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EVALUATION OF GOLD NANOPARTICLES FOR INNOVATIVE DRUG DELIVERY SYSTEM

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ABSTRACT

Drug delivery technologies are intricate and patented formulation technologies that aim to enhance the effectiveness and safety of drugs by modifying their release profile, absorption, distribution, and elimination. Additionally, these technologies strive to improve patient convenience and compliance. Although there already exist delivery devices capable of releasing two drugs, their release timing is predetermined and cannot be externally controlled. However, a ground breaking system employing gold nanoparticles has emerged, offering external control and the potential to deliver up to three or four drugs simultaneously. The administration of drugs necessitates precise calculations to ensure optimal utilization by the body, thereby requiring a drug delivery system that allows for accurate dosing. Furthermore, drug delivery systems must consider the specific metabolic processes by which drugs are broken down within the body. For example, certain drugs are rendered ineffective in the intestinal tract, rendering this avenue unsuitable for introduction. Likewise, some drugs pose significant risks in high quantities, necessitating the implementation of time-release methods to ensure patient safety.

Keywords: Innovative drug delivery system, Nanoparticles in pharmaceuticals, Utilizing Gold nanoparticles in medicine, Treatment of cancer using gold nanoparticles, HIV transmission through nanotechnology

INTRODUCTION

Nanotechnology refers to the exploration, design, formation, synthesis, manipulation, and utilization of materials, devices, and systems at an incredibly tiny scale, measuring in nanometers (where one meter consists of a billion nanometers). This scientific field is gaining increasing significance in various sectors including engineering, agriculture, construction, micro-electronics, and healthcare, just to name a few. One particularly noteworthy realm where nanotechnology has been receiving significant attention recently is healthcare. Currently, there exist numerous treatments that demand considerable time and financial resources. However, with the implementation of nanotechnology, it becomes possible to develop faster and more cost-effective treatment methods. By conducting in-depth research on this ground breaking technology, we can potentially discover cures for ailments that presently lack remedies. Imagine the possibility of producing surgical instruments with extraordinary precision and dexterity, enabling us to operate at the cellular and molecular level in our own bodies—this surpasses the realm of today's medical technology. Consequently, nanotechnology holds the potential to save numerous lives. When nanotechnology is combined with the fields of biology or medicine, it is commonly referred to as Nanobiotechnology. It is crucial to exercise extreme caution when employing this technology, as it directly impacts the lives of individuals. When used appropriately, it has the potential to offer highly effective treatments with minimal adverse effects.

Nanomedicine, a derivative of nanotechnology, entails precise medical interventions at the molecular level to address diseases and restore damaged tissues, such as bones, muscles, or nerves. A nanometer, measuring one-billionth of a meter, is too minuscule to be visible under a conventional laboratory microscope. It is within this size range, typically around 100 nanometers or less, that biological molecules and structures within living cell's function.

Nanotechnology encompasses the development and utilization of materials and devices at the molecular and atomic level. The exploration of nanotechnology commenced with the discovery of unique physical and chemical properties displayed by metallic or carbon-based materials when structured on a nanometer scale. This comprehension of nanoscale properties empowers engineers to construct innovative structures and employ these materials in novel ways. Similar principles apply to the biological structures found within the living cells of the human body.

Presently, nanotechnology in medicine is undergoing significant advancements, particularly in the utilization of nano-particles for targeted delivery of drugs, heat, light, or other substances to specific cells within the human body. By engineering particles to fulfil this purpose, diseases or injuries within these targeted cells can be detected and treated, thereby minimizing harm to healthy cells. Nanotechnology can be accurately described as the engineering and scientific discipline encompassing the design, synthesis, characterization, and application of devices and materials whose smallest functional organization is at least one billionth of a meter or on the nanometre scale. At this scale, it becomes crucial to consider individual molecules and their interactions in relation to the overall chemical and physical properties of the material or device. This understanding allows for precise control over the macroscopic properties by manipulating the fundamental molecular structure.

