Biomimetics and Its Influence in Plastic and Reconstructive Surgery

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Abstract The term “biomimetics” has evolved from technical achievements based on principles found in nature. Some of its general features are found in the four areas of plastic and reconstructive surgery: reconstruction, burns, hand and aesthetic surgery. A plastic surgeon mimics concepts of nature by transplanting tissue from one to the other side or rerouting tendons or muscles to another side in order to treat local or functional defects. In contrast, with biomimetics we try to implement principles and solutions from nature in order to form or create devices, materials or technical achievements which some of them can also help to restore human tissues, body parts or body functions. This article aims to highlight interfaces between biomimetic research and principles and practice of plastic surgery.

Keywords Plastic and reconstructive surgery · Biomimetics · Biomimicry · Tissue engineering · Bionic prothesis · Biomaterial · Sensors · Sensor networking

1 Introduction and Terminology

When we talk about *biomimetics* in general, we associate the term with technological achievements which have been developed based on principles found in nature. If we just take the term *biomimetics* from its old-greek origins into its parts, namely *bios*—βíος, which means *life* and *mimesis*—μíμησις, which means imitation, we realize that this term by itself comprises something much bigger.

The term *biomimetics* was formed by Otto Schmidt in the 1950s [1]. His work was influenced by his elder brother Francis, who was working as an assistant professor in zoology at Washington University und who was studying *the molecular organization of cells and tissues with particular reference to nerve fibres* [2].

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Otto Schmidt developed an electrical device in order to mimic *the formation and propagation of impulses along nerves* [2].

After the Second World War, Otto Schmidt was able to continue his research at the University of Minnesota, where he had his first appointment in 1939. By continuing his research on devices which would mimic natural systems, he claimed a different view towards biophysics as it was commonly perceived during that time:

> Biophysics is not so much a subject matter as it is a point of view. It is an approach to problems of biological science utilizing the theory and technology of the physical sciences. Conversely, biophysics is also a biologist's approach to problems of physical science and engineering, although this aspect has largely been neglected [3].

Whilst in the English literature the term *biomimetics* or *biomimicry* is being used, in the German language the term *bionics* is being employed synonymously. However, originally the term *bionics* was taken to describe the construction of body parts with a combination of biology and electronics, which is nowadays used to cover the field of implant technology e.g. for amputees.

The term *bionics* was officially made up by Jack E. Steele during a three-day conference on "Bionics symposium: Living prototypes—the key to new technology" in 1960 at the Wright Patterson Air Force Base [4]. Jack E. Steele was a member of the US Air Force with a background in general engineering, psychiatry and neurology, and by then was working as a researcher at the 6570th Aerospace Medical Research Lab. Steele defined bionics as:

> … the science of systems which have some function copied from nature, or which represent characteristics of natural systems or their analogues. [4]

Bionics is about the systematic recognition of solutions of living nature; it distinguishes itself from purposeless nature inspiration. Bionics is based on the assumption that living nature develops optimized structures and processes through the evolutionary processes from which humans can learn.

Besides of the terms *biomimetics* and *bionics*, the term *biomimicry* has also been introduced in the field by Janine Benuys in 1997 her book: "Biomimicry: Innovation inspired by nature", where she defines it as a "… *new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems*" [5].

So how does biomimetics connect to the field of Plastic and Reconstructive Surgery?

2 Principles and Practice of Plastic and Reconstructive Surgery

Plastic and Reconstructive Surgery is a relatively young surgical specialization with old roots based on four columns, namely reconstructive, aesthetic, burns and hand surgery. The main principles of plastic surgery are to restore and reconstruct form and function, often using the principle to “*replace like with like*”, but by implementing donor site morbidity when “*steal from Peter to give to Paul*”.

