Chapter 2
Human ICT Implants: From Restorative Application to Human Enhancement

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Abstract Human ICT implants such as cochlear implants and cardiac pacemakers have been in common clinical use for many years, forming intimate links between technology and the body. Such medical devices have become increasingly advanced in their functionality, with some able to modify behaviour by directly interacting with the human brain and others coming closer to restoring functionality which outperforms its natural counterpart. More recently, and somewhat more controversially, low-tech human ICT implants have been increasingly employed in healthy people, in non-therapeutic contexts. Applications typically focus on identification such as VIP entry into nightclubs, automated payments and controlling access to secure facilities. While reviewing the state of the art, this chapter makes the case that with the desire of technology enthusiasts and self-experimenters to push boundaries, increasing familiarity driving cultural and societal changes, advances in medical technology and the inevitable drift of medical technology to non-medical application, this is clearly just the beginning for human enhancement using ICT implants.

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M. N. Gasson et al. (eds.), *Human ICT Implants: Technical, Legal and Ethical Considerations*,
Information Technology and Law Series 23, DOI: 10.1007/978-90-6704-870-5_2,

2.1 Introduction

There is a fair range of 'restorative' devices already in clinical use, although many, such as artificial joints, could not through their function alone be considered ICT devices. Others, such as the artificial heart pacemaker, have become notably sophisticated in recent years with integrated sensors to adjust performance based on estimated demand, internal logging of biological data, and RF communication with the outside world.

These battery powered devices are known as Implantable Medical Devices (IMDs), and have been used for decades as lifesaving devices, becoming increasingly capable and multifunctional. The operation of such devices is not necessarily based on a routine that is periodically repeated—some actions are performed automatically as a result of a continuous monitoring of the patient's body by sensors embedded in the IMD. With such devices, there is usually a need for two-way communication between IMDs and the external world.

Data can be sent to the implanted device in order to programme its parameters or to trigger a specific action on demand. The device may in turn send data, for example the history of any measured characteristics or a log of device actions, which can be externally analysed. The most effective way of such communication is through wireless, radio transmission. However, such communication can raise concerns about privacy and security.

The main communication functions of IMDs are (see Fig. 2.1 below)

- Communicating the presence and type of device to medical staff
- Deactivation of the device on demand, e.g. before an operation
- Sending collected measured medical data (e.g. heart rate and body temperature) and data on the history of the device operation to help in the diagnostic process[1] and the auditing of the device's operational history
- Configuration of the device
- Manual control over the device
- Upgrade of the software included in the device

Of great interest is the development of IMD technologies that are able to interact with us on a neural level. The most ubiquitous sensory neural prosthesis is by far the cochlear implant[2]; where destruction of cochlea hair cells and the related degeneration of auditory nerve fibres has resulted in sensorineural hearing loss, the prostheses is designed to elicit patterns of nerve activity via a linear array of electrodes implanted in the deaf patient's cochlea that mimics those of a normal ear for a range of frequencies, (as discussed in detail by Tadeusiewicz et al. in Chap. 4). Current devices enable around 20% of those implanted to communicate without lip reading and the vast majority to communicate fluently when the sound

[1] Some modern IMDs offer the possibility of online home monitoring: data received wirelessly from the IMD by the base station are passed through a website to a doctor.

[2] Zeng 2004, p 1.

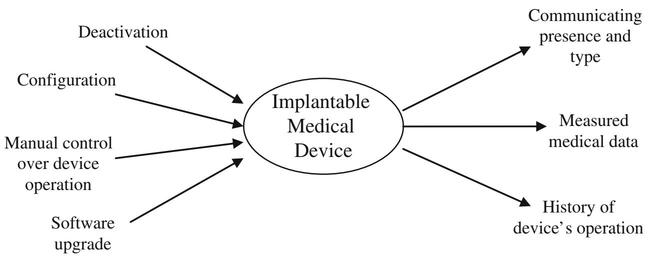

Fig. 2.1 Communication of a generic IMD with the external world, showing the directional flow of information

