A new frontier in switchable bioelectronics and bionanotechnology interfaces

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2.1 Introduction to bio-inspired materials, bioelectronics, and bionanotechnology

A complex set of functions is carried out by every cell in a living organism using a vast collection of proteins, ion channels, protein pumps, motor proteins, and signaling molecules, and cargo carriers [1]. The comprehension and interacting with living organisms at the complexity stage is behind much that civilization has accomplished to date in constructing advanced machinery and computer power. Bionanoelectronics is the integration of an artificial system with biological components. The main obstacle to this vision of bionanoelectronics is the lack of an adaptable functionality that facilitates biological and electrostructural two-way communication between the electronic component and biological entities. One-dimensional (1D) nanomaterials. Such as nanotubes and nanowires require tight configurations to be constructed that facilitate these bidirectional information flows within the system [2].

Most living systems employ a wide variety of autonomous self-replicating mechanisms to produce movement, signaling, sensations, and communication by the use and circulation of currents of ions, small signaling molecules, and protein interactions, as shown in Fig. 2.1. However, human-made construction uses nonorganically produced materials, electric currents, and electromagnetic fields while also generating power from fossil fuels, which are the foundation of prevalent architecture concepts but focus on a very different technology base [3]. The benefits of both methods are apparent. Society today has high-speed air transport and space travel and can also keep people alive at the bottom of the sea for months, clearly exceeding biological capacities. Nature manages much more for much less than that. This is shown by the fact that a massive machine (IBM Blue GeneL), one of the biggest and fastest computers in the

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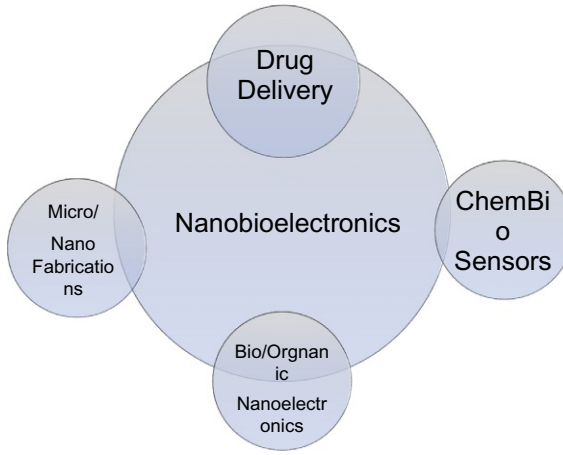


Fig. 2.1 Illustration highlights the central area of active research in the area of nanobioelectronics.

world, has a computing power roughly equivalent to two-thirds of the brain of one rat. However, the rat brain has just 1/500 of the processing capabilities of the human brain [4].

Bioinspired materials are broadly defined as composite materials designed to emulate the shape and mechanical properties of biological natural materials. Biological molecules are naturally multifunctional but have been designed to improve the main mechanical properties, such as failure tolerance, armor and safety damage, sharp and slashing parts for low flight weight, and chemical and mechanical extremities that have been added to removable adhesives [5, 6].

Bioinspiration relates to a mechanism and its fundamental principles in learning from nature. The science of bio-inspired materials seeks to develop new, advanced, and multilateral functionality materials using the nano-, micro-, *meso*-, and macrostructure of natural materials to meet the demands of well-being [7]. Increasingly, materials research is focused on designing bio-inspired materials attributable to resource constriction. Such materials possess novel properties, low prices, exceptional qualities, and the environmental and climatic concerns of natural resources. To this end, it is essential to understand fabrication or bio-inspired approaches to natural biological phenomena, the natural biological materials and processes involved in their natural production [8].