Historically, the first roots of plastic surgery can be traced back to the Edwin Smith Papyrus document, one of the oldest medical text of the ancient kingdom of Egypt around 3000–2500 B.C. containing descriptions of plastic repair of a broken nose and in India by Sushruta around 600 B.C for reconstruction of the nose by a cheek flap [6, 7]. The Sanskrit text was later translated into Arabic. In the sixteenth century, Antonius Branca and later the Italian surgeon Gaspare Tagliacozzi developed a concept of tubed and pedicled flaps for delayed transfer and reconstruction of the nose using tissue of the upper arm [8]. In the eighteenth century, the French surgeon Pierre-Joseph Desault used the term “plastic surgery” for a procedure to correct facial deformities [9].

The development of plastic surgery as a distinct surgical specialty was supported by the advances in local and general anesthesia in the late nineteenth century as well as the control of blood clotting via introduction of heparin in the early twentieth century [8, 9]. Johann Friedrich Dieffenbach was the first surgeon, who introduced ether narcotics in Germany (“Der Äther gegen den Schmerz” 1847). He and several surgical pioneers developed new methods such as free skin and fat grafting, scar release techniques such as z-plasties, local and pedicled flap surgery, facial reconstruction including nasal, ophthalmologic, ear, upper and lower lip or neck reconstruction and new advances in breast and body shaping techniques [8, 10–13].

Furthermore, the introduction of the operating microscope in the early 1920s together with microsurgical fine instrumentation and suture materials suitable for microvascular repair and neurosurgery was a milestone for the formation of the plastic surgery specialty [14].

The disabilitating injuries seen in World War I posed great challenges for surgeons of all disciplines such as Hippolyte Morestin, Harold Gillies, Erich Lexer, Varaztad Kazanijan, Hugo Ganzer, Christian Bruhn, Jaques Joseph and many others to initiate new ideas and ways to reconstruct mutilated faces, burned bodies and restore functional deficits resulting from traumatic amputations of extremities [11]. These achievements resulted in the foundation of plastic and reconstructive surgery as an autonomous surgical specialty.

Anatomical studies by Carl Manchot in 1898 about the skin arteries of the body and by Michel Simon in the 1930s using lead injection for radiographic studies of the skin and muscle arterial supply founded a basis for planning and design of tissue and muscle flaps [15, 16]. However, in the beginning of the twentieth century, the knowledge resulting from these studies was not well-known in the surgical society. Moreover, the design of local flaps for wound coverage was more or less based on random pattern with a defined base-to-length ratio rather than on a defined vascular supply.

The concepts resulting from these anatomical studies were reinvestigated in 1987 by G Ian Taylor and J H Palmer by ink injections of skin and underlying tissues [17]. The results of their research lead to the concepts of angiosomes with a specific perforator source artery supplying a three-dimensional composite tissue framework and providing an arterial roadmap for incision planning and flap design [17].

With the introduction and refinement of the microscope for use in the operating room, microsurgical free flap transfers, peripheral nerve surgery and limb replantation and revascularization after traumatic amputation became common procedures and opened a new field of reconstruction possibilities to the plastic surgeon [7, 12–14]. Further technical refinements in microsurgery opened the way to modern lymphatic surgery and perforator flap surgery [18, 19].

Nowadays, composite tissue allograft transplantation procedures such as face or limb allo-transplantation offer new reconstructive options and challenges [20]. These new methods, however, require a well-structured interdisciplinary approach for preoperative selection of suitable candidates, surgical team performance and postoperative immunological therapy and follow-up [13, 20]. Besides the demanding technical aspects of the surgical procedure, the big obstacle though is to find a suitable donor that matches the immunological characteristics of the recipient in order to be able to replace "like with like". Furthermore, the adverse long-term side effects of the required immunosuppressive therapy and the major psychological impact of these procedures on the recipients need to be considered.

3 Biomimetic Strategies for Surgical Techniques and Practices

By looking at nature's principles, several "biomimetic" strategies can be defined which already have a place in surgical research and clinical practice. We can define the following four main strategies:

1. Strategies to mimic properties of natural tissues by altering structures and functional aspects of organic or synthetic materials.
2. Strategies to mimic biological processes such as wound healing or scar formation.
3. Strategies to mimic movements or mobility which can be found in the field of bioelectrical prosthesis development.
4. Strategies to mimic complex biological processes or nano-networks for bioinspired principles for network sensor systems.

