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Nanotechnology and Biomedical Devices Used as a Novel Tool in Biosensing and Bioimaging of Disease

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Abstract

Nanotechnology is a vast field used in medicine as well. "Nano" is a prefix that stands for 10-9, i.e., one billionth of a meter. The design and synthesis of efficient drug delivery systems are crucial for the medical, pharmaceutical, and healthcare industries. Nanotechnology involves physics, biology, and chemistry. Many nanotechnology-based drug delivery systems, such as biopolymers, are used as anticancer, antibacterial, antiviral, antifungal, veterinary medicine, vaccines, and antitumor drugs. Since most biological systems are nanoscale, nanoscale materials integrate well into biomedical equipment. Carbon nanotubes, liposomes, inorganic and metal nanoparticles, and metallic surfaces are the materials most frequently employed to create these nanotechnology goods. In this review, we will focus on the importance of nanotechnology as well as the biomedical devices used in the characterization and diagnosis of many diseases. In the future, we can use nanotechnology-based biomedical devices in the field of regenerative medicine in addition to drug delivery, as well as in biosensing and bioimaging for disease diagnosis.

Keywords Nanotechnology, Nano Biomedical Devices, Biosensing, Bioimaging.

1. Introduction

The term "nanomedicine" refers to a wide variety of materials and technologies. Many types of nanomaterials have been researched for potential applications as medications, drug delivery systems, or other nano-medicinal agents (1). The nanoparticles used in this technology cannot be sensed by a human because they are very small particles. By promoting transport across membranes, extending circulation periods, and improving the stability and solubility of encapsulated cargo, nanoparticles have the potential to increase safety and efficacy (2). Due to the features of nanomaterials, new, adaptable medical devices can be created with improved tissue integration and therapeutic effect (3). Due to the wide range of potential applications that can be realized by combining the material world with its cutting-edge technologies and diverse properties with the biological world with its intricate molecular architectures, properties, and functions, the use of

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nanoparticles in biotechnology is growing in popularity (4). Many nanoparticles are desirable due to their inherent properties of optical clarity, controlled porosity, chemical inertness, and biocompatibility (5). To create nanoparticles with precisely controlled sizes and shapes, numerous synthetic techniques have been devised. With an incredible array of techniques for creating nanoparticles, research in nanotechnology and biopharmaceutics, or collectively nanomedicine, has recently taken on a new level. It is now possible to improve or regulate drug delivery; this is necessary when using poorly soluble medications or medications that must pass the blood-brain barrier (BBB) (6). Also, this method can be used to administer medications to specific areas. These methods include the Sol-Gel approach, vacuum-assisted drug solution spraying, solvent diffusion, and precipitation. Porous nanoparticles are mostly created using the first two methods. To provide information to individuals preparing to begin the manufacture of nanoparticles in a specific area of interest, the current work analyses these methodologies (7).

2. Nano-based Drug Delivery

2.1. Liposomes

The groundbreaking work of countless liposome researchers for almost five decades made it possible for significant technological advancements such as remote drug loading, extrusion for homogeneous size, long-circulating (PEGylated) liposomes, triggered release liposomes, liposomes containing nucleic acid polymers, ligand-targeted liposomes, and liposomes containing drug combinations (8) An alternate way to provide these drugs orally is using nanocarriers, which is currently common (9). This article describes the development of numerous nanocarriers for oral drug delivery systems based on a variety of nanomaterials, including nanoparticles, micelles, liposomes, nanocrystals, carbon nanotubes, nanoemulsions, dendrimers, and nanospheres (10).

2.2. Nanocarries for Oral Drug Deliveries:

Nano-scale medication delivery Carriers are a well-established technology for enhancing chemotherapeutic medicines' therapeutic index and resolving formulation issues with weakly water-soluble chemicals (11). Due to the unique chemistry of each treatment, it is necessary to formulate medications on an individual basis. Moreover, it is challenging to deliver huge quantities of medication precisely to the tumor's site (in part because of moderate to poor drug loadings). Addressing these issues by developing nanocarriers made of the medicine itself, in the form of so-called nanocrystals, is one of the most lucrative "nano" chances in this field (12). Yet "nano" presents both advantages and disadvantages for the administration of targeted drugs, which are extensively explored in both in vitro and in vivo situations (10, 11).

