Chapter 2

Nanotechnology and Current Applications in Biotechnology

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Abstract

The properties of nano-sized structures are crucial for the use of materials. By applying different surface modification methods, materials can become functional and increase their biocompatibility. Today, biocompatible nanomaterials, nanodevices, and nanosystems boast popular and innovative approaches for medical applications. Due to the growing interest in future biotechnological applications of nanotechnology, this multidisciplinary branch of science has expanded into medical and biomedical applications, environmental pollution control, cosmetics, optics, textiles, electronics, and more. The most popular and innovative approaches for medical applications are nanomaterials, nanostructures, and nanosystems. Agricultural biotechnology provides researchers with the opportunity to understand and manipulate agriculture and the genetics of all organisms. Similarly, biotechnology offers the opportunity to change different properties of nutrients, such as quantity, strength, and taste. While plant biotechnology aims to improve the productivity and quality of plants and make them resistant to biotic and abiotic stress, animal biotechnology focuses on animal organic genetics, artificial fertilization, embryo transfer, and the development of cheaper and easier diagnosis and treatment methods for animal diseases. This study examines nano-biotechnological applications that contribute to many fields.

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1. INTRODUCTION

1.1. "Nanoscience", "Nanoscale" and "Nanotechnology"

Before going into the details of Nanotechnology and Nanoscale science, it is necessary to clarify the subject by defining terms such as "Nanoscience", "Nanoscale" and "Nanotechnology". The Greek prefix "Nano" derives from the word nannos, meaning "very short man". The origins of most of the measurement prefixes we currently use come from Greek and Latin words. For example, hecto comes from the Greek word hekaton, meaning face, and senti comes from the Latin word centum, meaning face (Allhoff, Lin, & Moore, 2017).

"When we talk about nanotechnology, it is about a size or length scale; we're talking about an order of magnitude. When we speak of a nanometer (nm), we refer to objects whose dimensions are on the relevant scale" (Allhoff et al., 2017, p. 5). Thus, it becomes easier to talk about the size of atoms with nanotechnology. If we were to define the dimensions of atoms and molecules in meters, we would say that a hydrogen atom is 2.4x10-10 meters. However, when we use a nanometer instead of a meter, we can state that a hydrogen atom is 0.24 nm (Allhoff et al., 2017).

Nanoscale is defined as the size scale on which nanotechnology focuses. Although there is a limit value smaller than these scale sizes, it is very difficult to determine the upper limit.According to one view, "for something to exist at the nanoscale, at least one of its dimensions (length, width or depth) must be smaller than approximately 100 nanometers" (Allhoff et al., 2017, p. 5). The National Nanotechnology Initiative (NNI) also determined the limits of the nanoscale while defining nanotechnology. "Nanotechnology is the technology in which unique phenomena enable new applications and in which matter is understood and controlled when it is roughly 1 to 100 nm in size" (Anonymous, 2022).

After explaining that the expression "nano" in the word nanotechnology defines a certain scale, we can explain what the nanoscale is by comparing the size of the nanometer with better-known quantities to determine its relationship with our daily life (Allhoff et al., 2017). When materials are reduced to nanometer scales, quantum behaviors replace classical behaviors and their physical properties change intermittently. Since electrons in nanostructures are squeezed into an area of a few nanometers, they can greatly change the known mechanical and electronic properties of the structure by adapting to new quantumizations according to the geometry of the structure. For example, if a different atom is bonded to a nanostructure, it can change its electronic property (electrical conductivity). This different atomic transition element can add magnetic properties to the nanostructure it is attached to. In summary, the physical and chemical properties of the nanostructure show significant changes depending on the size and dimensions of the nanostructure (Çıracı, 2007).

Çıracı (2007) briefly defines nanoscience and nanotechnology as "Nanoscience enables us to understand these new behaviors that occur at very small sizes with the help of quantum theory. Nanotechnology aims either to design and synthesize new materials and nanostructures, or to functionalize existing nanostructures or molecules and use their extraordinary properties in new applications."

1.2. History of Nanotechnology

Chronological development of nanoscience and nanotechnology (Baykara, 2016; Erkoç, 2012).

• It is estimated that the first living cell appeared 3.5 billion years ago. A living cell can be defined as a machine that operates at the nanoscale.

• In 400 BC, Democritus, one of the ancient Greek thinkers, used the word "atom" for the first time. He is famous for his theory of the atom or indivisible essence.

