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Nanotechnology in the diagnosis of bacterial infection: current trends, challenges and future prospects

Salaudeen Abdulafeez Ololade[1], Ojo Josephine Folasade[1], Lawal Olukayode Adeayo[1], Imohimi-Oduru Richard Mofedamijo[1], Ibrahim Ayisat Abiola[1], *Emmanuel Ifeanyi Obeagu[2] and Abdulwasiu Oladele Hassan[3]

[1]Department of Medical Laboratory Science, Uniosun Teaching Hospital, Osogbo, Osun State, Nigeria.
[2]Department of Medical Laboratory Science, Kampala International University, Uganda.
[3]Department of Medical Laboratory Science, Achievers University, Owo, Ondo State, Nigeria.

ABSTRACT

By delivering quick, sensitive, and targeted detection methods that have dramatically improved the diagnosis and treatment of bacterial illnesses, nanotechnology has revolutionized the field of bacterial diagnosis. This abstract seeks to provide a concise overview of the present trends, difficulties, and potential applications of nanotechnology in bacterial detection. The creation of nanoparticles that can find bacteria at incredibly low concentrations is one of the most recent developments in bacterial diagnosis. Nanoparticles can detect bacteria with great sensitivity and selectivity by utilizing the unique surface characteristics of bacterial cells and their interactions with different nanomaterials. These nanosensors offer significant promise for point-of-care diagnostics since they can successfully identify bacteria in clinical samples like urine blood and saliva. However, bacterial diagnostics based on nanotechnology also faces substantial obstacles. The absence of regulatory standards and guidelines for nanosensors is a significant problem. In order to verify the safety and effectiveness of these devices for clinical application, regulatory guidelines are required because the lack of standardization makes it impossible to compare the results acquired from various nanosensor platforms. Further research is necessary since the possible toxicity of the nanomaterials utilized in nanosensors is a serious concern. Despite these difficulties, nanotechnology has bright future potential for bacterial diagnostics. The creation of nanotherapeutics that can specifically target and kill bacterial cells without endangering host cells is one possible application. In addition to providing an alternate method of treating bacterial illnesses, these nanotherapeutics can break the bacterial resistance to antibiotics. Additionally, the creation of cutting-edge nanosensors and imaging methods can advance our comprehension of bacterial pathogenesis and aid in real-time monitoring of treatment efficacy. In conclusion, nanotechnology has had a substantial impact on bacterial diagnosis and has enormous potential to enhance both bacterial infection detection and therapy. The difficulties of bacterial diagnosis using nanotechnology must be overcome, and further study is required to create and improve nanosensors, nanobiotechnology chips and nanotherapeutics for clinical usage.
Keywords: Nanotechnology, diagnosis, bacterial infection, current trends, challenges, future prospects

INTRODUCTION

The development of numerous assays for effectively reporting the fouling levels of pathogenic bacteria has received a lot of attention, but the majority of them are only able to detect a single species of bacteria, failing to concurrently respond to multiple harmful bacteria [1]. Understanding and controlling matter at dimensions between about 1 and 100 nm, where special phenomena allow for novel applications, is what the National Nanotechnology Initiative (NNI) defined as nanotechnology [2]. In reality, different harmful bacteria with varying and low levels of concentrations may coexist in a contaminated matrix. The discovery of a single microbe that yet poses a hazard to human health makes it challenging to establish effective disease control. Alternatively, it is necessary to achieve the simultaneous detection of various pathogenic bacteria using a smart sensing platform, which is crucial and accurately manage the pathogenic bacteria and safeguard human health [3]. As much as there are more advanced technology in vogue that help in identification of bacteria organism out of which include PCR and mass spectrometry there are still some odds standing against them which include relatively decreased sensitivity that may easily lead to false positive result. More crucially, the immunoreaction-based technology often only works to detect a single bacterium at a time and finds it challenging to simultaneously detect many harmful microorganisms. The multiple polymerase chain reaction (mPCR) appears to be an efficient method for simultaneously detecting several harmful bacteria in practical applications to multiplex detection [4]. While the (mPCR) is assumably a trusted technique in the diagnosis of multiple infections, there are still certain drawbacks facing it which usually are the complex pretreatment and decoding analysis, all this not particularly time friendly and ultimately may give rise to false negative results [5].