3. Physical and Chemical Stability of Drug Nanoparticles

Researchers are making use of the unique properties that nanoparticles possess to overcome the physical and chemical stability of nanosuspension and naturally possess for a variety of uses as nano-sizing is rising in popularity as a method for developing pharmaceutical products (Figure-1) (13, 14). While creating pharmaceutical goods, the stability of therapeutic nanoparticles continues to be a highly challenging issue. Stability is influenced by the dosage form (nanosuspension vs. dry solid), the dispersion medium (aqueous vs. non-aqueous), the mode of administration (oral, inhalation, IV, or other routes), the manufacturing process (top-down vs. bottom-up), and the nature of the medication (small molecules vs. large biomolecules). Notwithstanding the significant challenges involved in stabilizing screening (14).

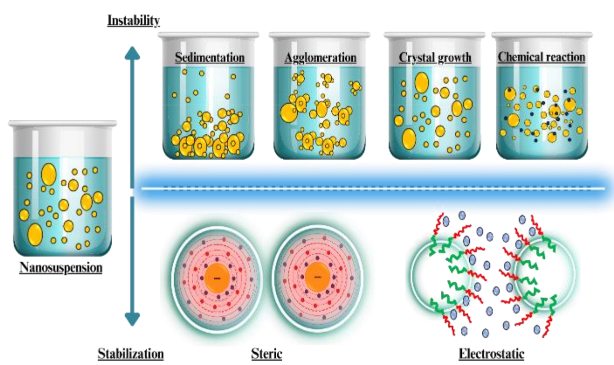

Figure 1: Physical and chemical stability of nanoparticles in nanosuspension

4. Nanoparticles' Size Maintenance

The maintenance of the size of nanoparticles used in drug delivery systems has always been an important task. The changes had been made using many techniques such as conventional nanoparticle

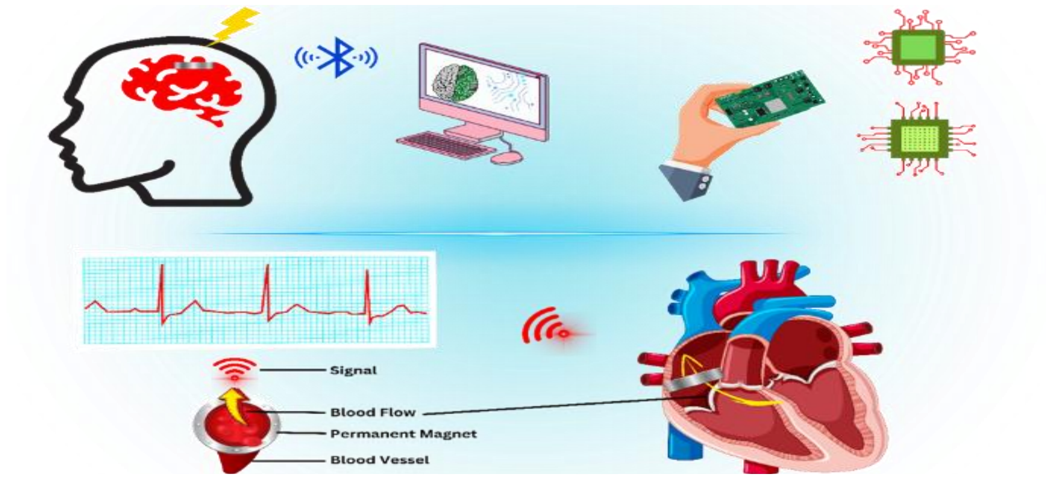

Figure 2: Implantable biosensors like silicon chips and micro-electromechanical systems (MEMS) that are implanted inside the human body and detect diseases.

preparation and modified nanoprecipitation method (15). Moreover, updated solvent evaporation techniques and a centrifugation-based separation method were employed, according to Korean process technology, also by changing polyvinyl alcohol (PVA) and polymer concentration (16).

5. Nanoparticles' Size Measurement

The air-based variable pressure module (VPM), which was used to quantify particle size, was paired with a qNano analyzer (IZON Sciences, Christchurch, New Zealand) to detect particle size (17).

6. Nanoparticles' Classification

Nanoparticles are classified as follows in table 1.

7. Nano-based Biomedical Devices

7.1. Implantable Biosensors

These might be silicon chips and micro-electromechanical systems (MEMS) that are implanted inside the human body and detect diseases as shown in figure 2 (21). This will open the door for implantable biosensors that can assess disease signs or symptoms and control the delivery of medications to aid in the treatment of diseases. An implanted glucose sensor with an insulin release system is an example of an implantable biosensor. When it detects a high glucose level, insulin is released without the need for an insulin injection or finger-prick testing (2, 21, 22).