• Lycurgus Cup in the 4th century AD, colour additives (nano-pigments) added by glass masters in nanoscale.

• 15-16. centuries - Iznik Tiles, colouring additives (nano-pigments) used by tile masters to obtain vibrant motifs and colours in production.

• 1905: Einstein published his paper stating that a sugar molecule is 1 nanometer.

• 1931: Max Knoll and Ernst Ruska built the first example of the transmission electron microscope.

• 1959: Richard Feynman's famous speech titled "There's more room below"

• 1974: Aviram and Seiden patented the first molecular electronic device.

• 1981: H. Rohrer and G.K. They invented the Binnig scanning tunnelling microscope (STM), allowing atoms to be imaged one by one.

• 1985: A new carbon compound C60 with a diameter of 1 nanometer is discovered.

• 1986: C.F.Quate, G.K Binnig and C. Gerber invented the atomic force microscope (AFM).

• 1987: The quantum property of conductivity was observed for the first time.

• 1987: G. J. Dolan and T. A. Fulton manufactured the single electron transistor for the first time.

• 1988: W. De Grado and his team produced artificial protein for the first time.

• 1989: IBM script was written from the 35Xe atom in Zurich, IBM.

• 1991: Lijima discovered multi-walled carbon nanotubes.

• 1993: The first Nanotechnology Laboratory was established at Rice University, USA.

• 1997: N. Seeman manufactured a nanomechanical device for the first time using the DNA molecule.

• 1997: Electric current was measured using nanotubes for the first time.

• 1999: M. Reed and J. M. Tour made an electronic key with a single organic molecule for the first time.

• 2000: For the first time in the USA, $422 Million was allocated for nanotechnology research.

• 2001: Transistors and logic circuits were made from nanotubes for the first time.

• 2001: ZnO nanowire laser was made.

• 2002: Superlattice nanowires were made.

• 2005: The first four-wheeled nanocar model was moved.

Green Nanotechnology

Nanoparticles can be synthesized using a variety of methods, including physical, chemical, biological and hybrid techniques (Mohanpuria et al., 2008; Tiwari et al., 2008; Luechinger et al., 2010). Production of nanoparticles by traditional physical and chemical methods results in toxic byproducts that are environmental hazards. Additionally, these particles cannot be used in medicine, especially in clinical areas, due to health-related issues (Parashar et al., 2009). Conventional methods can be used to produce large quantities of nanoparticles with defined sizes and shapes in less time; however, these techniques are complex, costly, inefficient and outdated. In recent years, there has been increasing interest in the synthesis of environmentally friendly nanoparticles that do not produce toxic waste products during the production process (Daniel and Astruc, 2004; Li et al., 2011; Chauhan et al., 2012). As an alternative to traditional physical and chemical methods, nanoparticle synthesis can be carried out using biotechnological tools that are considered safe and ecologically sound for nanomaterial production. The most striking use of nanotechnology; nanoparticle (NP) synthesis can be made using natural resources (Ahmed et al., 2021). Since green plants are mostly used when synthesizing nanoparticles (green synthesis), this new field of science is; It is called "green nanobiotechnology" (Narayanan and Sakthivel, 2011). Green synthesis provides the biological synthesis of metallic nanoparticles using plants or plant extracts, which are more environmentally friendly and provide a more controlled synthesis in terms of size and shape (Kumar and Yadav, 2009). In general, green nano biotechnology, various biotechnological synthesis of nanoparticles or nanomaterials using microorganisms, plants and viruses or their by-products such as proteins and lipids. Nanoparticles produced by green synthesis have much superior properties than those produced by physical and chemical methods in various aspects. The most important advantage of this green synthesis method is that it does not require the use of expensive chemicals and consumes less energy. In this way, it produces products and by-products that do not harm the environment (Humbal and Pathak, 2023). Three main steps are followed for the synthesis of nanoparticles using a biological system: the selection of the solvent medium used, the selection of an environmentally friendly and environmentally benign reducing agent, and the selection of a non-toxic material as a capping agent to stabilize the synthesized nanoparticles (Almutairi and Alharbi, 2015; Ambrosone et al., 2016).

Nanomaterials

Hett (2004) divided Nanomaterials (as cited in Ansari, Shahzadi and Ahmed, 2020) into three groups dimensionally.

