Prosthetics

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In a narrow sense, prosthetics is a branch of medicine, specifically of surgery, concerned with the replacement of missing body parts (upper and lower limbs, and parts thereof) after amputation. It is related to orthotics, a branch of medicine that deals with the support of weak or ineffective joints or muscles using supportive braces and splints. In dentistry, prosthetics or prosthodontics is that branch concerned with the replacement of missing teeth and other oral structures. In this narrow sense, a prosthesis is a replacement artificial limb or tooth. In a broader sense, *prosthesis* is the name for any artifact used to restore bodily functions, and *prosthetics* is the field concerned with the development and fitting of artificial body parts, which is the sense at issue here.

Approaches to Prosthetics

Prostheses in this broad sense are an important focus of the relatively new field of bioengineering, or biomedical engineering, which is concerned with the application of engineering techniques to medicine and the biomedical sciences. Bioengineering is itself a broad field, with applications ranging from molecular imaging tools to medical radiation devices. The development of prosthetic techniques and devices is only one of its interests.
Several areas in bioengineering have special relevance to prosthetics. Rehabilitation engineering is an area concerned with ameliorating the impairments of individuals with disabilities. It includes prosthetics and orthotics as defined at the beginning of this entry, but also addresses other disabilities, specifically sensory and speech impairments. It does not address functional impairments in internal organs, however. Other relevant areas include tissue engineering, which involves the repair or replacement of organic cells, tissues, or organs with laboratory-grown biological substitutes; biomaterials engineering, which aims to develop synthetic or natural materials that can replace or augment tissues, organs, or bodily functions; biomechanics, which studies the human musculoskeletal system and its mechanical aspects and includes

artificial limb and joint design; cardiovascular engineering, which studies the cardiovascular and blood system and develops techniques and systems for diagnosis, intervention, therapy, and replacement; and neural engineering, which studies the nervous system and develops means to repair or replace damaged and non-functioning nerves and sensory systems. Neuroprosthetics is a rapidly growing subfield of neural engineering that aims to develop devices or systems that communicate with nerves to restore functionality of the nervous system.

Although research in prosthetics and bioengineering is primarily aimed at restoring damaged human functions, there has been a growing interest in the augmentation of human functions. Human augmentation or enhancement is a relatively new field in bioengineering directed at developing prosthetic devices that augment normal function or prevent injury to function.

Together with artificial intelligence and robotics, bioengineering is the successor of bionics (a conflation of *biological electronics*), which emerged in the 1950s with the aim of using biological design principles to create novel technological devices and mechanical substitutes for the extension of biological organs. Bionics is specifically concerned with the development of bionic devices or bionic implants, which are electromechanical devices that do not merely replace a body part but also closely mimic or surpass the behavior of a replaced organ, and that are often able to communicate with the nervous system. To attain its aims, bionics relied on a feedback-control framework that was provided by cybernetics, the science of communication and control in animal and machine. Cybernetics has been partially superseded by systems theory, a field that studies the general principles underlying the organization of systems of any kind. Cybernetics has yielded the term *cyborg,* a conflation of *cybernetic organism,* meaning an organism that is part human, part machine. A cyborg is an individual whose biological functions are aided or controlled by technological devices, particularly by bionic implants.

A large number of human biological functions can be restored or improved with the aid of prostheses. The list of implants and related devices is extensive:

- artificial limbs, including robotic ones and ones with sensory feedback to the body
- artificial joints, hips, and vertebrae
- artificial muscles made of polymer
- artificial skin used to promote healing
- artificial bone used to help heal fractures and replace diseased bone
- bracing systems, cervical implants, and spinal cages to support the spine
- silicone or plastic implants to build bony structures of the face
- breast implants
- penile implants
- dental implants and false teeth
- speech synthesizers and artificial larynxes to restore speech
- retinal implants (experimental), intraocular lenses, and artificial corneas to restore vision