4 Strategies to Mimic Properties of Natural Tissues by Altering Structures and Functional Aspects of Organic or Synthetic Materials

The first part is implemented in the field of bioengineering and biomaterial research. Structural or functional aspects of biological tissues are being imitated by applications of synthetic or organic materials for tissue replacement and implant technology. However, so far, there is not a single material which is able to fulfill all qualities of its biological role model. Basic properties of biomaterials such as surface structure, composition, architecture, porosity and stability, structure and shape of the material might influence cell adhesion, migration, proliferation, differentiation and survival. Furthermore, functionalization of biomaterials by surface coating, or addition of molecules, proteins, growth factors or phage display technology will further influence the biological answer after implantation of the material into the body [19–24].

Research from bone tissue engineering, nerve regeneration and skin replacement have already produced a variety of medical products. These biomimetic products are then being used by surgeons in order to repair or replace tissues or body parts which are destroyed due to trauma, tumor and degenerative processes.

4.1 Bone Replacement

Artificial bone substitutes have been made from mineral composites such as hydroxyl-apatite or calcium-phosphate (which are also present in the anorganic section of bone), from ceramic or metallic material (which are inert, but may resemble bone structure by their mechanical properties), from bio-glass (which offers an osteogenic surface structure) or based on bone's organic components such as collagen in the form of synthetic collagen foams or gels or based on other fiber materials such as woven synthetic silk mats to mimic the organic tissue fraction of bone tissue [25].

The ideal material for bone replacement should support *osteoconduction*, *osteoinduction* and *osteogenesis* [26, 27]. An *osteoconductive* graft supports the ingrowth of bone from the surroundings and therefore requires an internal porous structure as well as a surface which enables bone cells to adhere and migrate. An *osteoinductive* graft supports the differentiation of osteoprogenitor cells into osteoblasts and the formation of bone extracellular matrix. This information can be provided by the material stiffness, which can be seen, e.g. in ceramics or metals such as titanium. Components of bone anorganic extracellular matrix such as hydroxyapatite or calcium phosphate can also induce differentiation of osteoprogenitor cells. Several growth factors from the group of BMP's, FGF's, VEGF's and IGF's can be osteoinductive and also support osteogenesis, but for osteogenesis active stem cells or osteoprogenitor cells are required [25, 28]. External factors such as mechanical forces, shear stresses from fluid flow or reduced oxygen levels also influence the osteogenic process as well as the dialogue between different cell types during bone formation and remodeling. Despite major achievements of past research, we still have not yet accomplished the level of being able to grow biologically full functional bone in vitro with cortical and cancellous bone components and the whole range of different types of functional cells such as osteoblasts, osteoclasts, osteocytes, fibroblasts, nerval and vascular cells. Therefore, for bone replacement surgical techniques are being used such as non-vascularized or vascularized bone transfer or the Masquelet technique to support bone formation *in loco* e.g. by providing a periostal flap coverage [25, 27, 28].

For clinical use, cell-depleted and processed frozen bone allografts (demineralized bone matrix, DBM) are also available as medical products for implantation e.g. beta-tri-calciumphoshate or hydroxyl-apatite, which can be combined with bone marrow aspirate concentrate [28, 29].

4.2 Skin Replacement

Soft tissue loss may result from various causes, which are trauma, burns, infection, arterious or venous ulcers, autoimmune disorders, or after removal of tumor lesions. Such a soft tissue defect can simply include damage of the epidermal or superficial or deep dermal layer of the skin. When a skin defect reaches the deep dermal layer, the self-regeneration potential of the skin is impaired, since it arises from stem cells of the hair bulbs located in the deep dermal layer of the skin.