is combined with lip reading. Its modest success is related to the ratio of stimulation channels to active sensor channels in a fully functional ear, with recent devices having up to 24 channels, while the human ear utilises upwards of 30,000 fibres on the auditory nerve. With the limitations of the cochlear implant in mind, the artificial visual prosthesis[3] is certainly substantially more ambitious. While degenerative processes, such as retinitis pigmentosa, selectively affect the photo-detectors of the retina, the fibres of the optic nerve remain functional, so with direct stimulation of the nerve it has been possible for the recipient to perceive simple shapes and letters. However, the difficulties with restoring full sight are several orders of magnitude greater than those of the cochlear implant simply because the retina contains millions of photodetectors that need to be artificially replicated, and so this technology remains in development. Sensate prosthetics is another growing application area of neural interface technology, whereby a measure of sensation is restored using signals from small tactile transducers distributed within an artificial limb. The transducer output can be employed to stimulate the sensory nerve fibres remaining in the residual limb that are naturally associated with a sensation. This more closely replicates stimuli in the original sensory modality, rather than forming a type of feedback using neural pathways not normally associated with the information being fed back. As a result, it is supposed that the user can employ lower level reflexes that exist within the central nervous system, making control of the prosthesis more subconscious.

While cochlear implants, retina stimulators and sensate prosthetics operate by artificially manipulating the peripheral nervous system, less research has been conducted on direct electrical interaction with the human central nervous system, and in particular the brain.[4] A Brain-Computer Interface (BCI) consists of hardware and software for direct communication between the brain and external devices. Information may be passed from the brain to an external device, for example to enable control of a computer or robot arm with thought or in the opposite direction

[3] Hossain et al. 2005, p 30.

[4] The following part of this subsection contains contributions from Ryszard Tadeusiewicz and Pawel Rotter.

such as from an artificial eye to the brain. The performance achievable highly depends on the degree of invasiveness:

- In a non-invasive BCI, no implant is used. The most common non-invasive method is based on recordings of brain activity taken from the outside surface of the head, known as an electroencephalogram (EEG). Other methods include magnetoencephalography and magnetic resonance imaging. Non-invasive BCIs typically pass information only in one direction (rarely to the brain). Signals are attenuated by the skull so non-invasive BCIs cannot achieve a performance comparable with those based on implanted electrodes.[5] On the other hand, they do not require an operation, do not cause side effects, and are easy to put on and to take off.
- An invasive BCI includes electrodes implanted directly into the grey matter of the brain, which requires a complicated and risky surgical procedure. There are a number of health and ethical concerns associated with this approach. Implanted electrodes enable applications which are unachievable by non-invasive methods.[6] However, most invasive BCIs monitor multi-neuronal intracortical action potentials, requiring an interface which includes sufficient processing in order to relate recorded neural signals with e.g. movement intent. The need to position electrodes as close as possible to the source of signals, and the need for long-term reliability and stability in a hostile environment are common issues.
- In partially invasive BCI electrodes are implanted into the skull but outside of the brain. The operation is easier and brings less medical risks than in the case of invasive BCI, but the expected functional performance is lower.

The selection of the method to be employed—invasive or non-invasive—will depend on the application. In some cases invasive methods must be employed because of the complexity of the application. However, non-invasive methods can be used for simple tasks in a range of fields, from entertainment to medical applications.

Simple control of external devices by intentionally modifying brain activity is possible using basic, non-invasive methods. In experiments carried out in mid-1990s with paralysed patients, intended variations of slow cortical potentials in their EEG were changed into binary signals so they could step-by-step select letters and write messages.[7] A further line of research has centred on invasive implants for patients who have suffered a stroke resulting in paralysis. An early example is the use of a ‘3rd generation’ brain implant which enables a physically incapable brainstem stroke victim to control the movement of a cursor on a computer screen.[8] Functional Magnetic Resonance Imaging (fMRI) of the

[5] Popescu et al. 2008, p 78.

[6] Graimann et al. 2011.

[7] Winters 2003.

[8] Kennedy et al. 2000, p 198 and Kennedy et al. 2004, p 72.

subject's brain was initially carried out to localise where activity was most pronounced whilst the subject was thinking about various movements. A hollow glass electrode cone containing two gold wires and a neurotrophic compound (giving it the title 'Neurotrophic Electrode') was then implanted into the motor cortex, in the area of maximum activity. The neurotrophic compound encouraged nerve tissue to grow into the glass cone such that when the patient thought about moving his hand, the subsequent activity was detected by the electrode, then amplified and transmitted by a radio link to a computer where the signals were translated into control signals to bring about movement of the cursor. With two electrodes in place, the subject successfully learnt to move the cursor around by thinking about different movements. Eventually the patient reached a level of control where no abstraction was needed—to move the cursor he simply thought about moving the cursor. Notably, during the period that the implant was in place, no rejection of the implant was observed; indeed the neurons growing into the electrode allowed for stable long-term recordings.