Nanotechnology

Nanotechnology is defined as the process of separation, consolidation, deformation of materials by one atoms or molecules. The central idea of nanotechnology is to employ individual atoms and molecules to construct functional structures [6]. The ability to build things out of atomic and molecular building blocks, creating and utilizing materials, electronics, and systems by controlling matter on the length of nanoscale, has been acknowledged as a new field of study. Employment of Nanotechnology in medicine and physiology has birthed creation of materials and equipment with increased specificity that interact with the body at the subcellular and molecular levels. This may lead to enhanced clinical applications in association to a particular cells and tissues that aim to create greatest therapeutic effects with least side effects [7]. The consideration of various spatial and temporal scales directly affects the possible influence of nanotechnology: Engineering at the nanoscale level involves carefully controlling the arrangement of the constituent molecules and atoms that make up the bulk macroscopic substrate. Because of the ability to regulate the molecule synthesis and assembly processes, it follows that nano-engineered substrate can be created to the very particular and controlled bulk chemical and physical properties [7]. In order to bring together the necessary collective skills needed to develop these revolutionary technologies, traditional sciences such as chemistry, physics, materials science, and biology have come together to form the growing field of nanotechnology. The improved surface area to volume ratio found in the majority of nanoscale components is one of the key features of nanotechnology. This offers potential for fresh quantum mechanical effects. Because of this "quantum size effects," it will be possible to change the electrical characteristics of solids with significant reductions in particle size [8]. New opportunities for the development of imaginative nanostructured materials and nanosystems are presented by the discovery of novel materials, nanoscale phenomena, and processes as well as by the advent o unique theoretical and experimental research approaches. In terms of its applications in agriculture, electronics, medical, energy, and other fields, nanoscale research and nanotechnology are now making significant strides and are likely to continue doing so. A greater number of these advancements are being produced [9]. Nanotechnology has immensely contributed to the expansion of cutting-edge techniques used to develop new products, replace existing production machinery, reformulate novel materials and chemicals for improved performance leading to reduced material and energy consumption, reduce environmental harm, and also for curation or remediation of the environment [10]). Owing to originality in existence of bioentities like the proteins, enzymes, carbohydrates, DNA, RNA, and viruses that make up cellular structures are typically synthesized using nanotechnology. Since many molecular structures in biology have sizes between 1 and 100nm, nanoscience is generally thought of as being representative of nature in the biological sciences [8]. Innovative nanoscale substances and nanosystems can be developed by the examination of novel materials, processes, and phenomena at the nanoscale as well as the development of cutting-edge theoretical and experimental methods of investigation. The characteristics of materials at the nanoscale can be very different from those of materials at greater dimensions, making the nanoscale structures, or nanostructure are thought to connect the largest molecules in living systems or bulk materials with the smallest manufactured devices or atoms [11].

History

A long while back the concept "Nanotechnology" was born by a physicist and a Nobel laureate Richard feymann in the year 1959. In his book, He stated that the rules of nature were not limited by our capacity to conduct study at the atomic and molecular levels but rather by our lack of the required instruments and procedures, saying "There's plenty of room at the bottom" [8]. He gave in to doing things at very small via "Extravagant biological systems" as well as the possibilities of having robust electron microscopes that can make images of atoms regardless of their minuteness. Other successful applications that resulted from feymann's lecture in 1959 include the positioning of single atoms by a scanning tunneling microscope (STM), the manipulation of single atoms on a silicon surface, and the electrostatic trapping of single, 3D, nanometer-diameter colloidal particles from solution [8]. In 1974, the expression "Nanotechnology" was firstly used and clearly defined by Japanese researcher by the name Norio Taniguchi, despite working with nanoparticles for decades, scientists' capacity to determine the structure of the particles has hindered the success of their research not until it was clearly defined. In the year 1981, an integral tool that driven the success of nanotechnology as a diagnostic tool was invented by two famous scientists Gerd Binnig and Heinrich Rohrer both from IBM Zurich invented the scanning tunneling microscope (STM), Additionally, Eric Drexler in early 1980's coined the word "Nanotechnology" from Feynman's concept of a billionth of a physical size thus he gave the idea of molecular machinery, manufacturing and computation [12]. In 1985, one important nanoparticle type "Fullerene" also known as "Buckminster" was discovered by a system theorist named "Debunking Uncle Bucky". "Fullerene" a name given as a result of similarities to the popularized geodesic domes. Furthermore advancement journeying forward led to discovery of a new Nanoparticle type known as carbon nanotubes by Sumio llijima in the year 1991.

Classification

A number of nanoparticles exist which happen to fall under different classes

CARBON BASED NANOPARTICLES

(A) FULLERENES

Fullerenes are molecular allotropes of carbon that display a variety of fascinating occurrences because of their nature as n-electron nature that can be easily manipulated by chemical means, The enormous curvature of these 'hollow spheres' conjugated n-electron systems has enabled a complex chemical activity that has made the fullerene family a useful building block for substances of significance in physics, chemistry, and biology. It is described as molecular and crystalline structure with sixty carbon atoms (C60) [13].

(B) NANOTUBES

Japanese electron microscopist Sumio lijima made the discovery of nanotubes in 1991. Similar to the structure of an empty carbon tube, nanotubes have a distinctive hexagonal form, with the small exception that they include extra atom groups on two sides. They exhibit thermal resistance at high temperatures and have a strong, flexible structure that makes them suitable for usage in a variety of industries, such as the food industry, nanomedicine, medical devices, etc. Alpha-lactalbumin (a-La), a milk protein, is significant as a case study related to food applications because under the right circumstances, it may change into self-assembling nanotubes [14].