- cochlear implants that replace the inner ear and involve a microphone, speech processor, and wiring to the nervous system
- artificial nerves (experimental)
- cardiac pacemakers, defibrillators, artificial heart valves, and heart-assist pumps
- artificial hearts (experimental)
- artificial blood vessels and urological systems
- artificial blood (experimental)
- implanted drug-delivery systems (experimental)
- artifical tracheas
- electrodes implanted in the brain to control seizures or tremor
- implanted chips to locate persons or to regulate devices in "intelligent environments"
- orgasmatrons (implants for women that produce orgasms; experimental)
- artificial ovaries for in vitro maturation
- spinal neuroimplants with handheld remote control to block pain signals
- motor neural prostheses based on functional electrical stimulation systems, which stimulate motor nerves for movement, respiration, and bladder function
- artificial hippocampi in the brain (experimental)

Research is underway on bioartificial livers, kidneys, pancreases, lungs, and other organs, as well as on more advanced neural prostheses to restore functions of the brain and nervous system. In recent year, there has been much interest into the possibility printing bioartificial tissues and organs using 3D-printing.

In recent years, major advances have been made in the development of brain-computer interfaces (BCIs). BCIs are neuroprosthetic devices in which the brain interfaces with a computer system through a direct communications pathway. BCIs exist in in invasive, partially invasive and non-invasive forms. Invasive BCIs are implanted into the grey matter of the brain, partially invasive ones are implanted in the skull outside the brain, and noninvasive ones are located outside the skull and use neuroimaging techniques to pick up brain signals. Applications of BCI technology are in the restoration, assistance, and augmentation of human cognitive, sensory and motor functions. BCIs have restored sigth, hearing and communciation abilities in patients, and are also used together with robotic devices to give paralyzed patients motor control. BCIs have also been used to improve abilities in healthy people like playing computer games.

Anthropological Theories

Most philosophical and anthropological theories that refer to the notion of prosthesis are not so much concerned with understanding prosthetic technologies as normally defined but with an understanding of technology in general by means of the concept of prosthesis. Prosthesis is used as a metaphor to understand technology and its relation to human beings. In prosthetic theories of technology, which have been proposed since at least the late nineteenth century by a variety of different authors, it is claimed that there is no essential distinction between prosthetic and other technologies, because all technologies in some way aim to replace or augment aspects of human functioning. This view has been proposed by, among others, Marshall McLuhan (1911–1980), Henri Bergson (1859–1941), Arnold Gehlen (1904–1976), Ernst Kapp (1808–1896), and Lewis Mumford (1895–1990).

According to the prosthetic view of technology, every technological artifact or system extends the human organism in that it takes human faculties outside the body, thus amplifying already present abilities. The body is itself a toolbox that its owner uses to do things in the world. Technical artifacts serve to replace, extend, or augment tools in this organic toolbox. Weapons and tools such as bows, knives, and saws are extensions of human hands, nails, and teeth; clothing extends the heat control and protection functions of the skin; the wheel extends the mobility functions of the legs; bags extend the ability of the hands and arms to carry things; the radio and telephone extend hearing; television and photography extend the visual function; writing and print media extend human language and memory functions; and the computer extends a large variety of human cognitive functions. Prosthesis, in the narrow sense, is therefore only an instance of the general ability of technology to extend or replace functions of the human organism, and all technologies should be understood in terms of their relation to human functioning.

Even if this view is correct, it is recognized by many authors that all artifacts do not extend the human organism in the same way. Some technological artifacts have a symbiotic relation to the body, whereas others function independently. A relevant distinction seems to exist between artifacts that serve as direct extensions of human functioning by engaging in a symbiotic relationship with human limbs, senses, or other body parts, such as telescopes, glasses, hammers, and canes, and those artifacts that operate separately from the body and are themselves the object of interaction or perception, such as dinner plates, stereo systems, and computer screens. Phenomenologist Don Ihde (1990), drawing on the work of Maurice Merleau-Ponty (1908–1961), argues that humans are able to engage in embodiment relations with some artifacts, which are incorporated into the body schema or body image, meaning that they are integrated with the image that human beings have of their own sensorimotor abilities—an image that defines them as agents and separates them from a world that is to be engaged. (Other artifacts remain separate and subject to interpretative or hermeneutic relations.) Embodiment relations have found support in psychological studies of body schemas.