The year 2005 saw the first surgery being carried out which enabled a quadriplegic patient to control their artificial hand using an invasive implant.[9] However, hand precision control is still generally unsatisfactory with these devices, even after long and frustrating training. It is therefore questionable whether currently the benefits justify substantial health risks (including infection and implant rejection), plus the economic costs associated with surgery. At this early stage, there is no wide deployment of this technology, although research has demonstrated its potential. Christian Kandlbauer was the first man with a mind-controlled arm prosthesis who attained his driving licence. His story is an example of success of this technology but his tragic death after an accident in a car he was driving highlights the technical, legal and ethical questions surrounding these developments.

Work on animals,[10,11] has demonstrated how direct brain stimulation can be used to guide rats through a maze problem, essentially by reinforcement, by evoking stimuli to the cortical whisker areas to suggest the presence of an object, and stimulation of the medial forebrain bundle (thought to be responsible for both the sense of motivation and the sense of reward) when the rat moves accordingly. Early work to translate this research to humans demonstrated radical (and occasionally dubiously interpreted) changes in mood and personalities when such 'pleasure centres' were stimulated[12,13]. This period saw some 70 patients implanted with permanent micro-stimulators to treat a variety of disorders with reportedly good success, although the indiscriminate use of the procedure and significant failure rate saw it largely condemned. This may have been in part because the disorders targeted were psychiatric rather than neurological, and it was

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9 Hochberg 2006, p 164.

10 Olds and Milner 1954, p 419.

11 Talwar et al. 2002, p 37.

12 Moan and Heath 1972, p 23.

13 Delgado 1977, p 88.

not until the 1980s, when French scientists discovered that the symptoms of Parkinson's disease (PD), with better understood anatomical pathology, were treatable using Deep Brain Stimulation (DBS), that research again picked up pace (see Chap. 4 of this book). However, difficulties in accurately targeting structures deep in the brain, lack of safe durable electrodes, problems of miniaturising electronics and power supply limitations meant that such therapy was not readily available for several more years.

The ability of electrical neural stimulation to drive behaviour and modify brain function without the recipient's cognitive intervention is evident from this type of device. Further, it has been demonstrated how electrical stimulation can be used to replace the natural percept, for example the work by Romo et al.[14] However, in all cases these devices operate in a unidirectional fashion—the ability to form direct bi-directional links with the human nervous system certainly opens up the potential for many new application areas. Nevertheless, bi-directional neural implants are very much experimental. Whilst they have much potential in the areas of prosthetics, major developments have been slow in coming. Recent research in the area of DBS has shown that by recording brain activity via the implanted electrodes used for DBS in Parkinson's patients it is possible to detect characteristic signal changes in the target nuclei prior to the event of tremor, and so stimulation based on a prediction of what the brain will do is possible.[15] The development of such technologies, which are able to decode the brain's function, are clearly of great value.

2.2 Application of ICT Implants for Enhancement

The application of human implants is largely medical, and the vast majority of these devices are not ICT devices. However, such passive devices have been utilised for many years for enhancement of healthy people through varying degrees of body modification from simple cosmetic improvements, body decoration to radical reshaping of the physical form. In 2006, self-experimenters began to utilise small sub-dermal neodymium magnet implants, typically under the skin of the fingertips, for sensory experimentation whereby the movement of the implant in the presence of magnetic fields can be felt by the individual. More recently this type of implant has been used to convert non-human sensory information, such as sonar or distance, into touch information by manipulating the implant via external electromagnets to control stimulation of sensory receptors.[16] However, largely because of the increased technical complexities, healthy people have only started to explore how implantable ICT technology can be harnessed to enhance their normal abilities.

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14 Romo et al. 2000, p 273.