The field of medicine and physiology encompasses the utilization of substances and tools intended to interact with the human body at a microscopic level, specifically at the molecular scale, while exhibiting a high level of precision. This has the potential to lead to the development of targeted treatments that specifically impact individual cells and tissues, resulting in maximum therapeutic benefits and minimal adverse effects. This article aims to provide an overview of the key scientific and technological aspects of nanotechnology, while also exploring some of its potential applications in clinical settings. The future of healthcare is undeniably intertwined with advancements in nanotechnology, as well as other domains such as stem cells, genomics, and proteomics. Nanotechnology has already made significant strides and is currently being utilized in an innovative manner to enhance the characteristics of various therapeutic and healthcare products.

NANOTECHNOLOGY IN MEDICINE: REVOLUTIONIZING HEALTHCARE

i. While numerous applications of nanotechnology in medicine are still in the developmental phase, nanocrystalline silver is already employed as an effective antimicrobial agent in treating wounds
ii. Tiny markers, known as dots, have been developed to precisely locate cancer cells within the body.
iii. Nanoparticles are utilized to deliver chemotherapy drugs directly to cancer cells, minimizing harm to healthy cells and optimizing treatment effectiveness.
iv. The advent of nano shells has revolutionized cancer treatment by concentrating the heat generated from infrared light to selectively destroy cancer cells, while minimizing damage to surrounding healthy cells. For a more comprehensive understanding of nano shells, refer to the provided visual explanation.
v. Nanotubes have emerged as a remarkable solution for mending broken bones by providing a framework where new bone material can develop and foster accelerated healing.
vi. Utilizing nanoparticles, doctors can now attach these minuscule particles to cells infected with various diseases, allowing for the identification of specific diseases in a patient's blood sample. This breakthrough has significantly enhanced diagnostic capabilities and disease detection accuracy.

NANOTECHNOLOGY IN THE FIELD OF HEALTHCARE

Nanotechnology in the field of healthcare has traditionally been associated with pharmaceutical applications, particularly in the realm of drug delivery. The focus has been on the size of the delivery vehicle, whether it is a liposome, a polymer, or even a metallic nanoparticle, and its unique ability to bypass our body's natural defence mechanisms. A recent development in this field is the introduction of the first nano-delivery system known as DOXIL, which is a modified version of the anticancer drug doxorubicin. In the case of DOXIL, the drug is encapsulated within liposomes that are coated with polyethylene glycol (PEG), resulting in a particle size of less than 200nm. This formulation allows for the sustained release of the drug from the liposomes and extends its circulation time in the body due to the "stealth" effect provided by the PEG coating. As a result, patients only require intravenous treatment every four weeks. The use of PEG to conceal drugs from our immune system has also been employed in antibody-based therapies. Furthermore, nanotechnology has made significant contributions to drug delivery through various other routes. One example is Visage, a topical formulation designed to combat HIV. This product is among the first of its kind to utilize dendrimers, which are nanoscale molecules with a hyper-branched polymeric structure and a size ranging from 2 to 10nm. According to a recent report, the effectiveness of delivering drugs through inhalation could potentially be improved by eight times by utilizing magnetic fields to guide drugs that are mixed with magnetic nanoparticles. While it typically takes longer to bring products to the market in the healthcare industry compared to other sectors, it is evident that the number of product launches is about to skyrocket. In 2004 alone, there were 38 products introduced to the market, and this trend is expected to significantly increase in the near future, not only limited to drug delivery. The implications of nanotechnology extend far beyond this, encompassing various areas such as:

1. Utilizing superparamagnetic iron oxide nanoparticles for magnetic resonance imaging
2. Incorporating nano powders to enhance the bioavailability of drugs that have low solubility
3. Developing wound dressings and medical devices that utilize antimicrobial nano silver
4. Exploiting magnetic and optically active materials for the treatment of cancer
5. Employing nanohydroxyapatite for coating implants and substituting bone
6. Creating nano sensors for point-of-care diagnostics.