In recent years, advances in nanotechnology have helped create new nanomaterials that have been used in medicine, high-energy environmental engineering, and storage and that have been influential in basic research. Carbon nanotubes (CNTs), graphene, soft polymer nanoparticles (NPs), metal nanomaterials, self-assembled and supramolecular nanostructures, and variations of these functional NPs are some of the properties of the present nanoelectronics and clinical evaluations. Due to their uniquely physicochemical properties such as catalytic, dielectric, optical, and mechanical

characteristics, various applications from nanosensors, pharmacology, materials protection, and biomolecular electronics, among others, are currently available globally. In particular, the biomolecular applications of biological structures such as lipid base vesicles, viruses, protein cages, and polymeric nanomaterials have strengthened the profound comprehension of novel nanomaterials and prompted the development of ecofriendly applications. In recent times, investigations have mainly focused on nanomaterial interactions with biological systems in therapeutics applications. Some possible adverse impacts of some of these systems are highlighted in Table 2.1. The aforementioned advantages of bionanomaterials ranging from the size monodispersity (similarity between NPs in both chemical composition and architectural arrangements), and typical repetitive building blocks (asymmetric units), such as protein cages, that both energy-based endocytosis and mechanical structural changes that allow their entry into the host-cell compartments. The physical and chemical characteristics of NPs such as size, geometrical shape, surface-functional groups, and chemical composition largely dictate their entry mode into cells. Protein cages in general, including viruses, are self-assembled asymmetric units that can be modified chemically and genetically to impart new functionalities for desired applications from electronics to biomedical.

The specific concept of bioelectronics is the integration between electronics and biological systems, where a bioelectronic interface transmits biology signals to electrical signals from the biological system via the bioelectronic interface. The advancement of biomedical technologies such as blood glucose regulators has contributed to critical biomedical devices such as cardiac pacemakers [19, 20] and deep-brain stimulators [21]. Although such systems have shown potential, it can be noted that the computer transducers were substantially different in size from the biological systems with which the devices interfaced. Thus, a considerable reduction in electronic transducer measurements as well as the natural appearance of their products may contribute to significant changes in the next-generation bioelectronic sense of responsiveness and biocompatibility, thus improving and/or creating new prospects in essential biology medicine [22]. A wide range of nanomaterials has emerged in this context in recent decades, including nanoparticles with zero dimensions (0D), 1D, CNTs, and two-dimensional (2D) nanoassemblies. The organic advancement, preparation, and characterization have improved significantly [23]. An underlying inspiration for these attempts was to understand how the shapes, architectures, and compositions of these nanostructures in one or more dimensions, including the quantum containment method, contribute to different electrical, optical, and magnetic properties. The increased physical characteristics, including unusual ones, of these nanomaterials offer potential unique biological opportunities [24]. Nanobioelectronics is a progressively interdisciplinary area, integrating nanomaterials, biological materials, and electronics, thereby allowing current bioelectronic challenges to be overcome and establishing new frontiers in the development of new products. These include biosensors based on affinity that use a protein or DNA sensor to interact with biological research in solution selectively, and generating an electrical signal that is directly related to test concentration [25].

Table 2.1 Examples of conductive polymers based on widely used bioscaffolds used for cellular studies and tissue engineering based on literature reports highlighting some of the reported conductivity values for each scaffold.

Bioscaffold template	Fabrication method	Conductivity	Cells	Biocompatibility	References
Carboxy functionalized MWCNTs with chitosan	Freeze drying	–	Human osteosarcoma cell line	Enhanced cellular proliferation	[9]
MWCNTs functionalized with gelatin	Electrospinning	–	Myoblast cells (C2C12)	Enhanced myotube maturation	[10]
SWCNT functionalized with collagen hydrogel	Sol-gel	1300–2400 ms/m	Dorsal root ganglia	Enhanced neurite outgrowth under electrical stimulation	[11]
MWCNT coated with a collagen sponge	Doping	8×10^3 Ωm	Mouse osteoblast cells	Enhanced cellular adhesion	[12]
Chitosan/fibroin hydroxyapatite	Freeze drying	–	Human osteosarcoma cells	Improved cell growth and enhanced osteogenic differentiation	[13]
Chitosan-functionalized silicon dioxide NPs	Lyophilization	500–1200	Human osteosarcoma cells (MG63)	Fast cell adhesion, excellent cellular proliferation, and rapid osteoblast differentiation	[14]
Poly(L-lactic acid)	Phase-separation process	10^{-12}	Cardiovascular progenitor cell (mouse embryonic stem cells)	Cardiac cell diffraction and tissue formation	[15]
Gelatin	Uniaxial stretching	4×10^{-2}	Human embryonic stem cells	Improved electromechanical signaling and cellular elongation	[16]
Nanofibrous cellulose	3D bioprinting	–	Human chondrocytes	Enhanced cellular growth	[17]
Hydroxyapatite graphene functionalized with chitosan	Self-assembly and lyophilization	–	Rabbit bone marrow stromal cells	Enhanced cellular attachment, extended times for proliferation and differentiation	[18]