Metal Based Nanoparticles

(A) QUANTUM DOTS

The optical and electrical characteristics of quantum dots, which are semiconductor particles with a size of a few nanometers, are different from those of bigger particles due to the laws of quantum mechanics. They are a key area of discussion in nanotechnology. Quantum dots (QDs), commonly referred to as "artificial atoms," were the first type of nanotechnology to be applied to biological sciences, and they have a wide range of uses in both medical and industrial industries [15]. With their distinct narrow emission spectra, great photochemical stability, and continuous absorption spectra, QDs exhibit distinctive electrical and fluorescent properties [14].

(B) GOLD NANOPARTICLES

The wine-colored gold nanoparticles (GNPs) are an antioxidant-rich substance. The diameters of GNPs range from 1 nm to 8 nm, and they also exhibit a variety of shapes, such as sub octahedral, spherical, octahedral, icosahedral multiple twined, decahedral, multiple twined, tetrahedral, irregular shape, nanotriangles, hexagonal platelets, nanorods, and nanoprisms [16].

Techniques of Nanotechnology

(A) BOTTOM UP

The conceptualized approach of bottom up is the reverse of the top down as it involves the self-assemblage of atoms, molecules, and machines from fundamental chemical building blocks, this method enables the development of macroscopic concepts for machines and devices at the molecular level [8]. This helps put forward the creation of nanostructures with dimensions around 2 to 10nm atom by atom under a controlled chemical reactions. It is believed to be promising as it thought to be the approach upon which nanotechnology would finally stand on, it involves building complexes from simple or smaller devices.

(B) TOP DOWN

The bulk material used in the top-down method is first broken down into smaller pieces using mechanical, chemical, or other types of energy. The top-down method is most successfully applied in the electronics sector. To create functional structures at the micro/nanoscale, this business employs a variety of processes, including physical vapor deposition (PVD), chemical vapor deposition (CVD), lithography (photolithography, X-ray lithography, and electron beam), and wet and plasma etching [17].

NANOTOOLS and TECHNOLOGY

There are several important modern developments that enhances the structural characterization of nanomaterials which determine their size, shape, lattice and crystallinity.

1. The atomic force microscope (AFM)
2. The Scanning Tunneling Microscope (STM)

A) **Atomic Force Microscopy**

The surface texture of nanomaterials can be examined using atomic force microscopy (AFM), a nondamaging method [18]. It comprises a probe with a pointed tip that is put close to the cantilever beam. As the particle surface comes in touch with the tip probe and cantilever beam, piezoelectric scanners are used to examine it. AFM aids in determining the nanostructure's surface characteristics [19]. This method doesn't call for any surface treatment prior to imaging. It's with a greater resolution that offers a 1000 times higher resolution than the traditional optical microscope this which is done in fractions of angiostrum. Its distinctive feature is a micro- and nanoscale cantilever that is utilized to scan the specimen surface at the nanoscale level and has a sharp silicon or silicon nitrite tip (probe) at its end [20].

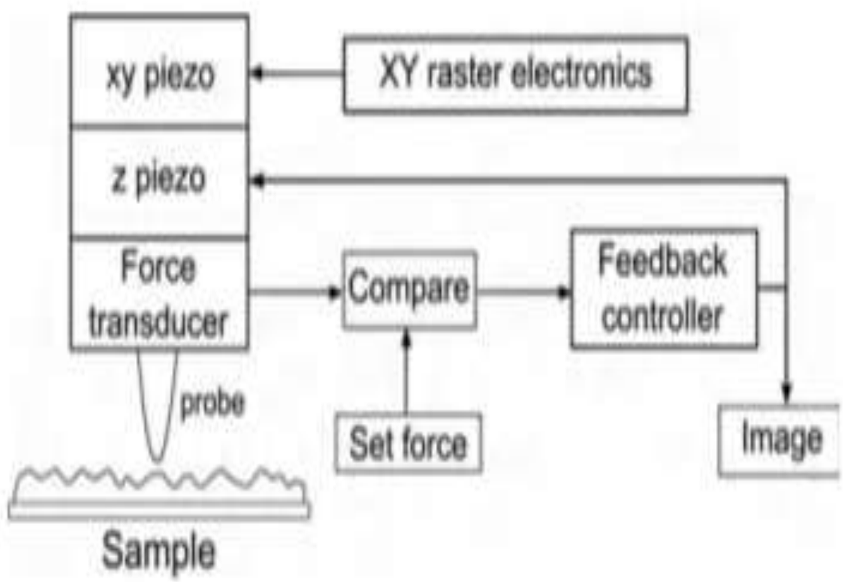

FIGURE 1: BLOCK DIAGRAM OF AFM OPERATION [21]

B) **Scanning tunneling microscope**

A scanning tunneling microscope (STM) allows for atomic-scale resolution when photographing solid surfaces. It operates on the principle of a tunneling current, which starts to flow when a pointed tip mounted on a piezoelectric scanner is offered to a conducting surface at a distance of about 1 nm. In fact, an STM can exhibit resolution down to the level of the individual atoms that make up a surface [8]. The method relies on a probe tip made of piezoelectric transducers that is placed over the sample from a nanometric distance. By measuring the tunneling current between the tip and the sample, a contour plot-image that allows you to see individual atoms in actual space can be obtained [22].