15 Gasson et al. 2005a, p 83.

16 Hameed et al. 2010, p 106.

Radio Frequency IDentification (RFID) technology was originally developed for automatic identification of physical objects. An RFID tag—a small device attached to the object—emits identification data through radio waves in response to a query by an RFID reader. This information is captured by the reader and then further processed. RFID technology has been increasingly employed as a 'barcode replacement' device due to the number of advantages that it offers. The RFID devices have been increasingly used in production lines and the logistics chain of enterprises and are starting to penetrate other sectors including, for example, medical and healthcare, defence and agriculture.

Governments around the world and industry itself have been keen promoters of RFID technology. All European Union (EU) Member States, the United States of America, Australia and many other countries are gradually deploying electronic passports. These new passports contain RFID tags that store personal data, including biometric data from the passport holder. This allows for semi-automatic authentication of people at borders. Credit-card-sized contactless smart cards are another example of an application based on RFID technology.[17] Such smart cards are becoming increasingly popular for access control. While some RFID-enhanced smart cards contain only identification numbers, other cards include additional cryptographic security features to protect the data during transmission. Sophisticated RFID-based devices not only identify, they can also be used to track people's location and activities.[18]

Whilst RFID tags have been commonly used for uncontroversial applications such as the supervision of stock and other animals for some time now, humans are increasingly coming to the fore. RFID implants that are introduced into the human body have already been commercialised; such implants were specifically designed to facilitate the identification and authentication process. RFID implants for identification and authentication of people provide some potential advantages compared to other established methods. The identification process is, for example, fully automatic and convenient: no typing or confirming of information, no remembering of password or carrying a token. Moreover, there is no need neither for the person to clean their hand(s) before putting it under the fingerprint scanner, nor having to stand still as they would have to do if they were having an iris scan done. Identification and authentication with an RFID implant is practically immediate; there is no loss of time associated with, for example, the typing of a password, for acquiring and matching of biometrics or for taking a smart card out of a wallet.

It can be argued that implants are also an extremely reliable method of identification, especially compared to biometrics, which—due to the statistical nature of their matching process—cannot guarantee error-free results.[19] While implants

[17] For example see Mifare, http://www.mifare.net.

[18] Smith et al. 2005, p 39.

[19] See for more detail FIDIS deliverable D6.1 'Forensic Implications of Identity Management Systems' and D3.10 'Biometrics in identity management'.

may require replacement during a person's lifetime, they are considered more durable than tokens and many types of biometrics, which usually change due to ageing. Unlike tokens, implants cannot be lost or stolen (unless an attacker extracts the implant). RFID implants can be used by everyone without exception, including people with cognitive impairment. The user will always be identifiable, even if they are unconscious or not carrying any identity documents.

Commercial RFID implants for people are best described as 'passive tags'—i.e. they do not require built-in batteries but operate by making use of the energy emitted by the external RFID reader. As a result, and since they have no moving parts, once implanted under the skin they can be operational for more than a decade. Some manufacturers have even made the claim that they will be operation for more than 40 years.

Their extremely small size and lack of any internal power source does however limit the devices' performance in terms of memory, processing power and communication range. These hardware limitations make it difficult to design RFID implants with advanced authentication methods. The limited communication range, is not necessary a drawback; it may also be an advantage from a security and privacy point of view.

The first recorded human RFID implantation occurred on Monday, 24 August 1998, when a groundbreaking experiment was conducted by Prof. Warwick's group at the University of Reading in the UK. At the heart of this work were the sub-dermal implantation of an RFID tag and the augmentation of the infrastructure at the university's Department of Cybernetics with RF nodes such that the system was able to track him, via the tag, as he roamed the building. The possibilities using this technology were, even at that time, not greatly limited, however the system was restricted to simple profiling of his behaviour. From this, automated customisation of his environment was possible, such as unlocking doors, turning on lights and brewing his coffee on arrival.

While the public response to this work was varied, from suggestions that this was the work of the devil,[20] to awe of the technological possibilities, acknowledgement of the prophetic merit largely mirrored that of academic musings on the scientific value. Few could appreciate the idea that people may actually be open to having such devices implanted if there was some net benefit in doing so. Equally, few entertained the realisation that, at that time, RFID technology was on the cusp of becoming cost effective enough to essentially become ubiquitous.