This chapter will address the recent advancement of semiconductor nanomaterial generations in nanobioelectronics. The fusion and electrical assets of such nanomaterials will be explored as novel bioelectronic nanomaterials. Nanosensor-based systems will be explored from applications to challenges facing the development of such materials into functional materials [26]. Furthermore, the chapter will address the interactions of nanoelectronics systems with biological systems through the use of semiconductor nanomaterials for cellular measurements incorporating multiple arrays of nanoelectronic devices within the three-dimensional (3D) networks within the tissue (natural or synthetic).

2.2 Features of biomaterials

Biomaterials possess many characteristics including the size of the nanomaterials, geometrical arrangement, chemical and biological stability, morphology of the NPs, topography (surface roughness), and elasticity [27].

2.2.1 Biocompatibility

Biocompatibility enables the nanosystem to function in vivo in an implant or as a drug carrier without triggering adverse local or systemic reactions [28]. The biocompatibility of biomaterials implies that they have the potential to remain in association with living tissues without inducing a harmful impact or an immune response. In general, the biocompatibility of biomaterials depends on their liquid-absorbing capacity, which promotes sustained and sustainable cell protection without inducing any cellular damage [29]. Different components and composites are known to be biocompatible and of great interest in the medical and pharmaceutical field. However, the biocompatibility of biomaterials under some cases is not feasible [30]. The optimal amounts are then improved by rendering their composites compliant with polymers that are more stable. Implantation of an acellular substance causes a series of activities comparable to an actual body reaction contributing to more acute inflammation and the creation of a chronic reaction in certain instances. A biomaterial will not, therefore, induce such a reaction that is closely related to its biological properties, its internal and external architectural features, surface characteristics, porosity, and the material resources used to manufacture biomaterial implants [31].

2.2.2 Biodegradability

When used in vivo, biomaterials are needed as nontoxic products at a regulated rate of degradation that closely correlates with the host tissue regeneration rate. As biomaterials are used as scaffolds, as cells are incorporated, they dissolve and metabolize their membranes and ultimately create 3D frameworks that strongly resemble the host tissue's natural microenvironment [32].

2.2.3 Electroconductive bioscaffolds

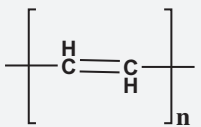
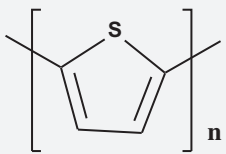
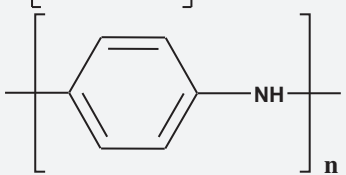
Conductive polymeric materials (CPs) represent a series of functional polymers that is strongly conductive electrically, and that can show reverting mechanical, electrochemical, and physical properties by doping a delayed backbone around the polymer chains [33, 34]. Compared to the various physical and chemical properties of organic polymers, they have gained considerable interest over the past two decades and are primarily associated with sensors, photonics, phonics, and biomedical instruments while retaining the electrical characteristics of metals [35]. Scientists use polymers to perform different manufacturing methods.

Numerous forms of conduction of electroconductive materials are combined by processes such as cross-linking, casting, drying, and electrospinning through electric hydrogels, aerogels, nanofibers, or membranes with a scraper solution, precursors, or monomers. Polyaniline (PAni) and polypyrene (PPy) are commonly used CPs with PCLs, poly (lactic acid), or gelatine as the electrospinning mixture [33]. Furthermore, electrical conduction bioscaffolds may be developed into the existing nanostructures of nonconductive scaffolds by polymerizing the CP precursors or monomers. To that end, with in situ chemical or electrochemical polymerization, CPs are inserted into the matrix. The alternative matrix for polymerization by CPs offers natural hydrogels with a subtle 3D architecture such as bacterial cellulose (BC). CP-based electroconducting bioscaffolds displayed promising properties for 2D and 3D cellular culture under electrical stimulation. Several recent findings have been outlined in favor of the possible use of electroconducting CPs in 2D and 3D cell cultivation [34].