One Dimensional

Nanomaterials with a dimension smaller than 100 nm are included in this group. Nanowires and nanorods are examples of one-dimensional nanoparticles used in the creation of various chemical and biological sensors, solar cells, IT systems, and optical devices (Ansari et al., 2020).

Two Dimensional

Nanomaterials with a size of less than 100 nm along at least two dimensions are known as 2D nanoparticles; carbon nanotube fibers and platelets (Ansari et al., 2020).

Three dimensional

Metallic nanomaterials with all dimensions, i.e., quantum dots, dendrimers, and hollow spheres <100 nm, are three-dimensional nanoparticles (Ansari et al., 2020).

Nanomaterials are also classified according to their structural form (Ansari et al., 2020) ;

- Polymeric micelles
- Metallic nanoparticles
- Dendrimer
- Nanocrystals quantum dots
- Carbon Nanotubes
- Liposome
- Polymeric nanoparticles

1.3. Nano Manufacturing Technologies

The advantages of nanoscale materials such as being lighter, more durable, using less material and less energy during the production phase, and error-free production without the production of waste materials are important features of nanomanufacturing (Erkoç, 2012).

There are two different approaches to obtaining very small materials and devices. The first is to cut, trim, crush, forge and shape a block of material to obtain a desired small structure, which is called the “top-down” approach. The second approach is to design atoms or molecules by lining them up side by side to form larger objects. This is called the “bottom-up” approach (Allhoff et al., 2017).

1.3.1. Top-Down Production Technique

The top-down approach is the process of separating a block of material into pieces that can be reduced down to nano size by mechanical or chemical processes. This approach is widely used in the electronics industry today. In the conditions of relentless competition based on information technologies, the race to place a large number of transistors on a circuit by constantly reducing the dimensions has reached undeniable dimensions. One of the techniques generally used in the top-down formation of nanoscale structures and in obtaining small structures from large ones is a technique called photolithography. It is a technique used to create patterns in semiconductors, and patterns can be made in sizes between 100 nm and 30 nm. In this technique, processing around 30 nm size is difficult and costly (Allhoff et al., 2017).

1.3.2. Bottom-Up Production Technique

The bottom-up approach is the process by which larger objects are formed by arranging molecules or atomic building blocks. Natural nanoscale processes in nature always occur in this way. For this reason, bottom-up production processes are encountered in organic materials and are known as activities related to the fields of chemistry and biology (Ateş and Bahçeci, 2015).

Chemical Synthesis

Mitra et al. (2015); Yuvakkumar et al. (2015) stated in their study (as cited in Ansari et al., 2020) that nanoparticles were synthesized by several chemical methods. Elghanian et al. (1997); and Hurst et al. (2006) , (Ansari et al., 2020) state that the most commonly used method among these chemical methods is the chemical reduction method. Tran and Le (2013); and Iravani et al. (2014) stated in their study (as cited in Ansari et al., 2020) that various organic and inorganic compounds were used as reductants for the production of nanoparticles. Sastry et al. (2003) studies (Ansari et al., 2020) Nanoparticles can be synthesized in bulk quantities using the reducing ability of different chemicals, and the reaction takes much less time to complete. However, they stated that they are also harmful due to the use of synthetic chemicals that are toxic and pose a risk to the environment and living things. For this reason, it becomes necessary to develop non-toxic, environmentally friendly and economically beneficial methods for the development of nanoparticles using methods other than chemical methods.

Biological Synthesis

Reddy et al. (2012) in a study (as cited in Ansari et al., 2020) defined the biological synthesis of nanoparticles (Biological entities; viruses, bacteria, fungi, microorganisms in the form of plant extracts or biomass) as an environmentally friendly alternative way for the production of nanoparticles rather than physical and chemical methods.

1.4. Tools Used in Nanotechnology

The development of new technologies accelerates with the development of new tools and theories that allow us to see the future. Nanotechnology is not much different from this perspective. While these tools in nanotechnology are still in the process of development today, most of the tools and theories in use are intertwined with the developments in the field of physics over the last 100 years (Allhoff et al., 2017).

The light microscope has played an important role in scientific and technological research, examination and studies for many years. However, due to its maximum magnification capacity of x2000, it could not achieve the desired image quality, so its use was limited to objects smaller than 1 mm. It is widely used in metallurgical and material science studies. Electron microscopes are used for nanotechnological studies (Baykara, 2016).