Some 6 years later, implantable identifying RFID tags were commercialised by 'VeriChip' and approved by the FDA in the USA for human use (for more discussions regarding the VeriChip, see Chap. 3 of this book). It was proposed that

[20] Revelation 13:16–18 "He [the beast] also forced everyone, small and great, rich and poor, free and slave, to receive a mark on his right hand or on his forehead, so that no one could buy or sell unless he had the mark, which is the name of the beast or the number of his name". Such scaremongering is in keeping with the flawed logic which demonstrates that the common barcode contains a hidden '666', e.g. as described by Relfe in her 1982 book "The New Money System: 666".

Fig. 2.2 An individual with two RFID implants: His left hand contains a 3 by 13 mm EM4102 glass RFID tag that was implanted by a cosmetic surgeon, his right hand contains a 2 by 12 mm Philips HITAG 2048S tag with crypto-security features, implanted by a GP using an animal injector kit (Graafstra 2007, p 18.)

these devices could essentially replace 'medic alert' bracelets and be used to relay medical details when linked with an online medical database. Such devices have subsequently been used to allow access to secure areas in building complexes, for example the Mexican Attorney General's office implanted 18 of its staff members in 2004 to control access to a secure data room, and nightclubs in Barcelona, Spain and The Netherlands use a similar implantable chip to allow entry to their VIP customers, and enable automated payments. By 2007, reports of people implanting themselves with commercially available RFID tags for a variety of applications became a familiar occurrence (see, for example, Fig. 2.2). The broad discussion on security and privacy issues regarding mass RFID deployment has since picked up pace, and security experts are now specifically warning of the inherent risks associated with using RFID for the authentication of people.[21]

Whilst the idea that RFID can be used to covertly track an individual 24-7 betrays a fundamental misunderstanding of the limitations of the technology, there

[21] RFID technology is still in its infancy and resource-constraints in both power and computational capabilities make it hard to apply well-understood privacy protection techniques that normally rely heavily on cryptography. For instance, a 'man-in-the-middle' attack would make it possible for an attacker to steal the identity of a person (i.e. tag identifier), while widely published techniques for RFID tag cloning make utilising this information technically feasible.

Fig. 2.3 An RFID tag is injected into the left hand of the author by a surgeon (*left*), shown in close up (*top right*). Two X-ray images taken post-procedure (*bottom right*) show the position of the tag in the hand near the thumb

are genuine concerns to address. The use of implanted RFID tags in this scenario is especially thwart with issues because being implanted forms a clear, permanent link with the individual and makes compromised tags hard to revoke.

In the early applications as an implantable device, RFID tags had very simple functionality—the ability to broadcast a fixed unique identifier over a short range on request. While largely deployed for animal identification, the implantable tags commercialised for human use had the same function—an identifier which could be cross-referenced with a database that held all other information. However, the core technology has continued to develop, and although non-implantable RFID devices in general remain more advanced than implantable, glass capsule types, these too continue to evolve which opens up new possibilities, and new issues. To further explore this, the earliest experiments with an implanted RFID device conducted in 1998 were revisited after ten years using the latest in implantable RFID technology.

On 16 March 2009, the author had a glass capsule HITAG S 2048 RFID device implanted into his left hand, as illustrated by Fig. 2.3.[22] While containing a 32-bit unique identifier number, similarly to older devices, the device also has a 2048-bit

[22] Gasson 2010, p 61.

read/writable memory to store data and the option of 48-bit secret key based encryption for secure data transfer. These are clear advances over the older implantable technology, which could only broadcast a fixed identifier, and enable new applications to be realised. As in the 1998 study, the tag was used as an identification device for the University of Reading's intelligent building infrastructure. A mobile phone was also augmented with a reader such that only the user with the correct tag could use the phone. In the 1998 study, simple profiles were constructed of users of the building, based on tracking their movements and preferences, which were stored on a central database.

Because data can be stored on the latest generation of implantable tags, in a modification, this profile information was stored both in the building's database and on the implanted HITAG S tag such that the user could enter a new building, which could then access the profile data. Updates to the profile were generated centrally, and written to the tag if it needed updating. While this is seemingly a useful extension to the original system, it comes coupled with new threats.