All of these advancements are driven by the revolutionary field of nanotechnology, and they have the potential to greatly improve healthcare practices and patient outcomes. The potential implications of nanotechnology that lie ahead of us are predominantly confined within the boundaries of scientific exploration. While the concept of tiny robotic agents navigating through our bodies, akin to miniature submarines eliminating diseased cells, exists merely in the realm of imagination, the manipulation and utilization of biomolecular machines and motors—such as proteins and nucleic acids, the building blocks of life—are unquestionably tangible and promising. A notable instance of this progress is the recent demonstration of a synthetic molecular motor, stimulated by bacterial pathogens, that possesses the remarkable capability of autonomous transport at the nanoscale. This biomolecular motor functions by polymerizing a double-helical DNA tail and, thus, operates by harnessing the abundant energy released during the process of DNA hybridization. On a parallel front, other scientists are harnessing the inherent coding properties of DNA binding to assemble intricate and sizeable structures, even achieving the spontaneous formation of letter-shaped arrangements. Although the precise practical applications of these advancements may not be immediately apparent, they undoubtedly mark significant milestones in the journey towards ground breaking innovations in the field of healthcare. The potential implications of nanotechnology that lie ahead of us are predominantly confined within the boundaries of scientific exploration. While the concept of tiny robotic agents navigating through our bodies, akin to miniature submarines eliminating diseased cells, exists merely in the realm of imagination, the manipulation and utilization of biomolecular machines and motors—such as proteins and nucleic acids, the building blocks of life—are unquestionably tangible and promising. A notable instance of this progress is the recent demonstration of a synthetic molecular motor, stimulated by bacterial pathogens, that possesses the remarkable capability of autonomous transport at the nanoscale. This biomolecular motor functions by polymerizing a double-helical DNA tail and, thus, operates by harnessing the abundant energy released during the process of

DNA hybridization. On a parallel front, other scientists are harnessing the inherent coding properties of DNA binding to assemble intricate and sizeable structures, even achieving the spontaneous formation of letter-shaped arrangements. Although the precise practical applications of these advancements may not be immediately apparent, they undoubtedly mark significant milestones in the journey towards ground breaking innovations in the field of healthcare. Nanomedicine, the future frontier of medicine, encompasses advancements that rely on the remarkable capabilities of nanorobots. These minuscule machines have the potential to revolutionize healthcare by harnessing their power to repair specific diseased cells, much like the natural healing processes facilitated by antibodies. Here are some exciting applications that could become a reality:

i. Swift Eradication of Bacterial Infections: A ground-breaking achievement would be the ability to eliminate bacterial infections in mere minutes. This remarkable feat would replace the conventional approach of using antibiotics over several weeks. Nanorobots, programmed with precision, could target and neutralize infections swiftly, greatly improving patient outcomes.
ii. Cellular-Level Surgery: Another awe-inspiring prospect is performing surgery at the cellular level. Nanorobots could navigate the intricate terrain of our bodies, meticulously removing individual diseased cells. The potential doesn't stop there; they could even intervene at a deeper level, repairing defective portions of these cells. This breakthrough would offer unprecedented precision in medical interventions.
iii. Extending Human Lifespan: Nanomedicine could also hold the key to significantly prolonging the human lifespan. By addressing cellular-level conditions that contribute to aging, nanorobots could potentially reverse or repair these mechanisms. This tantalizing possibility presents a new frontier in defying the limits of the human lifespan.

In summary, the future of medicine lies in the realm of nanomedicine. With the emerging field of nanorobots, we can envisage a healthcare landscape where bacterial infections are rapidly eliminated, surgery operates at a cellular level, and the aging process is addressed at its root. These advancements have the potential to transform the way we approach healthcare and enhance human well-being.

NANO DRUG DELIVERY SYSTEM

The Nano Drug Delivery System, which is based on Gold Particles, has a fascinating history. Although colloidal gold particles in nanometer sizes were initially created by Michael Faraday over 150 years ago, they were not associated with nanoparticles or nanotechnology until recently. However, approximately thirty years ago, colloidal gold particles were conjugated with antibodies for specific staining purposes, known as immune-gold staining. This application can be seen as a precursor to the remarkable advancements in nanotechnology utilizing gold particles. The significance of nanotechnology in drug delivery lies in its ability to manipulate molecules and supramolecular structures to create devices with programmed functions. Gold nanoparticles offer countless advantages due to their nanometer-scale size, enabling them to infiltrate the bloodstream and access cells efficiently. Moreover, these nanoparticles have proven to be highly stable and versatile scaffolds for drug delivery, thanks to their unique size and remarkable chemical and physical properties. By tuning the surface of the particle, it becomes possible to achieve cell-specific targeting and controlled drug release. In summary, the Nano Drug Delivery System based on Gold Particles has a rich history that dates back to Michael Faraday's discoveries. It has evolved significantly in recent years, thanks to advancements in nanotechnology and the remarkable characteristics of gold nanoparticles. These particles provide an array of advantages, including their ability to access cells and their potential for tailored drug release through surface modification. I have developed an innovative multi-drug delivery system utilizing a unique variety of gold nanoparticles. By attaching drugs to the surface of these nanoparticles, the drugs are released when the nanoparticles dissolve upon exposure to a specific frequency of infrared light. This infrared frequency is closely associated with the shape of the nanoparticles and enables precise and targeted drug release. As different shapes of nanoparticles respond to distinct infrared wavelengths, we have the capability to selectively control the release time for each drug by manipulating the infrared wavelength. However, the required infrared wavelength to dissolve a specific nanoparticle relies on its shape.