CP-based electroconducting bioscaffolds with adequate electrical stimulation can promote axonal regeneration in nerve injury repairs. The use of electrical stimulation (ES) via conducting PPy/chitosan in combination with olfactory cells (OECs) significantly increased cell proliferation as well as mRNA and protein expression levels and secretion in OECs. Those results have shown that an increase in the spread and secretion of ES neurotrophins in conductive scaffolds probably helped improve nerve regeneration; see Table 2.2 for further examples. Furthermore, the migration of epithelial cells is guided by endogenous electric current instantly created on skin lesions [44]. In the wound healing process, an electric stimulus often plays a significant role, promoting injury care rather than traditional energy-based medical bioscaffolds. The development of fibroblasts cultivated on it was significantly increased following the application of 100 mV DC stimulation on an electroconductive PPy/poly(D,L-lactic acid) (PDLLA) membrane [45].

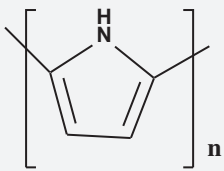
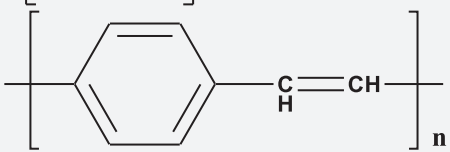
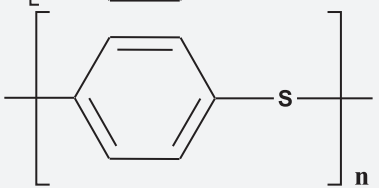
Various applications for conducting polymers have been developed and well explored, such as tissue-engineered organs [28], controlled drug release [46], nerve-channel repair, and nervous recovery stimulation [47] are currently being considered in clinical use. Electrically activated tissues (e.g., heart, brain, and skeleton) often help to build corporal interfaces with therapeutically electronic devices and human or animal tissues [48]. One of the unique approaches in designing unique biomaterial devices is the utilization of virus capsid coated with a thin metallic layer of the desired elements. It has been demonstrated that viruses with their unique monodispersity are perfect templates for metal coating [49, 50]. For example, metallic

Table 2.2 Some of the conductive polymers reported in the literature with some of their main applications.

Conducting polymer	Conductivity (Siemens/cm)	Chemical structure	Applications	references
Polyacetlene (PA)	200–1000		• Optoelectronics	[36]
Polythiophene (PT)	10–100		• Biosensors • Food packaging	[37]
Polyaniline (PANI)	5		• Biosensors • Drug delivery • Bioactuators • Tissue engineering (nerve and cardiac)	[38]

Continued

Table 2.2 Continued

Conducting polymer	Conductivity (Siemens/cm)	Chemical structure	Applications	references
Polypyrrole (PPy)	1–1000		• Biosensors • Drug delivery • Tissue engineering (nerve, cardiac, bone)	[38, 39]
Polyparavinylene (PPv)	1300–2400		• Light-emitting diode (LED)	[40, 41]
Polyparaphenylene sulfide (PPS)	3–300		• Accelerating nerve cell regeneration	[42, 43]

coatings of cowpea mosaic virus (CPMV) with iron platinum and cobalt platinum alloys through the mineralization process demonstrated excellent potential for systems such as data storage devices with enhanced charge-discharge properties in comparison to their synthetic counterparts [50, 51]. Zinc oxide coating on the virus capsid has shown potential for such materials to be used as semiconducting materials with applications in optoelectronic devices such as solar cells [52]. The metallization of CPMV particles with iron oxide has highlighted the potential use of such materials as magnetic resonance imaging agents for clinical applications [53–55]. Furthermore, the spatial decoration of preformed gold nanoparticles on the virus capsid of CPMV has shown that with a great degree of control, the assembly of conductive 2D and 3D nanoparticles but yet their applications in vivo yet to be established [56].