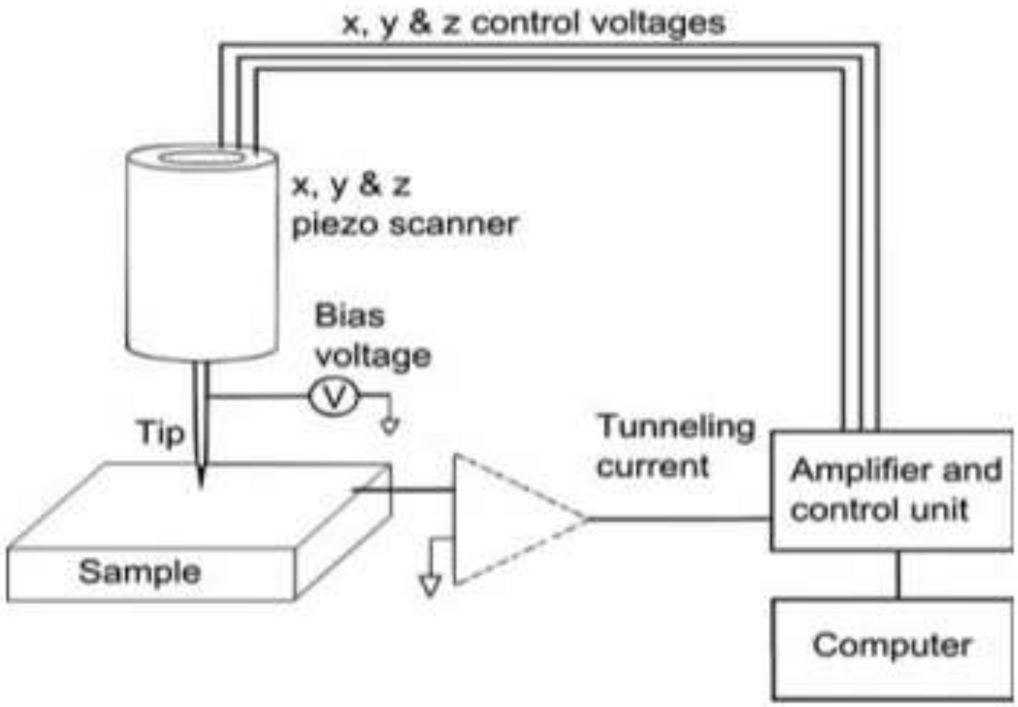

FIGURE 2: SIMPLIFIED SCHEMATIC OF A SCANNING TUNNELING MICROSCOPE (STM) [21].

Types of Nanomaterials

A) Clusters

They exist as a more compact atomic and molecular aggregations made up of molecules with nanometer-sized dimensions. Smaller, less than 2 nm-diameter atoms of one or more single or multiple elements make up metal nanoclusters. Because of their nanometric size, nanoclusters have favorable physical and chemical characteristics [23].

B) Nanowires

Carbon Nanotubes, metal oxides, or silicon are used to create Nanowires, which are nanoscale channels that provide a conduit for electrical currents with very low amplitudes. Their reduced size and diameter make it easier to detect even a slight alteration in their electrical characteristics.

C) Nanofibers

They are formed by interconnected porous mesh with exceptional networking of the pores. Nanofibers are frequently manufactured using natural polymers, synthetic polymers, carbon-based polymers, semi-conducting polymers, and composite materials [24]. They are as well employed for creation of biological sensors due to it well defined design and physicochemical properties [25].

Nanoparticles in bacteria diagnosis

A) Quantum Dots in Diagnosis

When a molecular probe (a protein or DNA sequence) is employed, quantum dots are used as molecular labels that are tagged with the probe. However, the Probe binds to its molecular target in a cell or other biological material, making it feasible to see where or how much of the molecule is present by illuminating the dots with UV light [26]. A notable feature of QDs is that it possesses a sizable Stokes shift, which can successfully neutralize the negative impact of excitation and emission spectrum overlap on sensing accuracy [27]. In relation to the study by wang *et al* a number of multi colored QDs were selected for use as a multi-color fluorescent indicators that covalently conjugate or bind multi pathogenic bacteria recognition antibodies to derive scaffolding that enhances simultaneous detection of organisms E.g S. enterica, S. aureus and E. coli with high sensitivity and selectivity [4].

b) Gold nanomaterials in diagnosis

The conceptualized features of Gold nanomarerials (AuNMs) has them termed the most attractive and extensively studied nano material in bioanalytical field and medical diagnosis, because of their fascinating features E.g. Ease of synthesis, increased biocompatibility and its non-cytotoxicity, they have been employed in biomedical application in labeling and biosensing. Owing to these characteristics, they have been used to separate multiple pathogenic organisms E.g. Viruses, bacteria etc [2]. With progression in research work, AuNMs has also found it use in colorimetric assay of analyte which depends on measuring solution color change to determine the levels of target analyte which doesn't require high cost and complicated sample pretreatment [28]. Thus the intuitive color change of AuNMs has been employed for performing the colorimetric assay of various pathogenic bacteria. This technique relies on anti-aggregation phenomena where the obvious color change can be observed. This method has therefore been employed for use in visual colorimetric detection of S. typhimurium, L. monocytogenes and E. coli O157:H7 [29].