In their study, I am designed two different shapes of gold nanoparticles. Nanoparticles known as 'nano bones' are melted by infrared radiation at 1,100 nanometres, while 'nano capsules' are dissolved by a wavelength of 800 nanometres. Having demonstrated the efficacy of these nanoparticle shapes, the research team envisions the creation of up to four distinct particle shapes. These particles could be utilized to carry drugs into patients, allowing physicians to release them at suitable times by employing different infrared wavelengths. This approach holds promise in treating various diseases, particularly cancer and AIDS, offering enhanced therapeutic precision. I have employed different forms of gold nanoparticles to effectively eliminate tumours. In each case, these tiny particles first target cancer cells. Subsequently, when they are exposed to near-infrared light, these particles generate heat that ultimately destroys the cancer cells. Importantly, this process of heating is localized, ensuring that healthy cells are spared from any harm. The utilization of this particular type of particle represents the most effective approach to selectively deposit energy exclusively in tumour cells.

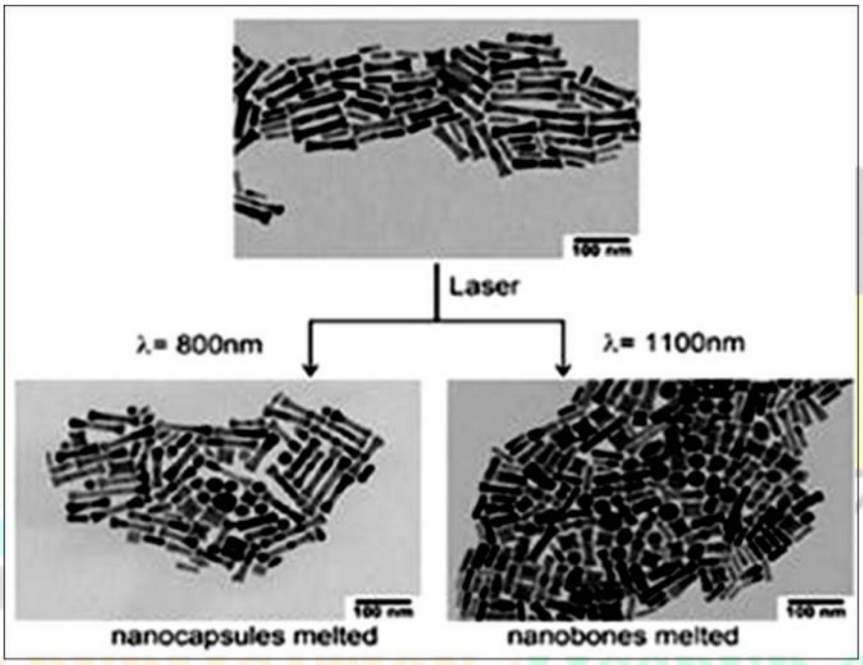

FIG. 1 IN THE FIRST ILLUSTRATION, A COMBINATION OF GOLD NANOPARTICLES. AMONG THEM, THERE ARE LONGER PARTICLES TERMED AS NANOBONES, WHILE THE SMALLER ONES ARE REFERRED TO AS NANOCAPSULES. SHIFTING OUR ATTENTION TO THE BOTTOM LEFT IMAGE, THE OUTCOME AFTER SUBJECTING THE NANOPARTICLES TO INFRARED LIGHT WITH A WAVELENGTH OF 800 NANOMETERS. IN THIS CASE, THE NANOCAPSULES LIQUEFY AND DISPERSE THEIR CONTENTS, WHILE THE NANOBONES REMAIN UNCHANGED. NOW FOCUSING ON THE IMAGE ON THE RIGHT, THE CONSEQUENCES OF EXPOSING THE NANOPARTICLES TO INFRARED LIGHT WITH A WAVELENGTH OF 1100 NANOMETERS. AS A RESULT, THE NANOBONES MELT AND RELEASE THEIR CONTENTS, WHEREAS THE NANOCAPSULES REMAIN UNAFFECTED.