2.3 Hybrid bionanomaterials

2.3.1 Carbon nanotubes (CNT)

CNTs have high aspect size-to-volume ratios, great strength, exceptional thermal and chemical resistance, and diverse optical and technological properties [57]. Efforts have also been made in recent years to explore the potential biological applications of CNTs. Seamless graphene sheet cylinders are rolled up to generate CNTs. CNTs are classified as single-walled CNTs (SWCNTs) or multiwalled CNTs (MWCNTs), similar to the sum of the structured walls [58]. Typically, generated SWCNTs have a diameter of 0.4–2 nm while MWCNTs have a diameter of 2–100 nm. This characteristic evaluates the electronic properties by SWCNT chirality, which is the angle of the graph sheets rolling up concerning the matrix vectors [59]. The chiral function (n, m), under which n and m are the numerical numbers of hexagons in the two spatial unit vectors of the grid, quantifies this angle of moving. This function is precisely correlated with the electrical features of SWCNTs. If the SWCNT (n-m) is multiple three and the semiconductor; otherwise, it is metallic. 1/3 is metallic, and 2/3 was semiconductive statistically [60].

A variety of strategies for CNT processing have been employed such as arc discharge at high altitude, laser ablation, and solar beam vaporization [61]; approaches such as CVD have been used for low temperatures. The first recorded SWCNTs were prepared in a carbon electrode by a carbon arc discharge process and a metal catalyst [62]. This method, despite its simplicity, can produce a relatively high yield of structurally uncluttered SWCNTs. CVD first grew CNTs in 1993 with the inclusion of nanoparticles in hydrocarbon gas substrates as the reactor [63].

CNTs, owing to their broad surface area with exceptional optical and electrical proprieties, are among the most versatile nanocarriers for the extremely efficient delivery of drugs and biomolecules. This can be mixed noncovalently or covalently for the creation of a next-generation medication and a biomolecular delivery method for medications, molecules, and nanomaterials. This section provides a brief review of CNT systems for the delivery of medicines and biomolecules developed over the past decade.

CNTs may also be used as building blocks for nanoelectronic equipment in the same manner that microchips revolutionized computer technology. Nevertheless, the incorporation of CNT building blocks into multifunctional/multicomponent systems or tools was a big long-term task. The use of CNTs with specific redox-active proteins, such as the glucose oxidase (GOX) enzyme, cytochrome-c, and horseradish peroxidase, was seen to be successful. Recently, researchers showed that CNTs could promote electrochemical transportation by specific proteins and enzymes [64, 65]. The biomaterial integration (e.g., DNA, protein/enzyme, or antigen/antibody) of CNTs provides modern hybrid structures, integrating the conductive and semiconducting properties of CNTs with biomaterial detection or catalytic properties. This will generate new bioelectronic structures (biosensors, field-effect transistors, etc.) or nanocircuit models. While being cytotoxic in concentrations of up to 10 mM, functional CNTs can cross cell membranes, migrate into the cytoplasm, and even enter the nucleus [66]. CNTs could act as carriers transporting bioactive components and delivering them into cells. Biomolecules were adequately supplied to cells for their immunization and improved the development of antibodies.

Furthermore, the design of a pH-responsive sensor using biocatalytic materials encompassing with the pH-responsive poly(4-vinyl pyridine, P3P) conductive polymer for molecular activity dependent on enzymes control and regulation. For electrochemical techniques, the interfacial electrochemical characteristics may be regulated with a small pH shift in the medium. Graphene oxide (GO) as a single carbon nanotube sheet is a vibrant material on its surface structures with oxygen moieties such as epoxy, hydroxy, and carboxylic groups allow the use of GO as a carrier for various biological entities and bioelectronics applications. GO paired with a pH-response polymer (P4VP) permits pH-responsive system monitoring and the regulation of biomolecular activity. The P4VP polymer is mainly inherently capable of reacting to chemical medium shifts. The protonation of pyridine groups in acidic environments in the polymer backbone allows the polymer framework to swell on the surface, allowing diffuse inspection via the electrode [67]. However, where a medium's pH is neutral, the movement of polymer chains is therefore limited. Also, an analyte with an electrode surface cannot be accessible, which implies that it is not activated [68]. The purpose of the published model system was to regulate the interaction of an electrocatalytic surface by changing the pH of the reaction media. Graphene and GOX with pH induction have facing charges over a minimal pH (i.e., at pH 4), which allows it to assemble under a proper structure due to the strong electrostatic attraction. The substrate (i.e., glucose) is then readily available to the enzyme, which enables the electron to pass to the electrode surface [68].