1.4.1. Electron Microscopes (EM)

In the electron microscope, electrons are used instead of light to obtain images. Instead of a lamp or daylight, an accelerated electron beam in a vacuum tube is used as the illumination source (Kapakin, 2007). The human eye has the power to distinguish 0.1 mm, the light microscope 0.2 μm, and the electron microscope 0.1 nm. For this reason, electron microscopy allows examination with a resolution far beyond the human eye and light microscopy (Karakoç, Ketani, and Ketani, 2016). There are three types of electron microscope: Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM) and Scanning Transmission Electron Microscopy (STEM). As a field of use, STEM is more limited than others. (Kapakin, 2007).

Transmission Electron Microscope (TEM)

It was discovered in the 1930s. It is preferred in nanotechnological applications. Magnifications of 400,000 can be achieved for many materials, and magnifications greater than 15 million times are possible for atoms. TEM works like a projection device. It passes the light beam over a thin leaf-like object and conveys information about the properties of the object it passes through. In TEM, electrons are used instead of light. The materials used in TEM must be thin enough for electrons to pass through. Otherwise, it becomes very difficult to get a good TEM image. This difficulty in sample preparation is a disadvantage of TEM versus SEM (Wilson, Kannangara, Smith, Simmons, & Raguse, 2002).

Scanning Electron Microscope (SEM)

The Scanning Electron Microscope (SEM) was developed in 1942 and was commercially released in 1965. The fact that SEM provides clearer, three-dimensional image quality and requires less preparation work before taking the spectrum of the sample has made it more popular than TEM.

Transmission electron microscopy (TEM) has a higher magnification. Scanning electron microscope (SEM), on the other hand, has a larger depth of field and allows the focused image to be further magnified, in the range of 10 to 100,000 times magnification. In addition, providing a three-dimensional and clear image of the sample provides researchers with detailed information about the shape and structure of the examined piece (Wilson et al., 2002).

Scanning Probe Microscopes (SPM)

Scanning probe microscope; It includes scanning tunneling microscopy, atomic force microscopy and several newly developed microscope technologies (Wilson et al., 2002).

Scanning Tunneling Microscope (STM)

Scanning tunnelling microscopy (STM) was discovered in 1981 by Heinrich Rohrer and Gerd Karl Binning. Five years after the discovery, the scientists who discovered the electron microscope, Heinrich Rohrer and Gerd Karl Binning, were awarded the Nobel Prize in physics for their discoveries. The scanning tunnelling microscope was the first microscope to provide real-space images of surfaces at atomic resolution. STMs are similar to AFM except for the use of a sharp and conductive tip where a positive voltage is applied between the sample and the tip. When the tip in the STM is brought close to the sample until it remains 1 nm, the electrons coming from the sample try to reach the tip by passing through this 1 nm gap or vice versa (depending on the phase of the applied voltage) to move from the tip towards the sample. Just as a wave in the sea passes over rocks and reaches the other side, electrons can reach the sample by bypassing the energy barrier. In other words, by activating the wave feature of the electron, it is made to behave like a particle and overcome the energy barrier that it cannot jump over. This movement is called tunnelling. The tunnelling current can vary depending on the tip-sample distance and is used as a signal in creating an STM image. For tunnelling to occur, the sample and tip must be semiconductor or conductive. STMs cannot take images from insulating samples. However, if a tunnel current is created using a water layer, observations can also be made in insulating materials. This feature is important for biological materials (Wilson et al., 2002).

Atomic Force Microscope (AFM)

The AFM technique is used for obtaining the 3D profile of a nanoscale surface. It is a powerful tool, frequently used in nanotechnology-related research. AFM is capable of examining the surfaces of a wide range of materials and objects, including but not limited to biological samples, metals, glasses, plastics, semiconductors, bacteria and cell walls. In AFM, the surface doesn't necessarily have to be conductive. However, accessing atomic resolution has some limitations. Even if an AFM probe tip is produced with high precision, it's impossible to achieve ideal sharpness. Therefore, the topographic images won't provide the exact real image, which is commonly referred to as "Twisting" (Baykara, 2016).