STAR-SHAPED GOLD NANOPARTICLES

The unique morphology of star-shaped nanoparticles allows for enhanced light reflection compared to nanoparticles with other shapes. Consequently, these star-shaped nanoparticles hold great potential for a wide range of applications, such as serving as a contrast agent or tracer. Additionally, due to their strong influence on the reflected light spectrum, gold nanostars (refer to fig. 2) can be utilized as labels to detect and identify specific molecules or compounds, making them valuable tools for controlled synthesis. NC have successfully harnessed the potential of these nanostars to amplify the signal of Raman Spectrum, a technique known as

Surface-Enhanced Raman Scattering (SERS). The study revealed that by coupling the target molecule with a metal nanostructure, the response is significantly intensified, often exceeding improvement rates of over a million-fold. SERS can thus be employed to detect various chemicals, including pollutants, disease markers, and carcinogens.

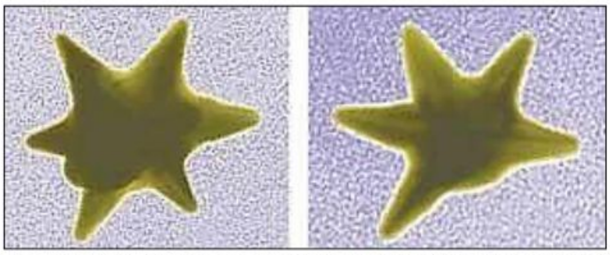

FIG.2 STAR-SHAPED GOLD NANOPARTICLES

HOLLOW NANOSPHERES

The nanospheres exhibit exceptional and distinctive characteristics, as they can be designed to possess a remarkable ability to either strongly or narrowly capture light. In other words, during their growth process, the spacing between these nanospheres can be adjusted, resulting in a higher density of objects occupying the same given area (refer to fig. 3). These formations hold promising applications in targeting tumors within the field of photo thermal cancer treatment. One of the primary features that make the structure of nanospheres special is the combination of their spherical shape, diminutive size, and their capacity to strongly absorb visible and near infrared light. The absorption not only boasts considerable strength but also offers a narrow and adjustable range. All these properties bear great significance in the treatment of cancer. The process of eliminating cancer cells through heat generation relies on the metal nanoparticles' ability to absorb light, thus increasing the efficiency of light absorption contributes to improved outcomes. Comparatively, hollow gold nanospheres exhibit a light absorption capacity in the near-infrared spectrum that surpasses solid gold nanoparticles by 50 times. This unique structural composition imparts genuine advantages over other nanostructures, highlighting its immense potential for diverse applications.