2.3.2 Bioelectronic device modulation

Bioelectronic device modulation in medicine is broadly defined as electronic circuits for regulating biological processes, treating illnesses, or restoring lost functionality [69]. Such devices will interact in different ways with the excitable tissue: they can cause an electrical reaction, signal obstruction, and detection. A variation of such functionalities may be needed based on the illness being treated. A system that

provides full control of the urinary tract, for instance, may require prompt activation utilizing time detection and sensing. For example, the human urinary system is complicated and extensive. It involves the kidneys, ureter, bladder, and urethra as well as the central and peripheral nervous systems (PNS) and their standard regulation mechanisms. Therefore, it may be feasible to reestablish complete control of the urinary tract using several approaching procedures; some of them will require a centralized nanoelectronic wireless network where each device has a specific task, and all of them interact and cooperate to conduct the required therapy [70].

2.3.3 Applications in biotechnology and bioelectronics

In the past few decades, mobile technologies have revolutionized biology and medicine. The invention of the electrocardiograph (i.e., monitoring the heart's electrical activity) more than 100 years ago was one of the pioneering moments in cardiology; today, it is an essential part of clinical practice [71]. The advancements in the area in radiology, which has evolved from a single mode (X-ray) through magnetic resonance imaging (MRI), computational tomography (TC), positron emission tomography (PET), and other modalities, have also been significant to electronic devices. In order to treat a physical injury, MRI has made it possible to image soft tissue. CT also enables anatomical aspects to be presented in 3D to enable tactical preparation. The demand in photography will reach $11.4 billion by 2012 [72].

2.3.3.1 Biosensors

The development of capable sensing devices as a potential application of biotechnology is of great interest in the clinical and medical fields. Enzymes and monoclonal antibodies (hlAbs) are especially suitable for use as sensors, given their high speciality for subpositives. Sensors with these biological molecules have a smaller and more sensitive potential than conventional sensors. For several years, enzyme-based biosensors have been used to identify the presence of specific organic compounds. Most use an ion-sensitive electrode and a free or immobilized enzyme that indirectly measures the existence of a product whose creation is catalyzed by an enzyme (e.g., by changes in the temperature or color during an enzymatic reaction). Such biosensors are fast and responsive due to their proximity to the enzyme and electrode. However, the high prices for certain enzymes, the scarcity of other enzymes, and temperature variability have not led to widespread use.

2.3.3.2 Biochips

Biomolecular electronics production is probably the newest possible application of biotechnology. Such a device will require organic molecules specially formulated to function as a semiconductor with different proteins surrounded and stabilized. The use of proteins as a matrix in semiconductors has been studied since the early 1970s, but computer-aided protein designs and the production of rDNA proteins have attracted more attention over the past few decades. For example, computers using

biochips based on proteins would become smaller, faster than computers that use silicon chips, energy-efficient, and possibly more reliable. The effect of such biochips, from hand-held calculators to robots, will be as significant as current computers.

2.3.3.3 Neuroscience

The use of conductive polymers as a novel nanomaterial for a neuronal cell culture has proven to be a very successful strategy. Poly(3,4-ethylenedioxythiophene) (PEDOT)-coated, polypoethylene nanofibrous scaffolds facilitated multidirectional neuritis outgrowth in neurotic SH-SY5Y cells [73]. A further study using p-toluene sulfonate-doped in addition to tracking and facilitating accelerated neuronal cell growth and activity, Welspun PPy was used. The dorsal root ganglia are axonally, and Schwandt paired with the PPy fibres [74]. Another advantage of conducting polymers is that they can be used in neuronal anatomy to induce electricity. Electrical stimulation was also included in all the publications above. Electrical stimulation has been shown to elicit an intracellular neuronal cell Ca^{2+} response. It is known to trigger several signal cascades linked to growth and differentiation [75, 76].