Cyborg Theories

Cyborg theory or cyborgology—the multidisciplinary study of cyborgs and their representation in popular culture—provides another perspective on prosthetics. Studies in cyborg theory tend to use the notion of the cyborg as a metaphor to understand aspects of contemporary—late modern or postmodern—relationships of technology to society, as well as to the human body and the self. In cyborg theory, the notion of cyborg refers to hybrid organisms in science fiction (e.g., *The Six Million Dollar Man*, *RoboCop*, *X-Men*, *Star Trek*'s The Borg), contemporary human beings with prostheses or implants, as well as (contemporary) human beings in general, who are all conceived as cyborgs in the sense of being inherently dependent on technology.
The advance of cyborg theory as an area of academic interest has been credited to Donna Haraway, in particular to her 1985 "Manifesto for Cyborgs." In this essay, Haraway presents the cyborg as a hybrid organism that disrupts essentialist presuppositions of modern thinking, with its black-and-white dichotomies of nature–culture, human–animal, organism–technology, man–woman, physical–nonphysical, and fact–fiction. Cyborgs have no preexisting nature or stable identity, and cut through oppositions because of their thoroughly hybrid character. Haraway holds that modernity is characterized by essentialism and binary ways of thinking that have the political effect of trapping beings into supposedly fixed identities and oppressing those beings (animals, women, blacks, etc.) who are on the wrong, inferior side of a binary opposition. She argues that the hybridization of humans and human societies, through the notion of the cyborg, can free those who are oppressed by blurring boundaries and constructing hybrid identities that are less vulnerable to the trappings of modernistic thinking.
According to Haraway and other authors such as N. Katherine Hayles (1999) and Chris Hables Gray (1995), this hybridization is already occurring on a large scale. Such hybridization is a consequence of the transition since World War II from an industrial to an information society, as a result of technological advances in biotechnology, information technology, and cybernetics. In the new world order that is ensuing, boundaries are constantly blurring, and linguistic categories and symbols increasingly reflect this fact. Many basic concepts, such as those of human nature, the body, consciousness, and reality, are shifting and taking on hybrid, informationalized meanings. In this postmodern, post-human age, power relations morph, and new forms of freedom and resistance are made possible.
Sharing the positive outlook of cyborg theorists on the technological transformation of human nature, but otherwise quite distinct from it both politically and philosophically, transhumanism is a recent school of thought or movement that advocates the progressive transformation of the human condition through technological means. Its early inspirational source was FM-2030 (formerly, F. M. Esfandiary) , a futurist who wrote on the notion of the transhuman in the 1970s and 1980s, while its current main organizing body is the World Transhumanist Association, cofounded in 1998 by Nick Bostrom and David Pearce. Transhumanists want to move beyond humanism, which they commend for many of its values, such as its orientation toward reason and science, its commitment to and belief in progress, and its rejection of faith and worship, but

which they fault for a belief in some fixed human nature. Transhumanists want to use modern technology to alter human nature in order to augment human bodily and cognitive abilities and extend human life. They see converging developments in genetic engineering, biomedical engineering, artificial intelligence, nanotechnology, and cognitive science as transcending human nature, thus leading humanity to a transhuman or posthuman condition. They argue that this development should receive full support, because of its potential to enhance human autonomy and happiness and eliminate suffering and pain, and possibly even death.

Ethical Issues

The research, development, application, and use of prostheses and implants raise a number of ethical issues relating to health and safety, distributive justice, identity, privacy, autonomy, and accountability. Special ethical issues are raised by human augmentation or enhancement research.

HEALTH AND SAFETY. The functioning of a prosthesis for the remainder of someone's life cannot be predicted reliably on the basis of a few clinical trials with human subjects or tests with animals. There is a real risk, therefore, that people will be fitted with prostheses or implants that malfunction, have harmful side effects, or are even rejected by the autoimmune system. Negative experiences with silicone breast implants and artificial hearts have already shown the body's resistance to technological interventions. Ideally, prostheses would be tested over many years, decades even, and involve a large number of human subjects. But such extensive clinical trials and experimental uses are often considered too lengthy and costly and raise ethical issues by making guinea pigs out of human beings. Tests on animals often cannot serve as a substitute, while raising ethical issues of their own.

