.

For this goal, knowledge about the location of functions of the nervous system and their interaction in a network has to be applied with high sensitivity and specificity for each individual patient. Because of these three aspects (localization, system, and subject-level accuracy), presurgical planning and intrasurgical monitoring are of tremendous importance (Ford and Kubu 2005; Kekhia et al. 2011; Borchers et al. 2012; Martino et al. 2011). Functional neurosurgery is therefore highly interested in any advances made in functional brain mapping and neuroimaging which could guide treatment and result in knowledge about biomarkers of disorders (Martin 2012). The fourth important aspect is the increasing understanding of the method of action of these interventions to the nervous system (Cheney et al. 2012; Kringelbach et al. 2010; Dzirasa and Lisanby 2012). This allows functional neurosurgery to improve its tools based on the expected effects of different interventions (Martin 2012; Min et al. 2012). With new technological tools for manipulating functionality and a scientific understanding of the method of action at hand, modern functional neurosurgery has tremendously evolved since the beginnings when therapeutic lesions were applied (Synofzik and Schlaepfer 2008).

Three Main Characteristics

With this in mind, we argue that modern functional neurosurgery is defined by three key characteristics. The first is the concept of *operative neuromodulation*, which is an "interventional field of medicine that alters neuronal signal transmissions by implanted devices, either electrically or chemically, in order to excite, inhibit or tune the activities of neurons or neural networks to produce therapeutic effects." (Sakas et al. 2007). (S4) The second is the concept of *closed-loop stimulation* which is often also called smart, intelligent, individualized, or on-demand brain stimulation (Benabid et al. 2011; Modolo et al. 2012). The common strategy behind these terms is to monitor online neurochemical (Shah et al. 2010) or neurophysiological activity (Berenyi et al. 2012) for real-time adaption of brain stimulation parameters. The third is the concept of *neural interfacing and prosthetics*, which includes two aspects: the possibility of real-time translation of signals from the nervous system into information which can be utilized for communication, control, or biofeedback (Daly and Wolpaw 2008) and the ability to replace neurological functions such as speech, motor, sensory, hearing, or vision with prosthetic devices at the cellular or systems level (Wang et al. 2010; Stieglitz 2007).

Examples for *operative neuromodulation* are deep brain stimulation (DBS) and epidural motor cortex stimulation (EMCS), which are used in the treatment of Parkinson's disease (Gutiérrez et al. 2009; Fasano et al. 2012), dystonia (Pagni et al. 2008; Vidailhet et al. 2012), or pain (Stadler et al. 2011). Developments of *closed-loop stimulation* are currently evaluated in Parkinson's disease (Tsang et al. 2012; Lee et al. 2009; Priori et al. 2012), pain (Zuo et al. 2012), and epilepsy (Berenyi et al. 2012). Research on *neural interfacing and prosthetics* is addressing speech, e.g., in patients suffering from amyotrophic lateral sclerosis (Brumberg and Guenther 2010) or motor control in patients with spinal cord injury (Bhadra and Chae 2009).

In this context, irreversible therapeutic lesioning is a last resort in functional neurosurgery and results often from insufficient knowledge, technical and financial limitations, or pressing medical needs (Raoul et al. 2009). In contrast, functional neurosurgery aims to keep the anatomy intact and to achieve therapeutic gains by modulating pathological functions. Most other branches of neurosurgery explicitly change anatomy, and obviously, the removal of pathological brain tissue might result in functional improvement as well. Nonetheless, such interventions would be attributed rather to classical general neurosurgery than to functional neurosurgery.

Specific Aspects and Differences to Other Medical Interventions

Although principles from general medical ethics are applicable to functional neurosurgery, this discipline is in many aspects different from other medical specialties. Special attention should be given to the fact that functional neurosurgery is a surgical intervention, usually in the brain, with an infamous history in the era of irreversible brain lesioning. At the same time, while being a last resort for many disorders, it offers unique opportunities for a deeper understanding of brain functioning and disease.