Table 1: Nanoparticle classifications based on their uses.

Nanoparticles	Polymer	Uses	Ref
Lipid-based	Liposome, Lipid nanoparticle, Oil emulsion	• Simple formulation with a variety of physical characteristics. • Excellent bioavailability • Payload adaptability • A low rate of encapsulation	(18)
Polymeric	Polymersome, dendrimer, polymer micelle, nanosphere	• Tight control over particle properties. • Flexibility in the payload for both hydrophilic and hydrophobic cargo • Ease of surface modification • The potential for toxicity and aggregation	(19)
Inorganic	Silica nanoparticles, Quantum dots, Iron oxide nanoparticles, gold nanoparticles	• Special optical, magnetic, and electrical characteristics • Size, structure, and geometry variety. • Suitability for theragnostic applications; flexibility • Limitations of toxicity and solubility	(20)

7.2. Subcutaneous Sensor

Long-term active monitoring of heart or prosthetic joint performance can be done with subcutaneous sensors built on nanoscale measurements. For instance, a subcutaneous EKG monitor can identify cardiac arrhythmia, and this information can be remotely be sent to the doctor's computer or smartphone (23).

7.3. GlucaGen Hypo Kit

Dasiglucagon is a next-generation, ready-to-use aqueous glucagon analogue formulation that has been developed for the treatment of severe hypoglycemia in diabetics (24). A gadget based on nanotechnology called the GlucaGen Hypo Kit is used to treat extreme hypoglycemia in diabetic patients. The device uses a pre-filled syringe containing glucagon, a hormone that raises blood sugar levels, in a stable, freeze-dried powder form. The powder is reconstituted with water using a built-in needle, and the resulting solution is injected subcutaneously (24).

7.4. Abbott’s Freestyle Libre

Abbott's Freestyle Libre is a continuous glucose monitoring device that measures interstitial fluid glucose levels using a tiny sensor connected to the skin. The sensor uses a thin filament containing nanoparticles of glucose oxidase, an enzyme that reacts with glucose to produce a measurable signal. According to research, adults and children with type 1 diabetes (T1DM) or adults with type 2 diabetes (T2DM), whether they are getting insulin therapy or non-insulin therapy, are now able to achieve effective glycemic control (25).

7.5. Chronic disease monitoring

When the information is sent to a data-gathering device that resembles a wristwatch, the nano pressure sensor may monitor pressure within the cardiovascular system. This external device transmits the data to a central remote monitoring station, where healthcare professionals can view it in real-time (26).

7.6. Implantable cardio-defibrillators

Due to ventricular tachyarrhythmia, the risk of sudden cardiac death is reduced. The patient’s information is gathered and can be viewed by the physician (27).

7.7. High-Performance Pulmonary Drug Delivery

The morbidity and mortality of public health are significantly threatened by respiratory illnesses. Pulmonary drug delivery based on nanotechnology employing metered dose inhalers (28). Systems for regulated, targeted, and systemic medication delivery based on nanotechnology have the potential to improve therapeutic efficacy with few side effects. When compared to other routes of administration, pulmonary distribution offers special advantages including avoiding first-pass hepatic metabolism and lowering doses and side effects. The morbidity and mortality of public health are significantly threatened by respiratory illnesses (28).

8. Using Therapeutic Nanotechnology to Address Microbial Resistance

By combining many antimicrobial medications into a single nanoparticle, resistance is less likely to develop (29). Nanoparticles can be used to circumvent existing drug resistance mechanisms, including intracellular bacteria, biofilm formation, decreased drug absorption, and enhanced drug efflux from the microbial cell (30). Finally, nanoparticles can be used to target antimicrobial drugs at the site of infection, delivering higher therapeutic dosages and overcoming resistance. When vancomycin is immobilized on the surface of NPs, the antibacterial activity of the drug is difficult to maintain. Vancomycin was mixed with aqueous tetrachloroauric acid at pH 12 and 25 °C for 24 hours to create vancomycin-immobilized gold (Van-Au) nanoparticles (31). Easy production of 8.4 1.3 nm Van-Au NPs is possible. The pathogens whose cell proliferation the produced Van-Au NPs inhibited while maintaining their antibacterial activities included Gram-positive and Gram-negative bacteria as well as antibiotic-resistant bacterial strains (31). Moreover, the minimum inhibitory concentration of the Van-Au NPs against bacteria was lower than that of free-form vancomycin. Dissolving microneedles (DMNs) and nanocarriers (NC) working together to deliver drugs transdermally has tremendous potential (32). There have been hydrogel microneedles that dissolve, are solid, coated, hollow, and available. Healthcare techniques are being altered by nanotechnology. It is anticipated to have a significant impact in the years to come and improve healthcare facilities (32).