JUSTICE. The development of increasingly sophisticated prostheses and implants presents issues of distributive justice: Will there be a division between biological haves and have-nots? Will there be a division between those who receive no prosthesis or a low-quality or high-risk one and those who receive the best medical care? Do people have a moral right to a replacement part for a malfunctioning organ, when such parts exist? And will all be able to obtain implants that are attuned to their biological characteristics and lifestyle? In a 2003 incident in the United Kingdom, a black woman with an amputated foot was told that she would have to be fitted with a white prosthetic limb unless she paid an additional £3,000 (U.S.$ 5,500) for a black one. Although this is an obvious instance of discrimination, the situation is not always so clear. Who, for example, should pay the extra costs when a person has mild allergic reactions to a prosthesis and demands a much more expensive version that will not cause such reactions? Do producers have a duty to develop special prostheses for people whose biological features do not fit the norm, and should they be able to charge extra for those?

IDENTITY. Acquiring a prosthesis requires people to come to terms with the fact that a part of their body is artificial, and that they are dependent on a piece of technology for their biological functioning. This may be even more of an issue with bionic and neuroprosthetic implants, which may display or induce behaviors only partially controllable, with which one may thus find it hard to identify. Even more so, cognitive prostheses, which are neuroprostheses that aid cognitive function, may be developed in the future, and these may undermine identity even more directly as they directly interface with the mind. Some critics of prostheses have argued for the integrity of the human body, with all its defects and flaws, and worry that as humans increasingly become cyborgs, the essence of humanity will be lost. Social identity may be at issue as well. A particular controversy has arisen over cochlear implants; deaf advocates have argued that they may place children in between the deaf world and the hearing world, and that they may end up destroying the deaf community with its rich history and culture.

PRIVACY. Privacy issues are at stake when implants process or store information or emit identifying signals that can be registered from a distance. Implantable chips for tracking, already common in pets and livestock, are also being considered for children and adults, and they make it possible to trace individuals over long distances. Sensory and neuroprosthetic devices and prostheses equipped with biosensors process and sometimes store information about people's biological states, behaviors, and perceptions that may be accessed by third parties. Brain-computer interfaces transmit and store information about people's cognitive processes which is privacy-sensitive.

AUTONOMY. Prostheses can clearly enhance individual autonomy by restoring functions, but it has been argued that they can also reduce it. Having a prosthesis means being intrinsically dependent on technology. A prosthesis also creates dependence on others for maintenance, diagnosis, and testing. Bionic and neuroprosthetic implants may not even leave their wearer in complete control of their actions or thoughts.

ACCOUNTABILITY. Bionic and neuroprosthetic implants may raise issues of accountability, because the behavior or cognitive processes of their wearers will be determined in part by the workings of machines. If such individuals cause accidents or make bad decisions, who is to blame: they or their implants?

ETHICAL ASPECTS OF HUMAN AUGMENTATION. The field of human augmentation or enhancement raises a number of special ethical issues in addition to the ones already mentioned. Is it ever morally permissible to destroy or impair healthy human tissue or organs to fit an augmentation, considering that this destruction may be irreversible? Can an employer require an employee to have enhanced functions, or put a premium on the possession of such functions? Human augmentations is still a young field, and questions of this sort have mainly been raised in relation to cosmetic surgery, which can be understood as a special type of human augmentation with the purpose of enhancing aesthetic rather than functional qualities. Specifically, breast implants intended to create bigger breasts—as opposed to restoring breasts after a radical masectomy—have created controversy because they have been argued to be "unnatural" and to involve health and safety risks that cannot be justified by reference to their subjective aesthetic value. If certain augmentations become popular, there is also a risk that they will become accepted as the norm and people without them will be seen as cripples. To an extent, this is already happening with breast implants and other cosmetic surgery in some communities, but it may also happen with prostheses that enhance perceptual, motor or cognitive functions.

A large part of the debate on human augmentation, finally, has focused on military applications, specifically the possibility of creating supersoldiers. But should military research be devoted to the creation of a supersoldier, involving implants, steroids, amphetamines, genetically altered muscles, integrated weaponry, and lightning-fast artificial nerves?

Many parts of the human body can already be replaced by prosthetic devices, and revolutionary developments in bioengineering are rapidly expanding the reach of prosthetics. Biomedical engineers and medical specialists have a special, professional responsibility in dealing with the ethical issues that arise as a result, as they are primarily responsible for the development and fitting of prostheses. Many ethical issues also need to be addressed at the level of legislation and public policy. Special moral concerns are raised in the areas of human augmentation or enhancement and neuroprosthetics.

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