It Is a Surgical Intervention

Any intervention in functional neurosurgery is essentially a surgical one. Therefore the topic of the invasiveness of the intervention is of importance.

Additionally, because the anatomy of every patient is very individual, there is a high need for correct localization. Presurgical mapping based on functional magnetic resonance imaging or transcranial magnetic stimulation becomes increasingly unreliable after the dura has been opened. “Following opening of the dural flap, surgical manipulation, CSF drainage, edema, and issues related to gravity and positioning cause the brain to shift, causing an anatomic discrepancy between the preoperatively acquired images and the surgical field. This displacement is exacerbated by the progression of the surgical procedure.” (Kekhia et al. 2011). From this perspective, stereotaxy is only one of the many options available to the functional neurosurgeon to ensure correct targeting. Usually, the neurosurgeon also relies on intraoperative measurements, e.g., spiking activity, local field potentials, or direct cortical stimulation. Because of the brain shift and the potential unreliability of presurgical maps, intraoperative measurements and events have to be interpreted on the spot and a need for adaptation may arise during surgery, also in the case of unplanned complications. This has an influence on how strong a neurosurgeon can rely on evidence-based knowledge for guidance. Often, a surgeon’s professional experience and know-how to employ his individual skill and judgment in unique cases must be balanced against a need to generalize knowledge and provide best care for groups of patients (Ford and Henderson 2004). Essentially, functional neurosurgery is a practice with a large heterogeneity between centers (Abosch et al. 2012), and its safety and efficacy relies heavily on the experience, competence, and decisions of the individual surgeon (Kleiner-Fisman et al. 2006; Kirsch and Bernstein 2012). Additionally, many of the functional measurements during the surgery make it necessary that the subject is awake. This presents several unique challenges. Insensitive comments by the staff will be overheard or the patient might misinterpret professional conversation. It is therefore important how patients perceive the surgical team, but this also puts the staff under scrutiny and increases their mental load. Awake surgery can also mean that consent is withdrawn during the intervention (Kirsch and Bernstein 2012).

It Is a Last Resort

Any surgery carries an inherent risk of adverse events of different severity. Adverse events can be attributed to one of three domains. They are either related to the surgery (e.g., transient confusion, hemorrhage, infection, seizures), to the device (e.g., dysfunction, replacement, infection, or migration), or to the modulation (e.g., cognitive, emotional, behavioral, or motor problems) (Kleiner-Fisman et al. 2006). Naturally, surgical risks increase from transcranial (essential noninvasive) to epidural to subdural to subcortical interventions. Complications during surgery can result in severe extension of duration and put a high toll on the stamina of the surgeon. At the same time, this need for individual decision making and the immediate perception of consequences of surgery mean that issues of adequate training, physical ability, professional responsibility, and coping with feelings of guilt present themselves in a special manner in neurosurgery. The challenge for the surgeon is to trust in one's abilities while being able to perform a critical self-assessment. "All surgeons reach an age when the technical competence and personal stamina necessary to perform surgical procedures may decline. We are responsible to adjust our activity as appropriate when that time occurs." (Umansky et al. 2011). Yet, risks for adverse events during surgery are not only attributable to the surgeon, but are mediated by several factors. Age, neurovascular disorders, other comorbidities, and the psychosocial state of the patient are essential aspects for any consideration of surgery. Therefore evidence-based inclusion and exclusion criteria should be developed to guide risk-benefit assessments. Additionally, there is an inherent, irreducible risk of mortality and permanent impairments. Functional neurosurgery is therefore by many considered to be a last resort treatment when the patient has been shown to be refractory to other treatments. Yet, in many disorders early intervention is being considered. In Parkinson's disease, there is the possibility of a neuroprotective effect and the prevention of psychosocial problems (Schermer 2011); and for amyotrophic lateral sclerosis, the early implantation of communication prosthetics might be necessary to prevent the extinction of thought in a completely locked-in state (Murguialday et al. 2011). Additionally, the different levels of invasiveness should be weighed against the potential benefit.