In 2006, researchers from Vrije Universiteit in Amsterdam demonstrated how commercially available RFID tags could be used to spread malicious computer code.[23] In order to do this the devices required the ability to store data and interact with a potentially vulnerable database system. To demonstrate the concept, a large form factor RFID sticky label tag was infected with a piece of malicious code and used to contaminate a database. However, despite the provocative paper title practically all implantable RFID devices at that time, typically being only readable or of very low data storage capacity, were not actually vulnerable to this. However, four years later as a proof of concept, the implanted HITAG S tag was successfully infected with malicious code containing a computer virus.[24] Because of the way the malicious code had been written, instead of simply reading data from the implanted tag to store in the database, the system also executed some SQL injection code, overwriting in the database valid data by a copy of the virus in such a way that any tag subsequently using the system will likely become overwritten and infected. A feature of a computer virus is that is must have the ability to self-replicate, and this is evident here. Having corrupted the database contents in such a way to allow replication, there is a further 'payload' (some additional malicious activity) associated with the virus. Administration of the database is typically done through a web browser, and once the system is infected the web browser is redirected to another website, denying easy access to rectify the problem. More potentially harmful payloads have previously been demonstrated[25] including enabling unauthorised system access.

Concerns for those who have decided to have an RFID tag implanted are valid, although an assumption is that such procedures will never become compulsory and so most people will remain unaffected. However, while mass deployment of RFID

[23] Rieback et al. 2006, p 169.

[24] Gasson 2010, p 61.

[25] Rieback et al. 2006, p 169.

technologies is well documented, especially in the context of commerce, it should be noted that, through non-nefarious means, it is possible that people could become implanted with RFID unknowingly. This is mostly related to safety issues regarding passive medical devices, such as hip replacements and breast implants, whereby being able to determine the exact manufacturing details non-invasively could be advantageous. This is especially valuable when manufacturing faults are subsequently discovered and devices of unknown provenance have been used. Thus, embedding an RFID enabled device in a unit before it is surgically utilised would enable this function. Further, following the polemic on silicone-gel breast implants[26] which resurfaced with a vengeance in early 2012 following a global health scare triggered by unapproved materials being used in Poly Implant Prothese (PIP) breast implants,[27] a device based around RFID technology, designed to be located inside the breast, which detects rupture has been developed, and many are investigating the benefits of being able to non-invasively monitor the condition of a medical device, such as a heart valve, using this type of technology. However, all these applications result in the wider issue of having RFID implanted.

Exact numbers of those who have received this type of low-tech implantable technology are not known, but it is clear that the figure is rising, and, with familiarity, public acceptance will surely grow. Because such uses of the technology were largely dismissed as improbable from the outset, a lack of timely debate on the wider implications means that we are now faced with the prospect of addressing them whilst the technology gets a foothold. Not least of all, this certainly leaves some open questions which technologists must now address. It is not hard to imagine that dealing with technical and wider issues retrospectively will be immensely more difficult. The potential application areas for implantable RFID are further explored in Chaps. 3 and 4.

2.3 Where Restorative Meets Enhancement

The relatively new trend for having passive RFID implants has recently risen in the public consciousness, although less publicised developments of high-tech implants in the medical domain have been progressing for several decades. Indeed, a significant drive behind the development of implantable devices is medical—i.e. restoring deficient abilities in humans. Given this, there are two clear routes by which technology developed for restorative application may ultimately lead to enhancement. The first is that it is conceivable that a piece of technology designed as a restorative device may actually give the recipient a capability which exceeds the normal human ability it is designed to replace. For example, advances in cochlear implants may result in the recipient having vastly improved hearing over

[26] Kessler 1992, p 1713.

[27] http://www.bbc.co.uk/news/health-16391522. Accessed 05 January 2012.

that of a normal human that could then be considered enhancement. The discussion in this context has begun on the topic of prosthetic limbs.[28] There are, however, no clear examples relating to implantable technology to date, although Moore[29] describes the case of a patient with an artificial heart who found he could use the device to lower his heart rate to help falling asleep.

The second is the application of implantable technology, developed initially in a medical context, to augment the abilities of healthy humans. Reports of this pioneering step are rare, although in a notable echo of 1998, the University of Reading in the UK has been active in this area. On March 14th, 2002, an array of 100 individual needle electrodes was surgically implanted into the median nerve fibres of the left arm of Professor Kevin Warwick, a healthy volunteer,[30,31](see also[32] for a personal account). This study demonstrated, in a rudimentary fashion, a range of applications, from nervous system to nervous system communication, feedback control of robotic devices and augmented sensory capabilities.