c) Magnetic nanomaterials based assay

Due to its advantages superparamagneticity, superior monodispersity, and rapid separation etc [6]. Magnetic nanoparticles have recently attracted increased interest for their enormous practical potential in biological investigation. Given these special qualities, magnetic nanoparticles are frequently used as an excellent carrier for pathogen enrichment and magnetic immunoseparation in the context of microbiological tests, thereby enhancing the selectivity and sensitivity of analytical techniques [30].

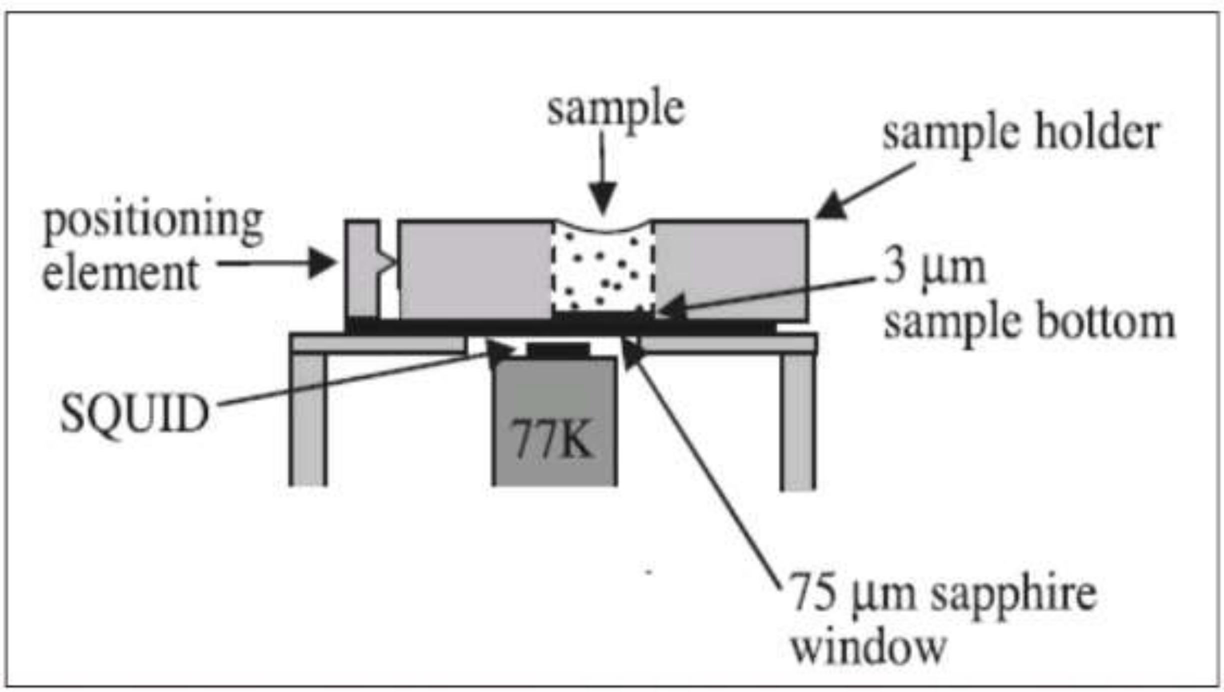

FIGURE 2: Simplified schematic of measurement of magnetic flux using squid (Ramane, 2020).

Given this features, the magnetic nanoparticles used are linked to an antibody, thus magnetically labeled bacteria can be detected by SQUID i.e. (Superconducting quantum interference device) which is a magnetometer that basically work on principle of detection of magnetic flux. Additionally, in this technique the SPMM (super paramagnetic magnetite) nanoparticles conjugated with antibody is added to aqueous solution of bacteria, then the pulsed magnetic field is applied followed by measurement of the magnetic flux using SQUID [26].