It Is an Intervention in the Brain

To common understanding, cognitive, sensory, and motor functions are manifested in the nervous system. Functional neurosurgery builds on the assumption that these properties can be localized and modulated. At the same time, the brain has a unique role for most individuals, and also in our society, and is therefore perceived as fundamental for the understanding of personhood. "Recognizing that the brain has a central importance in the organization of patients as persons makes performing brain surgery perceptively different from other types of surgeries." (Ford and Henderson 2004). In parallel, medicalization in the context of a professional interaction is characterized by a low responsibility of the patient for the onset and solution of a problem, but a high expectation to follow the advice of an expert (Brickman et al. 1982). At the same time, neuroscience has a big impact on our concepts of personhood (Farah and Heberlein 2007) and responsibility (Walter 2001), and the topics of medicalization, localization, reification, and exoneration (Fuchs 2006) are ever present. We believe that in many medical specialties, these topics are of reduced presence. But the strong foundation of functional neurosurgery in neuroscience, its high spatial accuracy, the praxis of surgery, i.e., the process of interaction with immediate consequences, and the strong medical primer of a surgery make it next to impossible to ignore these aspects. Therefore the framing of a treatment as "intervening in the brain" (Merkel 2007) or a disease as a "brain disorder" (Leshner 1997) based on functional neuroimaging (Ford and Kubu 2005) changes the perception of the stakes at hand.

It Is an Opportunity for Research

Additionally, any functional intervention in the brain is an opportunity for research and a better understanding of the human nervous system. This research happens as a fundamental part of functional neurosurgery, e.g., when activity in subcortical areas is measured to improve targeting during DBS implantation (Seifried et al. 2012). It can also be a result of postoperative evaluations and help detecting biomarkers of disorders (Bronte-Stewart et al. 2009) or be used for research of functions not directly affected by the disorder (Shibasaki 2012). Balancing the opportunity for research with the best interest of the patients can be a fine line. Patients might feel compelled to satisfy the demands of the clinical personnel or confuse research with a measurement necessary for medical treatment. At the same time, many interventions proposed as treatment are currently still under research. Patients, but also clinicians, can be desperate after unsatisfactory treatments, and the opportunity to take part in a clinical study or explore a novel treatment might feel very compelling in spite of the unknown dangers. Patient autonomy in this regard is therefore no fail-proof guardian against unnecessary or disproportionate risks. On the other side, many neurological disorders such as degenerative disorders or stroke often result in chronic, functional impairments which cannot be treated sufficiently with classical therapeutic approaches. In addition, accidents may result in amputations and losses of sensory organs. Therefore, anyone can get in need for novel functional rehabilitation approaches. Thus, if functional restoration might only be achieved with a neurosurgical intervention and prosthetic approaches, many people will take that risk. This development will be fueled by technological breakthroughs supported by respective funding agencies (Judy 2012).

It Has an Infamous History

Almost no ethical paper in the literature discusses DBS without mentioning the term psychosurgery. Egas Moniz suggested in 1935 the ablation of the frontal cortex as a treatment option for psychiatric disorders which were otherwise treatment resistant. In 1949 he won the Nobel Prize in medicine for this approach. Walter Freeman and James Watts simplified the approach to transorbital frontal lobotomy, on which the infamous story of the ice pick through the eye is being based. From 1945 to 1955 tens of thousands of patients were treated by this crude intervention (Tye et al. 2009). Relatively poor hygienic standards, the conduction with insufficient surgical training, lacking follow-up, and severe side effects resulted in increasing criticism.