To date, there are no studies involving implantation in the central nervous system of healthy volunteers that have been well reported. There is, however, some largely anecdotal evidence of the occasional positive side effect that DBS has had in patients. In one such case, a graphic designer, who received DBS surgery for a severe Tourettes disorder, found that stimulation through one specific electrode could actually make her more creative. Indeed, when this electrode was used, her employer noted an improvement in colour and layout in her graphic design work.[33] The application of this type of effect in the long term clearly cannot be discounted, and so nor can the translation of medical devices to enhancement. Indeed, the ability to form direct, bi-directional links with the human brain will open up the potential for many new application areas. Scientists have indicated for some time that a human/machine symbiosis—a physical linking of the two entities such that humans can seamlessly harness the power of machine intelligence and technological capability—is a real possibility. The typical interface through which a user currently interacts with technology provides a distinct layer of separation between what the user wants the machine to do and what it actually does, which imposes a considerable cognitive load. The main issue is interfacing the human motor and sensory channels with the technology in a reliable, durable, effective, bi-directional way. One possible solution is to avoid this sensorimotor bottleneck altogether by interfacing directly with the human nervous system. While still in its infancy, scientists predict that within the next

[28] Camporesi 2008, p 639.

[29] Moore 2008.

[30] Gasson et al. 2005b, p 365.

[31] Warwick et al. 2003, p 1369.

[32] Warwick 2002.

[33] Cosgrove 2004.

30 years neural interfaces will be designed that will not only increase the dynamic range of senses, but will also enhance memory, enable "cyberthink"—invisible communication with others and technology[34] and increase creativity and other abstract facets of the human mind.

2.3.1 Human Enhancement and Bodily Boundaries

While being a clear demonstration of how implantable devices are becoming more complex, capable and potentially vulnerable,[35] being susceptible to malicious attack, e.g. a computer virus, also raises interesting questions linked to the concept of the body.

As functions of the body are restored or further enhanced by implanted devices, the boundaries of the body become increasingly unclear. Previous recipients of RFID implants echo the sentiments of many cochlear implant and heart pacemaker users—the implant becomes perceived as being part of the body.[36] That is, what the user understands to be their body includes the technological enhancement. In essence, the boundaries between man and machine simply become theoretical. This development in our traditional notion of what constitutes our body and its boundaries leads to two notable repercussions here. Firstly, it becomes possible to talk in terms of a human (albeit a technologically enhanced human) becoming e.g. infected by a computer virus. Thus, in that light, the simple experiment conducted by the author's group in 2009 gave rise to the world's first human to be infected by a computer virus. Secondly, this development of our concept of the body impacts on certain human rights, in particular the right to bodily integrity. Bodily integrity constitutes a right to do with one's body whatever one wants (a right to self-determination) and it implies the right to prevent one's body from being harmed by others. In this context, a computer virus infecting an implanted device constitutes an infringement on the right to bodily integrity. These issues are further considered by Roosendaal in Chap. 8. A number of wider moral, ethical and legal issues stem from applications of these technologies,[37,38,39]and it is difficult to foresee the social consequences of adoption long term which may fundamentally change our very conception of self and sense of identity. It is clearly timely to have further and rigorous debate regarding the use of implantable technology in individuals for human enhancement.

[34] McGee and Maguire 2007, p 291.

[35] Maisel and Kohno 2010, p 1164.

[36] Warwick 2003, p 131.

[37] Rodotà and Capurro 2005, p 18.

[38] Hansson 2005, p 519.

[39] Kosta and Gasson 2008.

2.4 Terminology and Crucial Distinctions[40]

For a proper understanding of the wide scope of human implants we will briefly discuss the different types of implants and their different functions. Technological implants are often used to restore bodily functions, as in the case of cardiac pacemakers or deep brain stimulation (see Chap. 4). Moreover, entirely different uses can be envisioned, like monitoring of biological functions to enable real time diagnostics or the identification of clients or patients in order to grant them a right of access or to streamline the information system of healthcare institutions. The most imaginative usage of human implants is human enhancement or the creation of human–machine hybrids that challenge our notion of what it is to be human and raise the issue of who is in control: software programmes, the individual human mind of whoever 'has' or 'is' the implant, or the data controller who holds the remote control.