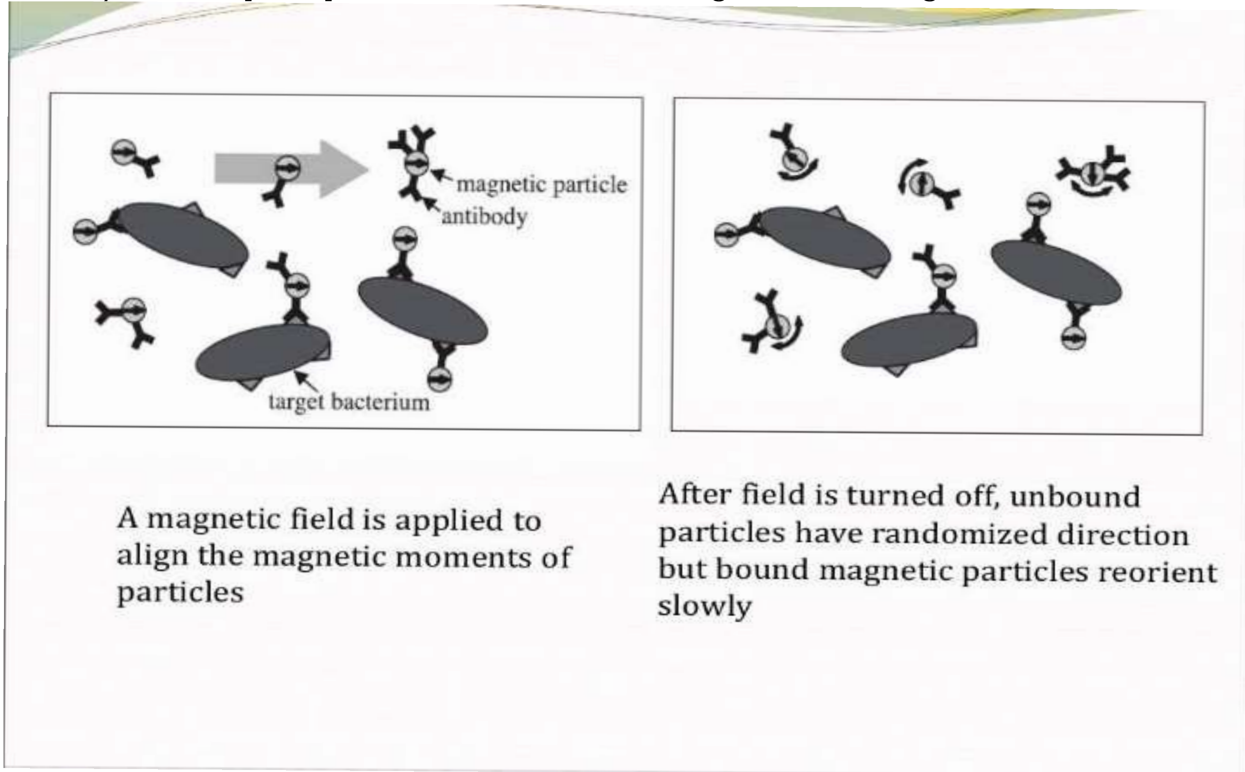

FIGURE 4: Schematic showing alignments of magnetic particles [26].

D) Colorimetric detection of *H. Pylori* DNA using AuNP probes

This is yet another nanodiagnostic technique that uses gold nanoparticle probes and thermophilic helicase dependent isothermal amplification (tHDA). This method makes use of primers that specifically target the ureC gene (from H. pylori) and amplify the bacterial DNA, producing DNA amplicons that are then hybridized with certain gold nanoparticle probes and detected colorimetrically by the assembly of gold nanoparticles. However, within an hour, this technique can identify as few as 10 bacteria per milliliter.

(1) **Smart phone based nanodevice for in-field diagnosis**

Today's world is standing on technology and digitalization, it is with this fact that enable scientific upgrade which caught across all fields in which nanotechnology is not an exemption, there's been a number of recent advances that specifically look inwards the disease diagnosis, one type of it that cannot be overemphasized is the application of smart phone for nanodiagnosis, driven by this facts the smart phone contains various sensors e.g. the pedometer that can detect the footsteps so is the image sensor that could be employed for use in fluorescent imaging that's coupled with the use of nanomaterials like Quantum dots.