Modern functional neurosurgery takes a completely different approach. Many authors see the development of stereotactic procedures as a reaction to the crudeness and high morbidity of lobotomy (Krack et al. 2010). Others see the origin of functional neurosurgery in brain stimulation studies, e.g., in electroconvulsive therapy (ECT) introduced by Ugo Cerletti in 1938 for the treatment of severe psychosis (Sironi 2011), and in reports on intracranial stimulation of the median forebrain bundle in rats (Appleby and Rabins 2009). Hence, “ablative surgery and electrical stimulation developed in parallel, practically since the introduction of human stereotactic surgery” (Hariz et al. 2010). After high-frequency DBS was introduced and shown to mimic the effect of a lesion, the field of functional neurosurgical interventions changed drastically, as it allowed for adaption of stimulation, reversibility, and reduced morbidity (Benabid et al. 2009a). It should therefore be noted that comparing modern functional neurosurgery to early psychosurgery is wrong in many regards. Modern functional neurosurgery is based on informed consent, clearly defined inclusion and exclusion criteria, clinical decision making by an interdisciplinary team, reversibility and precise targeting, and neuroimaging (Synofzik and Schlaepfer 2008). The comparison of functional neurosurgery to ECT, mind control, or psychosurgery only feeds ungrounded fears (Clausen 2011) and is very unfortunate (Synofzik and Schlaepfer 2008). Yet, the other side of the coin is the hyperoptimistic presentation of DBS in the media (Gilbert and Ovadia 2011).

Ethical Questions

General medical ethics is based on the principles of beneficence, non-maleficence, patient autonomy, and justice (Beauchamp and Childress 2009). These principles also apply to functional neurosurgery. Neuroenhancement and privacy are additional issues that have to be addressed with regard to functional neurosurgery. These issues will be discussed in this chapter.

Beneficence, Non-maleficence, and Cost-Benefit Analysis

Beneficence and its antonym maleficence can be integrated into the concept of a cost-benefit analysis. Due to the large number of interventions possible in functional neurosurgery, a detailed analysis for each intervention is beyond the scope of the present article. As already explained, risks can be related to the surgery, the device, or the modulation. For functional neurosurgery, two aspects are specifically important. First, regular follow-ups are necessary to achieve and maintain the gains of the intervention. This should be factored into any analysis, e.g., by assessing social or familiar support or the distance of the patient’s home to the treating institution for regular follow-ups. Second, a surgery involves not only certain costs, but also risks and uncertainties. Even if a certain treatment would show to be effective in every case, there would still be a risk for a negative outcome due to complications related to the surgery. Therefore, these surgeries cannot be expressed uniquely in cost-benefit analyses, but need a risk assessment as well. As these risks may be related to patient-specific criteria, this means that a reliable cost-benefit analysis can only be performed if definite patient inclusion and exclusion criteria have been established. Yet, humans are notoriously bad at judging and perceiving risks (Lloyd et al. 2001), this is true for both patients and surgeons. Moreover, quantitative statements may confuse rather than inform those not familiar with these statistical information (Schwartz 2011). It is known that surgeons may suffer from overconfidence in their ability to reduce risks (Kissinger 1998). All these aspects have a direct impact on how patients should be informed for their consent to the intervention.

Autonomy

Every medical intervention needs informed consent, which "implies three basic requests: (1) all medically relevant information about diagnosis and prognosis of a patient's disease, the therapy, its potential risks and alternative therapies must be disclosed. (2) The patient should have the mental capacity to understand his or her situation and the presented information. (3) The patient must not be coerced or compelled, but autonomously decides about a treatment on the basis of the information disclosed." (Skuban et al. 2011). Yet, autonomy in the context of functional neurosurgery faces some special considerations. Many functional neurosurgeries are performed with awake patients. That means, that consent could be revoked at any time during the procedure. Although rare, such cases have been documented. Rules need to be put in place to deal with this situation. Patients may be more likely to suspend a surgery once informed of this option, and surgeons should consider discussing how requests for discontinuation will be handled. Guidelines regarding advanced directives, appropriate intraoperative measures of persuasion, and the possibility of returning to surgery at a later date need to be developed. If the patient would benefit greatly from an intervention, a higher level of convincing might be mandated. Additionally, functional neurosurgery often relies on implanted devices that are in need of ongoing maintenance and professional supervision. Withdrawal of consent by the patient or reduced compliance can result in medical problems and could happen at any time. This withdrawal poses an ethical challenge. In functional neurosurgery, ending treatment will be realized by turning off the device. But in some cases, explantation of the device might be considered – resulting in additional risks. On the other side most of the implantable devices allow for fine-tuning. How much freedom should patients have in changing the parameters of these devices knowing that too much freedom may result in abuse, e.g., self-stimulatory behavior in DBS (Morgan et al. 2006)? At the same time, informed patients' control over the device may reduce side effects of the stimulation and save battery life.