Autologous split skin grafting is usually required in order to achieve coverage of the defect. When huge areas are involved, a temporary coverage with skin allograft e.g. from cadavers or even autologous transplantation of cultured keratinocyte layers might be necessary [30].

Artificial skin substitutes have been developed as bilaminated membranes with different compositions and material properties mimicking the layered organization of normal skin [30]. Examples are the combination of a collagen matrix as a dermal substitute covalently bonded to a flexible nylon fabric or with an upper outer layer of silicone rubber epidermis (e.g. Integra® Dermal Regenerative Template) [30]. Other approaches use sheets, e.g. a collagen-elastin matrix mimicking dermal composition (e.g. Matriderm®), which can be combined with autologous split skin grafts and are also slowly invaded by patients own fibroblasts, macrophages or ingrowing capillary sprouts from the surroundings [31].

Membranes made from poly-L lactide can be used in superficial partial thickness burns in order to mimic the epidermal layer to provide a temporary coverage until the wounds are re-epithelialized (e.g. Suprathel®) [32].

Further strategies combining biomaterials with immortalized cells, such as StrataGraft® which is a stratified epithelial tissue combining living dermal matrix with fibroblasts overlaid by normal immortalized human keratinocytes or Apligraf® which is a bovine collagen matrix containing a combination of human keratinocytes and fibroblasts derived from neonatal foreskin [32]. Transplantation kits for spray application of keratinocyte suspensions together with fibrin glue are also commercially available (ReCell$^{\text{TM}}$) [30].

Tissue engineering strategies serve as well-known examples, which intend to build or grow functional tissues or organs mainly outside the human body for later implantation.

An example is the expansion of autologous keratinocytes in vitro and the generation of cultured epidermal autografts (CEA's) for skin transplantation in severe burn victims, where more than 50 or 60% of the body surface is affected [30]. More recent approaches, which are currently still in the experimental stage, have used three-dimensional printing of complex skin substitutes with keratinocytes, fibroblasts and other cells (endothelial cells, melanocytes, neural cells etc.) in a fibrin, hydrogel or collagen matrix [31]. Other research strategies have described tissue-engineered skin substitutes formed by laser printing, cultivation of skin composites in an air-fluid interphase in order to establish a corneated epidermal layer or cultivation of vascularized skin derivates [30, 31, 33].

New approaches use immunocompetent 3D skin models in order to better understand the role of the immune system in skin biology and tissue engineering [34].

4.3 Nerve Replacement

Biomimetic technologies for neural scaffolds use material components, mimic inner architecture and surface structures of anatomical organization of original nerves and use biological modifications such as growth factors or cell additives in order to achieve a close resembling to its biological counterparts [35].

Nerve repair requires tension-free suture which can be achieved only in defects of 5 mm or less without the need of transplants. For nerve defects larger than 5 mm size, biologic or synthetic nerve guide conduits as scaffold for neural regeneration are being used. The golden standard nowadays are nerve autografts, which have their limitation and disadvantages due to second side of surgery, donor side morbidity, mismatch of diameter, size and shape and limited availability. Biological alternatives for small nerve gaps of less than 3 cm size are conduits from small vessels like peripheral veins, which might be also filled with small muscle fibres in order to promote nerve growth and conduction [36–38]. Use of allografts (or xenografts) requires immunosuppressive therapy and therefore has considerable limitations from medical and economical aspects. Various bio-adsorbable nerve guide conduits based on collagen type I, poly-glycolic acid (PGA) or poly (DL-lactide-*co*-e-caprolactone) (PLCL) have been approved by the US Food and Drug Administration, which vary in respect to their inner diameter, porosity, rigidity and biocompatibility and degeneration rates [35]. Regarding their different properties of the nerve conduits, direct comparison studies between the different materials are not always feasible, since e.g. the variance between the diameter of the nerve conduit and the diameter of the study nerve chosen will affect nerve regeneration [39]. Best results with nerve conduits have been seen in nerve defects smaller than 3 cm [39].