9. Nanoparticle Synergies for On-Demand Drug Delivery

The application of synthetic amphiphilic block copolymer (ABC)-based nano-delivery devices in experimental medicine and pharmaceutical sciences is expanding quickly (33). An inventive method for creating multicomponent systems with a variety of functionalities within a hybrid hydrogel network is the inclusion/incorporation of nanoparticles in three-dimensional polymeric frameworks (33). The creation of nanoparticle-based drug delivery systems (DDS) can advance immunotherapy while also enhancing the immunosuppressive tumor microenvironment (ITM), opening up new possibilities for the treatment of cancer (34). The new 3D structures benefit from the synergistic effects of nanoparticle-hydrogel pairings. New nanocomposite methods have also been described as using hydrogels as delivery systems for cancer treatments and injectable gels with enhanced self-healing capabilities (35). As a safe and efficient method of drug delivery, magnetic drug targeting uses the fewest possible magnetic particles to deliver the highest amount of medication to the desired location. By combining polyvinyl alcohol (PVA), kappa-carrageenan (Cara), and magnetite Fe3O4 nanoparticles, magnetic nanocomposite hydrogels with an emphasis on targeted drug delivery were created (35).

10. Nano Characterization

Nano characterization techniques cover the main characterization techniques used in nanomaterials and nanostructures. These are the analytical tools for the measurement and visualization of nanoparticles.

10.1. Scanning Electron Microscopy

The sample's surface is examined and altered using SEM. It is used to record and decipher some signals produced when the electron beam interacts with the sample. The electron beam can locally alter the surface material of the sample when it has the energy to do so, which could result in the creation of nm structures, which is why surface modification occurs. The most widely used method of sample surface modification, known as electron beam lithography, uses an electron beam as a writing and design tool with a precision of a few nanometers (EBL) (36).

10.2. Transmission Electron Microscopy

Using TEM to image nanoparticles successfully requires contrast between the sample and the background. Nanoparticles are dried on a copper grid that has a thin layer of carbon coating to prepare samples for imaging (37). It is simple to photograph materials with electron densities that are noticeably higher than those of amorphous carbon. The majority of metals and most oxides, such as silicon, aluminum oxide, and titanium oxide, as well as other particles, such as polymer nanoparticles, carbon nanotubes, quantum dots, and magnetic nanoparticles, are included in these materials. To directly evaluate the particle size, grain size, size dispersion, and shape of nanoparticles, the optimal technique is TEM imaging. The size accuracy often falls within 3% of the true number. Since TEM makes it possible to take high-resolution photographs of specific nanomaterials, it may be one of the most practical ways to figure out the morphological characteristics of a particular nanomaterial. Moreover, TEM has remarkable potential for use in statistical research due to the ease with which pictures of hundreds of nanomaterials can be obtained at any given time. Nonetheless, quantitative analysis of the morphological characteristics of nanomaterials continues to be a crucial test (37).

10.3. Atomic Force Microscopy

The AFM pictures can undergo a variety of processing procedures, including the use of particular algorithms and software to characterize the sample in a way that is more objective, quantifiable, and automated. The collected photos are stored as binary files with header information for deciphering data and supplying the x, y, and z scales of the image. Analyzing images involves measuring the properties of the image's constituent parts. Focus is placed on analyses involving object recognition, counting, and area calculation (using segmentation techniques), roughness measures (using various parameters), statistical distribution measurements (using histograms), and other characteristics that define the sample's topography (38).

10.4. Dynamic Light Scattering

The size of nanoparticles and an assessment of their stability over time in suspension, under various pH and temperature settings are measured using dynamic light scattering. The physical features of the sample are determined by the detection of the light scattered by the interaction of light with matter. In investigations using light scattering, a monochromatic beam is pointed at the sample, after which a detector captures the dispersed light at a specific angle. It's known as the Tyndall effect (39).