Privacy

With many implanted devices, neuronal activity is constantly monitored during regular activity of the patients. This is commonly the case with electrodes implanted for epileptic diagnostics, but storage is also necessary for many other neural interfaces. Additionally, one might consider other types of data stored in implanted devices, e.g., kinematic data. Already, commercial use of brain-computer interfaces spawn discussions about side-channel attacks (Martinovic et al. 2012). Data security against malicious intrusion might therefore be topic in the development of safe readouts from implantable devices. There are also non-malicious dangers to privacy. Stored data could be used as evidence in a law trial, and the device could be exploited as a lie detector (of uncertain accuracy). If any information stored in the device is being "disclosed without proper consent, such information could lead to unanticipated insurance, employment, or legal problems for the individual" (Wolpe et al. 2010).

Neuroenhancement

Neuroenhancement has been defined as any "technical intervention aimed at improving some physical or psychological aspect of an individual, but which cannot be categorized as treatment" (Merkel 2007). Currently, to our best knowledge, no functional neurosurgery has been performed worldwide on healthy subjects. It is therefore unknown whether a specific treatment improving functionality in a pathological state might also show efficacy in healthy subjects. That makes it difficult to assess whether neuroenhancement is even feasible. Currently, in the field of *neural prosthetics*, an artificial enhancement is unlikely as any sensory or motor replacement today cannot compete with the original, healthy organ. Yet, additional senses or brain outputs could be an option for enhancement. Brain-computer interfaces used, e.g., for controlling a cursor on the computer screen, already work in healthy subjects with noninvasive recordings (Wolpaw 2007; Silvoni et al. 2011). Invasive recordings would improve the accuracy, speed, and flexibility of the device. Also, noninvasive neuromodulation has been shown to improve a whole range of cognitive and motor functions (Hamilton et al. 2011), from working memory (Polanía et al. 2012; Zaehle et al. 2011) or sensory discrimination (Ragert et al. 2008) to motor performance (Joundi et al. 2012). *Operative neuromodulation*, maybe in combination with *closed-loop stimulation* adapted to the individuals' anatomy and cerebral networks, might further exploit these effects. In the course of a regular treatment, it could happen that a further (or the same) functionality may be improved above the average, an effect coined incidental enhancement by Peter Kramer (Kramer 2009). In depression treatment, mood could be improved above average; in treatment of spinal cord injury, external gadgets could become controlled directly, and in treatment of blindness, additional spectra could be included.

We therefore have no doubt that neuroenhancement with functional neurosurgery is theoretically possible (albeit risky). Therefore, this option might generate a demand. Applications in healthy subjects might be funded by the military. Or wealthy individuals with a transhumanist agenda could start recruiting their own neurosurgical staff. Even when stipulating that "enhancements which cannot at least count as prevention of disease/disability [. . .] should not be included in the sphere of proper medicine as a social system," (Merkel 2007) dealing with privately paid functional neurosurgery may become an issue in the future. Just as plastic surgeons "shifted from reconstructive to cosmetic procedures," (Hamilton et al. 2011) a similar fate might occur in neurosurgery. Sliding down a slippery slope (McNamee and Edwards 2006) or thanks to a "diagnostic bracket creep," (Kramer 2009) they could become "future providers of neuromodulation technology." (Mendelsohn et al. 2010). From an ethical perspective, that means that it will be important to consider how to deal adequately with such possible developments in advance.