ApplIcatIons of Nanotechnology In nano-bıotechnology

The world population is projected to reach 9.1 billion by 2050, according to the Food and Agriculture Organization of the United Nations. However, the end of fertile agricultural lands and population growth are leading to a decrease in agricultural areas per capita, leading to problems such as soil erosion, salinization, pH, compaction, pollution, organic matter loss, and mineral nutrient deficiency. Additionally, an estimated 38% of the 1.47 billion hectares of land used for crop production is in the degradation phase. Burning forests to gain agricultural land and polluting water resources exacerbate these issues. Therefore, the use of new technologies in agricultural production is becoming increasingly necessary. Nanotechnology has the potential to improve environmental conditions, design new systems for animal and plant food production and pesticide production, increase efficiency and quality in production, and obtain products with high added value. In agriculture, nanotechnology can be applied in various areas such as rapid diagnosis and treatment of diseases, nano drugs, parasitology and vaccine research, animal nutrition, plant production and growth, abiotic stress, nano phytopathology, plant pest management, post-harvest preservation and storage of agricultural products, detection and diagnosis of harmful and toxic substances in the environment, and reducing pollution in soils.

2.1. Rapid Diagnosis and Treatment of Diseases

Nanodiagnostic technologies are becoming increasingly important in the field of diagnosis. Since cell components are typically in nanoscale sizes, diagnostic devices that can monitor and diagnose these molecules must also be in nanoscale sizes. Some examples of nanodiagnostic technologies include nanoscale imaging, biochips, microarrays, nanoparticle-based nucleic acid diagnostics, nanoproteomic diagnostics, biobarcode testing, DNA nanomachines, nanoparticle-based immune tests, nanobiosensors, quantum dots, and nanoshells.

2.2. Biochip and Microarray Devices

Biochips and microarray devices are also commonly used in diagnosis. Examples of these devices include nanofluidic arrays and protein nanobiochips. Nanofluidic devices are particularly useful for the analysis and isolation of diagnostically relevant biomolecules such as DNA and protein sensing, which have created new detection schemes for cancer. Biochips can also be used in the early diagnosis of animal diseases. They can detect the source of pathogens such as mad cow and bird flu, and monitor the source of food and feed.

2.3. Biosensors

Biosensors are devices that use a combination of a biological element and a physicochemical transducer to detect a chemical substance. The biological element interacts with the substance to be analyzed, resulting in changes that are then converted into measurable electrical signals by the physicochemical transducer. Most biosensors are amperometric enzyme biosensors. Amperometric biosensors applies a constant potential to the reference electrode and measures the current on the electrode surface used during the process (Budak, 2022). Amperometric biosensors are redox enzyme based. Preference The biggest reason for their consumption is fatty acids, sugars, amino acids, aldehydes and phenols. The oxidoreductase enzyme that can interact with it is easily available.Potentiometric biosensors analyze the potential difference across the membrane. It is used to carry information about water and concentration. Nowadays, biosensors have different area of use. Biosensors are sensitive to biological or chemical active substances. It must bind and react selectively, rapidly and continuously. In order to achieve this it must have the following features;

- Bioactive and biosensing material must be available.

- These materials must be able to recognize the elements or analytes of interest.

- The biosensing material must be in close contact with the transducer.

In general, a biosensor measures a biological, chemical or biochemical signal and

converts it into a processable electrical signal. The electrical signal is then chemically or physically combined with the converter. For this reason, the properties of biosensors and the environment in which they are used conditions are important. Biosensors can be classified based on the type of bioreceptor and transducer used, as well as the relationship between the transmission and measurement systems. The types of bioreceptor interactions include nucleic acid, biomimetic material, antibody-antigen, enzymatic, and cellular interactions. The types of transducer measurements include electrochemical, thermal, magnetic, optical, and mass sensitivity-based measurements. Table 1 shows the classification based on the relationship between transmission and measurement systems. (Tüylek, 2017 b).

Table 1. "Classification of Biosensors According to Transmission and Measurement Systems" (Tüylek, 2017 b).