10.5. X-ray diffraction technique

XRD begins with the interaction of photons with electrons in the material by means of an elastic (no energy misfortune) and coherent (clear-cut stage connection between the incident wave and the scattered wave) scattering process. The consequence of the interaction of an electromagnetic wave with an electron is referred to in electromagnetism as Thomson scattering (40).

10.6. Surface Plasmon Resonance

Label-free optical biosensors can work with surface plasmon resonance (SPR) biosensors (41). The SPR method relies on optical measurements of refractive index changes associated with the binding of analyte molecules, for instance, to immobilized biorecognition molecules. SPR biosensors have evolved into the principal tool for studying biomolecular interactions in both life science and pharmaceutical research since the late 1990s. Also, they have been gradually used in important fields, including medical diagnostics, environmental monitoring, food safety, and security, to find chemical and biological compounds (41).

11. Conclusion and Future Prospects

In conclusion, medication delivery systems and biomedical devices have been significantly impacted by the application of nanotechnology in medicine (42). These systems have been developed using nanoscale materials such as carbon nanotubes, liposomes, metallic surfaces, inorganic and metal nanoparticles, and nanoscale metal particles. The incorporation of nanotechnology has made it possible to create organized drug delivery systems that have proven successful in several sectors, including veterinary medicine, antitumor, anticancer, antibacterial, antiviral, and antifungal treatments. Nanotechnology has also made it possible to create nano biomedical devices with crucial qualities like high precision and accuracy, biocompatibility, and durability that make them useful in a variety of biomedical applications (43). Also, by increasing the solubility, stability, and bioavailability of pharmaceuticals using nanotechnology-based drug delivery systems, the pharmacokinetic profile of those drugs has been greatly enhanced. Drugs can now be delivered specifically to certain cells and tissues thanks to the use of nanoscale materials in drug delivery systems, decreasing adverse effects and increasing effectiveness.

Moreover, the application of nanotechnology-based biomedical devices has produced notable improvements in several industries, including diagnostics, imaging, and therapy. For instance, the use of imaging probes based on nanotechnology has made it possible to image biological structures in high resolution, enabling the early detection and diagnosis of diseases. Similarly, the effectiveness of stent-based therapy for cardiovascular disorders has greatly increased with the use of drug-eluting stents based on nanotechnology (44, 45). The use of nanotechnology in medicine has significantly enhanced biomedical equipment and drug delivery systems, which has improved patient outcomes. Future improvements in medicine are highly anticipated because of additional research and development in this area.

Biomedical gadgets and drug delivery systems based on nanotechnology have enormous future potential. Nanotechnology is anticipated to have a substantial impact on the development of personalized medicine, where medications are matched to a patient's genetic profile and disease state, in the area of drug delivery. Furthermore, drug delivery systems based on nanotechnology have the potential to enhance medication transport across biological barriers, such as the blood-brain barrier, enabling more efficient treatment of neurological illnesses. The creation of more accurate and effective diagnostic instruments, as well as more successful implants and prostheses, is anticipated to be facilitated by nanotechnology-based systems in the field of biomedical devices. For instance, coatings made with nanotechnology can help implants better integrate with the surrounding tissue and lower their risk of infection.

In the future, nanotechnology-based biomedical devices are anticipated to significantly influence the field of regenerative medicine in addition to drug delivery. Using nanofibrous scaffolds, which can imitate the structure and functionality of original tissue and encourage tissue regeneration, is one promising strategy. These scaffolds can be employed for a variety of purposes, such as the regeneration of bones, skin, and nerves. Additionally, the use of sensors and imaging methods based on nanotechnology can deliver important details regarding the initiation and course of tissue regeneration, allowing doctors to keep an eye on the healing process in real-time. The utilization of biomedical equipment and drug delivery systems based on nanotechnology is also anticipated to have a substantial impact on global healthcare. Nanotechnology-based systems can offer economical and efficient solutions in developing nations where access to healthcare is frequently constrained. For instance, diagnostic equipment based on nanotechnology can enable the quick and precise identification of infectious diseases like malaria and tuberculosis in rural areas with few resources. Moreover, the adoption of drug delivery systems based on nanotechnology can enhance the distribution of necessary medications to disadvantaged communities, resulting in better health outcomes. In general, it is anticipated that the application of nanotechnology in biomedical devices and medication delivery will revolutionize the healthcare sector in the years to come, resulting in more individualized and successful therapies for patients.

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