Another option for nerve replacement is the use of acellularized nerve allografts (ANA). ANA's are nerve allografts, were the immunogenic components such as the highly antigenic Swann cells are removed by decellularizing techniques such as detergent processing, radiation, freeze-thawing cycles or cold preservation [39, 40]. The preserved endoneuronal architecture together with collagen and laminin within the basal lamina guides cell migration and nerve fiber sprouting [39]. Commercially available and FDA-approved acellularized nerve transplants (Avance^{TM} Nerve Grafts) have been shown superiority to collagen conduits (Integra NeuraGen®) and comparable results to autografts for small diameters (1–2 mm and short gap (<3 cm) [41].

In experimental settings in animals and as healing approach in humans in compliance with ethical standards (approved by the ethics committee of Hannover Medical School) very long nerve grafts (>10 cm) from saphenous veins filled with spider silk have been shown to be immunologically well tolerated from the recipient side. Results of reconstructed 6 cm nerve gaps in sheep showed excellent functional regeneration comparable to autologous nerve grafts [42].

Despite advances in tissue engineering and generation of artificial nerve grafts, the main prerequisites for successful recovery of peripheral nerve injury are still the process of active axonal sprouting and the preservation of functional motoric end plates during the repair process.

5 Strategies to Mimic Biological Processes Such as Wound Healing or Scar Formation

Whilst skin substitutes can survive the first days after transplantation solely by diffusion from the underlying wound bed, other tissues such as bone require immediate connection to the blood circulation and also an internal preformed capillary bed for sufficient oxygen supply. Tissue engineering strategies in order to improve vascularization of the host involve the implantation of cell-free autologous or allograft connective tissue structural components with preformed capillary networks in order to facilitate vessel ingrowth [43, 44]. Engineered tissue matrices with free or attached growth factors or hormones for time and place-controlled-staged release for angiogenesis and vascular ingrowth have already entered clinical testing for special indications [43, 44]. Further strategies imply transplantation of vessels into the host bed or transplantation of endothelial cells which have been isolated and cultivated from the host beforehand [43, 44]. Moreover, application of autologous fat stem cells into chronic problematic wounds, fistulae, radio-dermatitis or instable scar tissues have demonstrated impressive effects on wound healing, scar tissue remodeling or local vascularity by exhibiting paracrine effects by growth factors, hormones, cell-cell interactions and cell-extracellular-matrix interaction [45, 46].

For wound therapies, many approaches mimic closely the staged wound repair process of our body by providing an enzymatic or surgical preparation of the wound bed, e.g. the application of plated-rich plasma [47], or the use of polymers or a connective tissue layer to give a structure e.g. for capillary ingrowth [33, 48, 49], or to provide a closed environment to support the reepithelization process [31, 50].

6 Strategies to Mimic and Support Movements or Sensibility Which Can Be Found in the Field of Bioelectrical Prosthesis Development

Loss of functionality of limbs can be caused by an amputation or also by traumatic peripheral nerve injuries, by spinal cord or cerebral injury or by ischemic, immunologic or vascular events. When nerve pathways get injured, nerve reflexes and circuits are being interrupted and distorted, leading to flaccid or spastic paresis or paralysis of the affected limb, loss of sensibility and chronic pain. The internal repair capacity of the central and peripheral nervous system is limited, resulting in lasting deficits. Glial scar formation from astrocytes, oligodendrocytes and Schwann cells produces factors that inhibit neurite outgrowth, remyelination and axonal repair [51].

Furthermore, when injury causes partial or complete transection of peripheral nerves, surgery cannot restore the electrical transmission potential of the nerve itself. Surgery can only reconstruct the outer nervous sheaths, which is mandatory for guided axonal regeneration, by direct epineural sutures or insertion of nerve grafts for lager defects.