Biosensors	Classification
Electrochemical Based Biosensors	-Amperometry Based Biosensors (Electrodes) -Potentiometry Based Biosensors (Electrodes) -Semiconductor (conductometry) Based Biosensors (Transistors)
Optical Based Biosensors	-Photometry Based Biosensors (Optical Fibers) -Fluorometry Based Biosensors (Optical Fibers) -Bioluminescence Based Biosensors
Calorimetry Based Biosensors	-Thermistors (Heat, Isothermal, Isoperibol)
Piezoelectric Based Biosensors	- Piezoelectric Crystals

Biosensors are widely used in various fields like medicine, engineering, chemistry, and biology due to their miniature size, low-cost, and convenience. They are also used in agriculture to measure artificial fertilizers, bad odours, pesticides, and plant and animal diseases. Biosensors can measure heavy metal and pesticide levels in soil and groundwater and predict soil diseases that cannot be detected with today's technology. Early prevention and disinfection of soil diseases can also be achieved by using biosensors. Another use of biosensors in agriculture is the rapid detection of plant pathogens, bacteria, and viruses. Plant pathogens such as bacteria, fungi, viruses, viroids, phytoplasma, and nematodes cause significant crop losses worldwide. Detecting plant pathogens is the prerequisite for treating a plant disease in fields and greenhouses. ELISA and PCR are time-consuming and not suitable for on-site analysis. As a result, biosensors are preferred for detecting plant pathogens because they are fast, easy to use, inexpensive, and suitable for on-site analysis. In a study conducted in the agricultural field, a surface plasmon resonance (SPR)-based biosensor was used to rapidly diagnose maize chlorotic mosaic virus.

Biosensors have various applications in dairy technology, including detecting the different components of milk such as water, non-fat dry matter, fat, lactose, protein, casein, fat in dry matter, minerals and organic acids. They are also used to detect milk contaminants such as veterinary drugs, heavy metals, radioactive substances, pesticides, mycotoxins, products with genetically modified organisms, and nitrate contamination. Additionally, biosensors are useful in identifying microorganisms. Moreover, they are used for monitoring biological warfare agents and environmental pollutants. For instance, they can detect bacillus anthracis (anthrax bacteria).

2.4.Nanobiosensors

Nanobiosensors have been in use since the late 1990s. These devices are capable of measuring biochemical or biological events using a compact probe and various optical, electronic or magnetic technologies. They are made with nanoparticles, nanowires, quantum dots, field-effect transistors, and sensors based on electronic detection. Nanobiosensors are highly sensitive measuring devices that can provide dozens of pieces of information at micro and nano scales in a short time with very small samples taken from body fluids like blood, sweat, tears, saliva, urine and sperm. They are capable of detecting and measuring biological substances found in living organisms at nmol/L or pmol/L level, which means that changes in the organism can be detected and measured immediately, and necessary interventions can be made without delay. Early diagnosis of diseases can lead to prompt treatment, which is why nano biosensor applications are highly needed today.

Blood shows that many organs are healthy or diseased. For this reason, blood tests performed with today's technologies are the most common clinical diagnostic applications. Blood fluid provides the opportunity to evaluate health and disease through molecular fingerprint detection (Tüylek, 2021). "Molecular electronics and nanoscale chemical sensors are microscopic sensors that can detect chemicals in a liquid" (Tüylek, 2021, p.23). These devices, which provide a large amount of information from blood, also reveal the properties of small chemicals in the macroscopic tissue volume. Long-term use of nano biosensors is promising for monitoring changes and diagnosing the disease. Shortly, biosensors developed with nanotechnology will play an important role not only in diagnosis but also in the treatment and development of personalized medicine. Another application area will be early diagnosis of cancer. When cancer is diagnosed using current methods, it is often too late for treatment. Nanobiosensors will provide sensitivity in detecting biomarkers that can be used in the early diagnosis and treatment of cancer in the future (Tüylek, 2021). Application areas of nano biosensors in agriculture: Detection of agricultural chemical residues, GMOs, pathogens, gases, cancer and biotoxins can be demonstrated.

2.5. Nanoshells

Nanoshells are small spheres that have been developed for use in drug delivery, cancer diagnosis, and treatment. They consist of a silicon core at the center, which is covered with a layer of gold. The thickness of the gold layer can be adjusted to absorb light at specific wavelengths. Antibodies and drugs used in cancer treatment are placed on the surface of the nanoshells and directed towards cancer cells. These cells engulf the nanoshells through a process called phagocytosis. The nanoshells are intended to be metabolized by the enzymes inside the cell and then eliminated. However, they cannot be metabolized, so instead, they enable the cancerous cells to emit heat with infrared light at a suitable wavelength. The heat emitted by the nanoshells destroys the tumour cells, which are then cleared from the body without damaging the surrounding healthy cells. This method is highly effective in treating cancer while minimizing harm to the rest of the body (Oylar and Tekin, 2011).

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