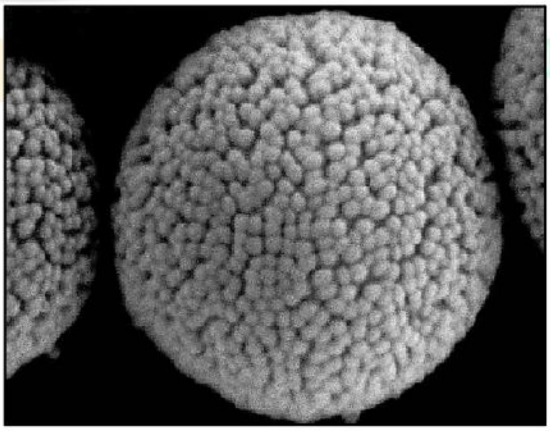

FIG.3 HOLLOW NANOSPHERES

THE INGENIOUS GOLD NANOCAGE

This innovative nanocage has been intricately designed to be infused with a valuable medicinal compound, for instance, a chemotherapy drug or a bacteria-fighting agent. By precisely releasing controlled doses of the drug exclusively at the specific tissue site where the drug is meant to take effect, this groundbreaking delivery system aims to amplify the drug's advantageous impacts while drastically reducing any potential adverse effects. Gold is a valuable component in the medical treatment of prostate cancer. By employing minute particles of gold, similar in size to a grain of rice, medical professionals can accurately determine the exact location of the patient's prostate during the treatment process. This enhanced precision enables the delivery of a more accurate radiation dosage and targets a specific area to treat the tumour more effectively. Gold has proven to be highly beneficial in treating prostate cancer. Through the utilization of minuscule amounts of gold, comparable in size to a grain of rice, doctors are able to accurately locate and determine the position of the patient's prostate during treatment. The enhanced precision achieved by this method allows for a more targeted and effective radiation dosage, specifically targeting the tumour. Gold is the material of choice for these positioning particles due to its significant density and its capacity to obstruct X-rays. In addition to the conventional use of gold, an alternative approach is being pursued by the US-based company Nanospectra. Their focus lies in the development of a groundbreaking therapy known as Aurolase, which aims to selectively eliminate solid tumours. Rather than utilizing solid gold nanoparticles, Nanospectra employs gold nano shells, which are minute particles of gold enveloped by a layer of silica. These nanoshells are administered through injection into the patient's body. Once the gold nanoshells have accumulated within the tumor, a specialized treatment process commences. The affected area is illuminated with a near-infrared laser emitting wavelengths that maximally penetrate tissue. Unlike solid gold nanoparticles, the Auroshell particles are precisely engineered to absorb this particular wavelength, effectively converting the laser light into heat. This leads to the rapid destruction of the tumor, effectively eradicating it along its irregular borders.

GOLD NANOPARTICLES IN DNA TECHNOLOGY

Gold nanoparticles have been utilized in the advancement of self-assembling DNA nanotubes, which could offer a recent approach for targeted drug delivery to specific cells. Scientists at McGill University in Montreal have successfully constructed three-dimensional triangular chambers using double-stranded DNA nanotubes. By incorporating gold nanoparticles of various sizes during assembly, these metallic particles became entrapped within corresponding capsules, resembling peas in a pod. Essentially, the nanotubes act as sieves, selectively encapsulating particles of the appropriate sizes. In order to release these particles, the researchers introduced DNA strands that complemented the ones used for particle entrapment. Such a system holds potential in transporting cancer treatments within the body until they reach diseased tissue, ultimately releasing them at the appropriate location.

HOT GOLD NANOPARTICLES CAN COOK CANCER CELLS

There exist numerous potential methods to eliminate cancer cells, and among them is the strategy of subjecting them to high temperatures until they perish. Remarkably, scientists at the Niels Bohr Institute, situated at the University of Copenhagen, are currently exploring the immense potential of nanoparticles made of gold in achieving this goal with exceptional precision. Specifically, they are investigating the capability of these minuscule gold particles in melting the protective layers of lipid membranes surrounding cells, offering a groundbreaking pathway for targeted tumor destruction. To facilitate their experiments, the researchers employed an ingenious technology called optical tweezers, which employs focused laser beams to capture and immobilize the gold nanoparticles. By utilizing infrared light emitted from the optical tweezers and modulating its intensity, it becomes feasible to control the temperature at which the particles are heated. In order to quantify the extent of temperature increase experienced by the gold nanoparticles, they were progressively moved closer to an imitation cell membrane consisting of lipids. The point at which the lipids started melting was regarded as an indication of temperature levels achieved. Intriguingly, the gold particles were found to reach temperatures of several hundred degrees using a mere 1 watt of light intensity. Consequently, by melting the lipids in a cell membrane, the targeted cell perishes. Importantly, the heat dissipation occurs within a limited range, ensuring that only the intended cell is affected.

GOLD NANOPARTICLES TO HELP IN FASTER DETECTION OF MENINGITIS

Gold nanoparticles have the potential to revolutionize the detection of meningococcal meningitis, offering a faster and more efficient method that can greatly reduce fatalities. Meningitis is a rapidly progressive condition that, if left untreated, can lead to death. Common symptoms include fever, chills, headache, vomiting, stiff neck, rash, confusion, seizures, coma, as well as stiffness in the knees and hips, and shock. These nanoparticles exhibit a colour change when exposed to meningococcal DNA, allowing for quick and easy identification of the presence of the disease. Remarkably, this color change can be discerned by the naked eye. The technique is currently undergoing further refinement to ensure its applicability in clinical settings and immediate bedside diagnosis. This groundbreaking development holds great promise for the future in terms of expediting meningococcal disease detection and enabling earlier treatment, ultimately leading to a significant reduction in fatalities and mitigating severe complications. By swiftly diagnosing the disease, it becomes possible to prevent deaths and minimize the occurrence of severe side effects by providing patients with the most suitable and timely treatment.