Secondary surgical options in order to reconstruct muscle function are neurotization procedures by transfer of intact motoric nerves onto a distal motoric nerve stump leading towards a paralyzed muscle which may allow muscle regeneration as long as functional motor end plates are preserved. Exemplary, in total brachial plexus injuries, the biceps brachii muscle for elbow flexion can be reinnervated by transfer of several motoric branches of the intercostal nerves to the distal musculocutaneus nerve. If muscle paralysis was prolonged or local muscle tissue had been severely damaged, a free microvascular functionalized muscle transfer with connection to local vascular and nerve bundles is another option. For instance, a free gracilis muscle can be connected to the microvascular and functioning neural network of the recipient side.

Another reconstruction option can be achieved by means of muscle or tendon transfers: Lost mobility may be regained and activities of daily living improved by giving up power and strength of donor muscle functions however. A well-known procedure is the transfer of wrist flexors into wrist and finger extensors in radial palsy in order to improve function of the hand.

When parts of limbs are completely lost, a prosthetic device can substitute form and function to a certain extent. The use and development of prostheses has a long history.

The first models were simply walking aids or cosmetic prothesis: Famous examples are a wooden prosthesis of a big toe dated back to 1000–600 B.C which had been found in a sarcophagus of ancient Egypt [52], and a lower limb prosthesis from the time of the Roman Empire around 300 B.C. which had been located in Capua.

Prothesis development further proceeded with mechanical or body powered devices, where positioning was adjusted by means of harnesses, lines or straps.

From medieval times, the articulated hand of Ambrosius Paré in 1579 or the iron hand of Goetz from Berlichingen with two different designs around 1510 and 1530 are two examples [52]. However, these prostheses had to be adjusted and aligned by the healthy other hand in order to allow some grip functions [52, 53]. Around 1818, the German dentist Peter Baliff, designed a prosthetic device, where muscular forces from the shoulder girdle and trunk were transferred via leather straps into the terminal device attached to the arm stump, which later inspired Giuliano Vanghetti and Ferdinand Sauerbruch to prepare amputation stumps by kineplastic operations to allow transfer of muscle and tendon forces directly onto the prosthesis in order to allow active movements [53, 54]. The Bowden cable body-powered prosthesis from 1948 was another example for a mechanical prosthetic device which allowed the user to control a two-pronged hook via preserved shoulder and body movements by variable tensions of cables.

With technical advances of the twentieth century, electrically-powered, myoelectric prosthesis were created, which are controlled by sensors amplifying surface electro-myographical potentials from contracting residual muscles in the prosthetic socket. In Germany, the first myoelectric prosthesis was created by Reinhold Reiter, a physics student at Munich University, and presented 1948 at a fair trade in Hannover [55]. Another myoelectric arm prosthesis designed by the Russian Alexander Kobrinski in 1960 went into commercial production and was also tested in British and Canadian institutes [53]. Obviously, the weight of the batteries for power supply was a challenge for the first models. Furthermore, the initiation and proceeding of movement commands into the mechanical reaction chain were slow, and changing sensor positions due to sweating or moving distorted electromyographical signals [53, 55].

Modern approaches use different interfaces to link the human body with neuroprothesis and hybrid bionic systems [56]. The connecting interfaces between prosthetic devices and the nervous system can be based on chemical, mechanical, magnetic or electrical sensors and can be invasive versus non-invasive [56].

Targeted muscle reinnervation (TMR) was introduced by Kuiken and describes the transfer (rerouting) of remaining peripheral nerves (e.g. median and ulnar nerve) after amputation to preserved muscles, e.g. the chest muscles. The amplified neuronal signals from the muscle amplifiers can be then transduced through e.g. transdermal sensors which pick up the muscular signals from underneath and allow control of the prosthesis functions by their specific determined nerves [52, 57].