Due to the different affordances of distinct types of implants in the human body, and the different consequences they may have, we will discriminate between:

1. Implants that aim to *restore* or *repair* human capabilities
2. Implants designed for the *diagnosis* of a biological state
3. Implants that *identify* a person in order to e.g. provide access to certain locations, information or knowledge, or to automatically pay/bill for services rendered
4. Implants that aim to *enhance* human memory, vision, auditory perception, alertness or other human capabilities

Technically, we will discriminate between:

1. *Active* implantable devices which can function using an internal power source, and *Passive* implantable devices which depend on power supplied to it remotely
2. *Online* ICT implants that rely for their operation on an online connection to an external computer and *Offline* or stand alone ICT implants that can operate independently of external devices

2.5 Conclusion

For many years it has been all too easy to dismiss the idea of implanting technology in our bodies to enhance our abilities as science fiction and simply improbable. To many, violating their bodies in such a way is unthinkable regardless of the (albeit seemingly unrealistic) benefits it may bring. While the layperson holding this position is to some degree understandable, surprisingly it

[40] This section was written by Mireille Hildebrandt.

has also taken the wider academic community some time to agree that meaningful discourse on the topic of human implantable ICT technology is of value. Indeed, the term ‘cyborg’ (a blend of cybernetic and organism) was until very recently largely met with derision. This chapter has sought to highlight in what ways this scenario is evidently a very real possibility.

Advances in medical technologies are notoriously slow in coming, not necessarily because the enabling technology does not exist, but largely due to the safeguards surrounding their efficacy, safety and commercialisation. Equally, there is a substantial gap in our combined knowledge regarding how the human body, and in particular the brain, actually functions on a low level. As research and new instrumentation, such as medical imaging technology, allows us unparalleled access to the fundamental workings of the body, and gives hints as to how the abstract components which form our complex personalities manifest; we will find new ways to apply technology to manipulate them. Already familiar implantable medical technology exists which is designed to interact with the human body on an intimate level. The capabilities of cardiac pacemakers, which include wireless communication, far exceed most people’s expectations, and deep brain stimulators, which are implanted in their thousands globally every year, interact directly with the brain. The use of these devices is tantamount to having a computer system implanted in the body and this, and the issues it brings, is described further in Chaps. 4 and 6 using a sample of state-of-the-art medical devices. It is clear, especially as new medical applications are found, that many of us will evidently end up with some sort of implanted piece of computing technology at some point in our lives.

Developments in implantable medical technologies also point to greater possibilities for human enhancement. Here there are two distinct routes by which this may happen. Restorative technology aims to repair or ameliorate some form of deficient functionality, with most implantable medical devices falling into this category. However, the device could well give the user functionality which out performs the ‘normal’ range, or has additional functional elements. Consider a retinal implant which gives someone their sight back, but in a form that is twice as efficient as the human eye, and with an augmented display for additional information. This is a form of human enhancement. Interesting questions then arise as to whether a person with ‘normal’ vision should then be able to ‘upgrade’ themselves using this technology. Indeed the desire for people with no medical need looking to harness the opportunities presented by medical technologies is the second route by which human enhancement can be envisaged. If, for example, deep brain stimulator technology can be repurposed to give better memory, more creativity, a different sense, or a new form of communication, then surely a market for this will appear. It may well be that the benefits of whatever is achievable, and that we can only begin to imagine, will mean that in reality there is no real option to having it. There are obvious parallels here to the wide uptake of technologies such as mobile phones, computers and use of the internet.

The foundation for the novel deployment of technologies grounded in medical devices has been set by the willingness of self-experimenters to push the boundaries. The more advanced and invasive examples of these have largely been in the academic research domain, but the recent phenomenon of even basic RFID implants for a variety of applications is also a hugely important milestone in this evolution. It is clearly impossible to discount the use of invasive, implantable technologies for human enhancement, and acknowledgement of this as fact is of utmost importance as we consider how we may need to deal with the host of changes and challenges it will bring.

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Springer
http://www.springer.com/978-90-6704-869-9

Human ICT Implants: Technical, Legal and Ethical Considerations
Gasson, M.N.; Kosta, E.; Bowman, D.M. (Eds.)
2012, XXII, 186 p., Hardcover
ISBN: 978-90-6704-869-9
A product of T.M.C. Asser Press