GOLD NANOPARTICLES TO BLOCK HIV

Currently, there is a belief that gold nanoparticles possess the potential to revive and enhance drug candidates that were once promising but abandoned due to adverse effects. Specifically, there is a compound known as TAK-779 that was originally developed to halt the spread of HIV (human immunodeficiency virus). This compound was initially suggested by researchers in 1996 and demonstrated efficacy in preventing the virus from infiltrating the body's immune system. However, it was discarded by 2005 due to recipients experiencing severe irritation at injection sites, while oral dosing failed to be effective because of ammonium salt molecules present in the compound, triggering negative reactions. Recent laboratory tests have revealed a groundbreaking discovery. By attaching 12 modified molecules of TAK-779, devoid of ammonium salt molecules, to a single gold nanoparticle, the drug's ability to prevent HIV infection has been restored. The gold nanoparticles have a diameter of two nanometers, equivalent to the size of the HIV proteins they aim to obstruct. This characteristic renders them highly suitable for impeding viral proteins from making contact with crucial receptors (ref. Fig. 4).

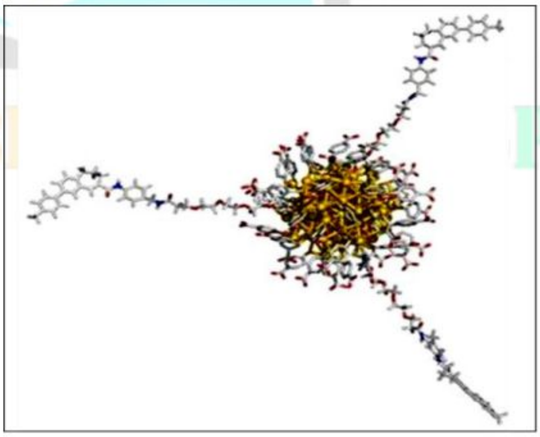

FIG. 4 A GROUNDBREAKING METHOD INVOLVING THE REPLACEMENT OF AMMONIUM SALT MOLECULES WITH GOLD NANOPARTICLES CAN RESULT IN THE FORMATION OF A COMPOUND THAT EFFECTIVELY INHIBITS THE TRANSMISSION OF HIV BY BLOCKING THE INTERACTION WITH RECEPTOR PROTEINS. THIS PROCESS ACHIEVES REMARKABLE RESULTS IN PREVENTING HIV INFECTION, WHILE MITIGATING ANY POTENTIAL ADVERSE EFFECTS TYPICALLY ASSOCIATED WITH ALTERNATIVE TREATMENTS.

In the realm of pharmaceutical research, nanotechnology plays a pivotal role in the detection of diverse diseases. Particularly, the emergence of gold nanoparticles as part of a controlled drug delivery system has revolutionized drug administration. These gold nanoparticles have the potential to deliver not just one, but up to three or four drugs simultaneously. This presents a remarkable opportunity, especially when dealing with ailments such as cancer and AIDS, where a synergistic effect can be achieved by administering multiple drugs. The beauty of this gold nanoparticle drug delivery system lies in its ability to provide a diverse range of drugs for the treatment of cancer or AIDS. Each drug can be encapsulated separately within the nanoparticles, allowing for their targeted release. By manipulating the infrared wavelengths, which different shapes of nanoparticles respond to, we can precisely control the release timing for each drug. Essentially, this system provides a means to tailor the drug release schedule according to the specific requirements of the treatment. In the future, such a sophisticated drug delivery system holds great promise in offering enhanced control for combating diseases that typically demand the usage of multiple drugs. The utilization of this system not only ensures more effective treatment but also minimizes potential side effects caused by uncoordinated drug administration. With continued advancement in nanotechnology, the potential for leveraging multiple drugs within a single delivery system brings new hope in the battle against various complex diseases.

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