Distinguishing the enhancement of cognitive and motor skills from the modulation of emotion and motivation might be of ethical relevance. Many ascribe the latter functions as more relevant role for the concepts of personal identity (Jotterand and Giordano 2011) or authenticity (Leefman et al. 2011). At the same time, these functions are located more in deeper brain structures (Cardinal et al. 2002); hence, no consistent influence of noninvasive neuromodulation has been shown so far (Hamilton et al. 2011). These targets might be achieved by functional neurosurgery. This means that the issues of personality changes, personhood, authenticity, and personal identity will gain more importance in the assessment of neuroenhancement in this context.

Justice

A main argument against research on functional neurosurgery is that it is too costly and drains funds from established treatments. This concern has, e.g., been expressed against the research of DBS for the treatment of addiction: "The addition of an expensive neurosurgical treatment that costs of the order of US$50 000 (with maintenance costs of approximately US$10 000 every few years) will worsen this situation by utilizing scarce health resources to treat a very small number of patients with the income to pay for it" (Carter and Hall 2011). For many functional neurosurgical interventions, this argument does not hold. DBS, for example, is cost-efficient for addiction (Stephen et al. 2012) and for Parkinson's disease (Valldeoriola et al. 2013). Yet, most DBS surgeries are performed in large teaching hospitals in metropolitan areas (Lad et al. 2010), possibly indicating differences in regional availability of this treatment option. The relative high costs of stimulation devices make it certainly difficult to propagate DBS as a replacement for therapeutic lesions in developing countries (Benabid et al. 2009b), especially when there is already a lack of receiving basic care in these areas (Rosenfeld et al. 2008). At the same time, vulnerable patients from wealthy countries might decide traveling to countries with a lower standard of ethical or scientific scrutiny paying for treatments without any proven benefit (Rosenfeld et al. 2008).

Conclusion

What has already been achieved with functional neurosurgery was a science fiction only a decade ago. Robotic limbs are controlled by thoughts, implanted devices change mood and influence motor skills, and sensors constantly record brain activity and modulate it. We believe that the topics of privacy, autonomy, enhancement, and individual benefit are already in the focus of functional neurosurgeons. On the other side, while there is awareness that global justice and a fair distribution of health resources are important, these topics receive relatively little attention. Probably this will be one of the issues that will be tackled in future together in the context of studies on the socioeconomic impact of operative neuromodulation, closed-loop stimulation, interfaces, and prosthetics. With the words of William Gibson, "the future is already here – it's just not very evenly distributed."

Cross-References

▶ Awake Craniotomies: Burden or Benefit for the Patient?
▶ Compulsory Interventions in Mentally Ill Persons at Risk of Becoming Violent
▶ Deep Brain Stimulation for Parkinson's Disease: Historical and Neuroethical Aspects
▶ Deep Brain Stimulation Research Ethics: The Ethical Need for Standardized Reporting, Adequate Trial Designs, and Study Registrations
▶ Ethical Implications of Brain–Computer Interfacing
▶ Ethical Implications of Brain Stimulation
▶ Ethical Implications of Sensory Prostheses
▶ Ethics in Neurosurgery
▶ Ethics of Epilepsy Surgery
▶ Impact of Brain Interventions on Personal Identity
▶ Mind Reading, Lie Detection, and Privacy
▶ Neuroenhancement
▶ Neuroethics and Identity
▶ Neuroimaging Neuroethics: Introduction
▶ Parkinson's Disease and Movement Disorders: Historical and Ethical Perspectives
▶ Research in Neuroenhancement
▶ Risk and Consent in Neuropsychiatric Deep Brain Stimulation: An Exemplary Analysis of Treatment-Resistant Depression, Obsessive-Compulsive Disorder, and Dementia
▶ Sensory Enhancement

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