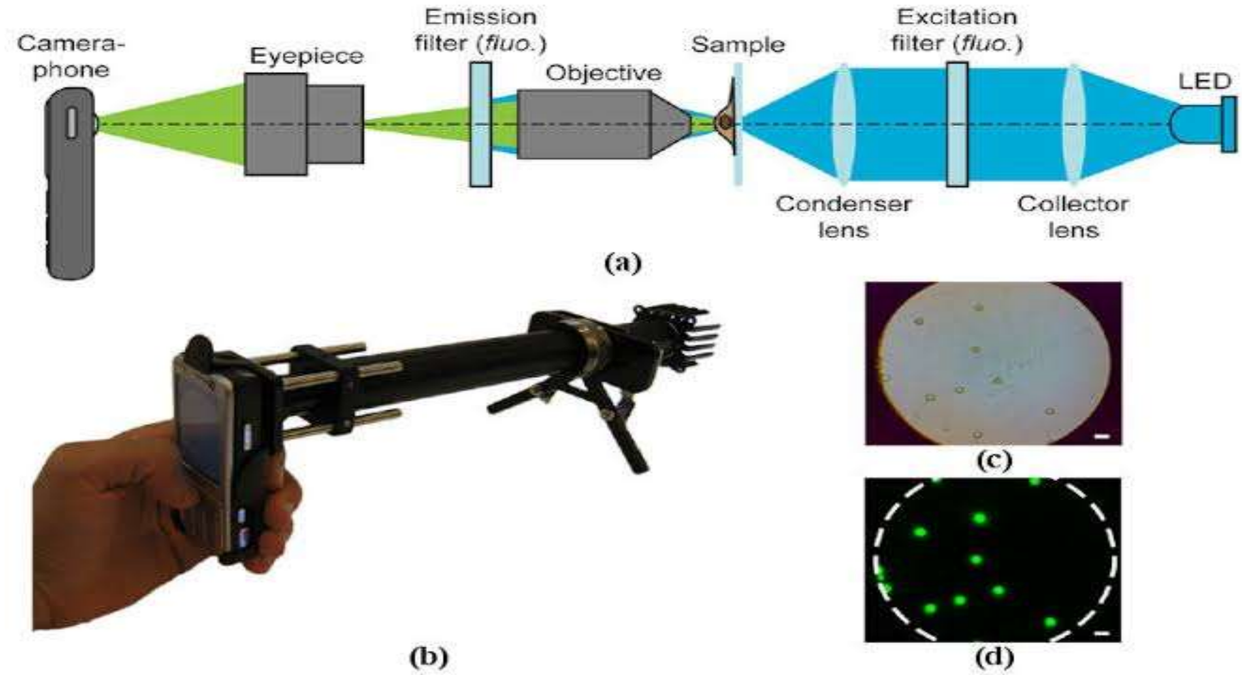

FIGURE 4: Illustration shows a smart phone based fluorescent imaging [31].

This technique uses Light Emitting Diodes (LEDs) as an excitation source which is used for detecting fluorescently labelled compounds e.g. Nucleic acids, Proteins and bacterium. In-field diagnosis via fluorescent imaging plus Q.Ds, the optical camera of the smart phone contains a complementary metal oxide superconducting image sensor that has its own photodiode and peripheral data circuits that transfer photons (optical image) into electrical signal output.

(2). Nanoscale identification of a single-cell or molecule

The development of nanotechnology has made it possible to successfully identify a single cell or a small number of molecules. The use of biomedical nanotechnology in proteomics, or "nanoproteomics," can make it easier to find a single protein molecule. One method for separating bacteria cells from closely related non-pathogenic cells is nanolaser scanning confocal spectroscopy. Biobarcode assays allow for the 2D identification of protein concentrations in bodily fluids that are too small for conventional approaches to pick up on.

The interaction between a nanopore and solutes provides the basis for mass spectrometry in solution. The current is lowered according to the size of each individual chain as charged molecules (such as ssDNA) are forced serially into the nanopore channel (1.5 nm), making it simple to quantify their mass. This method of single-molecule analysis may be helpful for the real-time characterisation of biomarkers [32].

3). Nanoparticles in the discovery of biomarkers

The existing molecular diagnostic tools for the detection of biomarkers can be replaced by biomedical nanotechnology. Nanoparticles are excellent candidates for biomarker detection due to their enormous surface area and unique physicochemical properties. In order to selectively bind and sequester protein complexes and other biomarkers for later evaluation utilizing high-sensitivity nanoproteomic tests, it is possible to modify the architecture of nanoparticles. Although the field of biomedical nanotechnology has not seen much activity in the area of biomarker development, it is anticipated to increase significantly in the next years. Polymercoated nanoparticles have been developed and put to use right now for quick biomarker identification [22].

4). Nanotechnology-based cytogenetics

The description of chromosome structure and the detection of chromosomal abnormalities connected to disease are done using molecular cytogenetics. Fluorescent in situ hybridization (FISH) is now being used to its maximum capacity. Biomedical nanotechnology, such as atomic force microscopy (AFM) and quantum dot (QD) FISH, is increasingly used to improve molecular cytogenetics. G-bands and chromosomal probes have both been studied using scanning near-field optical microscopy. This method's excellent resolution enables for very minute amounts of chromosomal DNA. The process combines biochemical and nanomanipulation techniques, enabling chromosomal DNA to be extracted and dissected at the nanoscale [33].

5). Nanodiagnostics in infectious diseases

It is crucial to develop a quick and accurate method for identifying infections in patients. Yet, conventional diagnostic techniques lack ultrasensitivity and are not as quick. For in-situ pathogen detection, nanoparticle-based methods have been developed that can quickly find and count bacteria in specimens. Multicolor oligonucleotide-functionalized QDs can be used as nanoprobes to bioimage a single molecule. When the nanoprobes hybridize with target-specific sequences, spectrum codlings are produced. In order to examine anthrax pathogens, our detection approach concurrently identifies numerous pertinent sequences. A highly sensitive method for amplifying and detecting traces of viruses has been created using silver nanorods and a very quick SERS-based spectroscopic test. This method detects viral DNA or RNA with high degree of sensitivity. This method involves scattering viral DNA or RNA, and measuring the change in frequency of the infrared laser. This frequency variation can identify the spectrum differences between different virus strains and is as distinct as a fingerprint. It is a novel virus nanodiagnostic technology that is quick, affordable, and reproducible [34].