2.3.3.4 Infection

For some infectious bacterial species that form biofilms (a dense population of microorganisms embedded in the extracellular matrix), it is vital to develop a method to prevent medical tools. Biofilm formation aids the bacteria population to firmly adhere to the surfaces of materials. This biofilm ability conceals and removes the clean-up of immunogenic bacterial cells from the immune system. The production of "persisters," which are bacterial cells with a metabolism far slower than usual, is often related to the creation of biofilms. This contradicts the way most antibiotics function in order to kill bacteria [77]. Biofilms are usually found in patient settings with embedded medical equipment. Invasive procedures, together with prosthesis implantation and a tool, constitute an access point for bacterial invasion and are an environment for the initiation of the attachment and development of biofilms. Treatment for biofilm-related infections is complicated, with high rates of systemic antibiotics typically needed at relatively high levels for longer-term use at infection sites [78]. The latest investigation aims at developing new surfaces that can either minimize the risk of biofilm development or destroy biofilm by more efficient bacterial kills. An excellent method for the more efficient killing of bacteria is to enable the release directly from the surface of bactericidal medicines. This method benefits by providing high levels of antibiotics in sites where there is no requirement for invasive operation and high systemic antibiotic doses (as with oral or intravenous drug administered) [78]. The release of antibiotics from an established conducting polymer will reduce this issue, as the concentrations released locally are large and the systemic concentrations are small [79, 80]. A preventative approach to prevent the development of biofilms on implants may be to facilitate implant growth and to avoid inflammation on site. In line with this, PPy films coated on implants and prostheses have shown electronically controlled drug release. Functional prostheses made with an antibiotic coating avoided contamination at the

implantation site and increased prosthesis interaction with the surrounding tissue [81]. Titanium (Ti) is the most widely used substitute for bone and joint protheses in hospitals with a high risk of contamination because of the intrusive surgery required to achieve implantation. Inflammatory behavior delays growth and contributes to the failure of the implant [82].

2.3.4 Future outlook

Advances have progressed dramatically over the past decade in metallic bio-inspired nanomaterial synthesis through the possibility of a broad range of conceptual systems and creative protocols for carefully monitoring crucial parameters of nanomaterials production, such as morphology, measurements and assemblies of bionanoelectronics and related superstructures, for the significant number of biologically based candidates (microorganisms, viruses, phage's proteins and DNA). Metallic bio-inspired nanomaterial synthesis has made recent progress. Out of the possibility of providing for the right numbers of naturally occurring nanomaterials (microorganisms, bacteria, plant viruses, proteins, and DNA), a wide variety of novel and innovative protocols that have been developed to closely track the main properties for nanomaterials growth, such as morphology, and assembly to generate nanodevices. Around the same time, the compatibility differences between the biological environment and nanomaterials are significant and should not be overlooked, particularly as the simple incompatibility between the signal transduction mechanisms used for microelectronic and biological systems is essential. Fortunately, there have been many strategies that aim to transcend these disparities and understand the bioelectronic dream.

Researchers in this field are looking optimistically at the design and development of more complex circuits where biological molecules operate, interface, and connect effortlessly with nanotubes and nanowire scaffolds, respond to optical signals, or even execute the local memory or shifting functions. The new tissue interfaces could revolutionize the way we do medical diagnostics, protheses, or even simple computer-human connections at a higher complexity stage.

In the past 20 years, hand-held devices and diagnostic instruments have played a vital role in the industrial production of nanomaterials. Indeed, it is expected that scientists could generate many advances in nanotechnology and new prospects for the world economy. NMs may be commonly used in different fields, in particular in tumor therapy, as in the future, nanomaterials will increasingly and extensively be used. Nanomaterials may be extended based on scale, biocompatibility, surface chemistry, relative excellent stability, and toxicity in biological systems to clinical diagnoses, electronic sensors, and tumor therapy.

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