For bionic limbs, the connection between the body and the prosthetic device requires a stable mechanical interface, a dynamical interface to support movements and an electrical interface to connect and communicate with the muscle and nervous system. Nowadays there are new compound materials with better mechanical properties which allow change from soft and flexible to hard and durable stabilizers to connect between the amputation stump, skin and the prosthesis [58, 59]. Another option are the so-called endo-exoprothesis where the artificial limb can be directly fixed with the bone via osseointegrated titan pins, providing therefore maximal stability and endogenous proprioception of the prosthetic limb [53, 60].

The electrical interface can be achieved by sensors which record signals from the muscular surface, or directly inside muscles, or directly within or around nerves by implanted sieve or cuff electrodes. Long-term stability and reliability as well as possible damage to the structures have to be considered, especially with implanted nerve sensors.

The interface electrodes have to meet the standard requirements of compatibility between a technological and a biological system, where from the technological sight the interface device is a bi-directional transducer to record bioelectrical signals from the body (muscles, nerves etc.), whereas from the biological perception, the interface resembles a foreign body [56].

Non-invasive electrodes are surface electrodes usually applied to the skin which can record signals from muscles, central nervous system or from the heart. They also can be used to activate peripheral nerve tracts for sensation, chronic pain suppression transcutaneous electrical neural stimulation (TENS) or even as a functional electrical stimulation (FES) to correct foot drop [56]. In experimental settings, non-electrical interfaces working by magnetoneurography to detect nerve action potentials or by acustic myography of muscle vibrations during voluntary or provoked contraction have been tested [56, 61]. Muscle electrodes are either placed on the muscle surface or within the muscle fibers and can be used for stimulation or recording. Whereas most of these electrode systems function by direct electrical coupling, there is also one interesting microstimulator device which can be activated by coupling to a wireless control system by an externally generated radiofrequency magnetic field [62]. Extra neural electrodes can be placed epineural or in form of “cuff”-electrodes around the nervous sheat.

Other electronical devices may improve lost functions in central, spinal cord or peripheral nerve lesions: Deep brain stimulation uses “brain pacemakers” in order to apply controlled electronic impulses to specific targets in brain areas (“brain nuclei”) which are an accepted treatment in Parkinson’s disesases, essential tremor or dystonia/ataxia. Spinal cord stimulation may help patients with chronic back pain by triggering and suppression of nociceptive pathways in the spinal cord. A peripheral paralysis might be improved by implantation of functional electrostimulation systems close to peripheral nerves such as the peroneus nerve. The effectivity however depends on the degree of residual function which is intended to be enforced.

7 Strategies to Mimic Complex Biological Processes or Nano-Networks for Bioinspired Principles for Network Sensor Systems

Nature has been an inspiration for computer scientists and engineers to mimic nature principles to design network sensor systems which can adapt to various changing conditions, self-organize, adjust scaling and provide robust an durable operation for long-term survival. Many biological systems have an internal dynamic which is guided by a small number of simple rules, do not require a central controlling head and allow synchronization, task allocation, resource management, and efficient communication with adaption to environmental changes [63]. Examples of nature-inspired principles which have been used for the design of network sensor systems are swarm intelligence, particularly ant colony optimization and the particle swarms optimization algorithms, natural time synchronization, artificial immune system and intercellular information exchange [63, 64]. These natural principles are not only used for sensor development for medicinal devices, but also used for other computer and robotics applications in tracking, filtering, selecting, signaling or detection of invading elements, to name a few examples.

8 Conclusion

In the field of plastic and reconstructive surgery, biomimetic principles can help to replace parts which the surgeon otherwise has to borrow from other body parts or locations. Biomimetic strategies may revolutionize new approaches in reconstructive surgery and medicine, such as tissue engineering, artificial intelligence, sensor development or material sciences: Tissue or body parts or their functions are newly re-created outside the body in order to be implanted at a later time point. Further challenges include the connection with the peripheral nervous systems and the human brain functions as a central driving motor via biomimetic sensor systems as well as the implementation of neural networks in the control module. A cross-disciplinary working relationship between material scientists, engineers, physicists, chemists, mathematicians and medical doctors has been essential for current and will be for future achievements.

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