6). Mechanistic understanding of NPS' antibacterial actions

NPs use a variety of methods to fight bacteria. They can adhere to the surface of bacteria by a variety of interactions, such as electrostatic, hydrophobic, van der Waals, receptor-ligand, or they can pass the bacterial membrane and gather inside bacteria [35]. By fatally stretching the bacterial membrane, NPs have the ability to mechanically destroy bacteria.

They can shred membranes after adhering to the bacterial surface and/or obstruct respiration, the efflux pump, electron, ion, and nutrient transport and balance. While inside bacteria, NPs have the ability to cause oxidative/nitrosative stress, produce reactive oxygen species (ROS) and reactive nitrogen species (RNS), harm DNA, alter gene expression, and deactivate key proteins and enzymes involved in a number of signaling cascades. They can also harm/kill microorganisms by dispensing poisonous ions.

Several NP kinds with various characteristics have been created to eradicate particular bacterial species. Different antibacterial efficacies/effects are displayed by NPs depending on their concentration, physicochemical characteristics (such as size, shape, surface chemistry, hydrophobicity/hydrophilicity), and incubation conditions/time. In addition, a bacterium's susceptibility to and resistance against NPs is determined by its growth rate, species, wall structure, genetic background, and capacity for adaptation [36].

Challenges

The application of nanotechnology in disease diagnosis comes with some challenges posing itself as a risk factor.

1. Mesothelioma: Mainly due to their small size and large surface, there's problem associated with respiratory systems, research has shown that certain nanomaterial like the carbon nanotubes (CNTs) is similar to asbestos particle mainly due to their small size and large surface where they are deposited in the lungs with subsequent translocation to the mesothelial cells of the lungs given rise to uncommon malignant tumor of the inner lining of the chest cavity, Mesothelioma [37].
2. NP Effects on Bacterial Communities in Soils increased NP release into the environment during synthesis, shipment, and trash was brought on by the widespread use of synthetic NPs in industry, medicine, and consumer goods. Many bacteria with genes for antibiotic resistance are found in soil [38]. Concerns concerning the negative effects of NPs on soil antibacterial resistance are raised by the discharge of NPs into the environment and/or the coexistence of NPs and soil bacteria. By increasing the expression of antibiotic-resistant genes and facilitating horizontal gene transfer, rare earth oxide nanoparticles (REONs) including La2O3, Nd2O3, and Gd2O3 improved soil bacteria's resistance to tetracycline and macrolide lincosamide-streptogramin B [39]. It is generally known that when NPs are discharged into the environment, their physicochemical characteristics and synthetic identity change. The exposure of NPs to the environment may endanger healthy bacteria. One novel form of nanosized complex metal oxide used for energy storage in batteries is lithium intercalating compounds [40]. When the batteries are thrown away, these NPs are, nevertheless, released into the environment. This nanocomplex releases Co and Ni ions, which interfere with cellular respiration, damage DNA, and promote sporulation to slow the growth of soil bacteria [41]. Due to their distinctive optical properties, quantum dots (QDs) are a different class of manufactured NPs that are frequently used in commercial applications [42]. Various QD derivatives, including silicon QDs, cadmium selenide, and cadmium selenide coated with zinc sulfide, shown additional harmful effects against helpful soil microbes [43]. Whereas other kinds of QD derivatives had minor antibacterial effects, cadmium selenide killed both gram-negative and gram-positive bacteria in a concentration-dependent manner by interfering with membrane integrity and respiration. Due to their less potent antibacterial effects, silicon-based QDs are chosen over cadmium-based QDs for commercial goods.

Future prospect

A variety of biological studies could use the flexible and effective conceptual framework of nanotechnology. Protein nanobiochips are an illustration of a device that makes use of nanotechnology-based biochips and microarrays. These nanobiochips are adaptable for usage at the point of care.The most foreseen diagnostic use of nanodiagnostics will be in the detection of bacterial amino acid sequences, which will be accomplished by further miniaturizing the current biochip technology to the nanoscale level [33]. The identification of these microorganisms will operate as molecular fingerprints, enabling a quicker and more accurate evaluation of the status of health. Additionally, nanodiagnostics may speed up the turnaround time (TAT) for results. To get over the current delays in bacterial detection, genomic profiling of bacteria will be increasingly used over the decade that follows. Nanorobotics are nanodevices that can be used for both diagnosis and treatment. Such nanodevices would eventually replace the periodic detection of biomarkers in patient body fluid samples because in vivo assessments performed continually would yield more reliable results. In the coming years, biomedical nanotechnology will be crucial to the development of personalized medicine, as well as in diagnosis and therapy. The decision-making process for high-quality healthcare delivery in the future will be led by the technicians who perform these tests because of the interactions between a number of biomedical nanotechnologies used in nanodiagnosis.

CONCLUSION

In conclusion, biomedical nanotechnology holds the possibility of expanding the boundaries of existing medicines and diagnostics and enabling the creation of more individualized medicine. The technology would be utilized more frequently in the decade that follows for the quicker and more accurate diagnosis of bacteria as well as the detection of other infectious agents.

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