Nanotechnology and Its Implications To the Wider World

BY

Roxanne Tajbakhsh
&
Paramdeep Singh Duggal

PASS WITH MERIT

RESEARCH PAPER
BASED ON
PATHOLOGY LECTURES
AT MEDLINK 2010 AND VETMEDLINK 2010

Abstract

Nanotechnology is a mysterious, vast and ever developing field within the colossal world of science. To date, scientists have only dabbled within the potential usage of this futuristic ideology with the application of nanotechnology to the development of bionanotechnology and its advancements into nanomedicine. In this paper, after presenting a brief on the evolution of nanotechnology and its ideologies, we will be directing our attention towards overcoming global issue such as the ever escalating predicaments within Africa. We will look at how nanotechnology can be adapted, via nanobased water treatments nanosensors to prevent the spread of cholera, and silver nanoparticles/quantum dots in the monitoring and treatment of HIV/AIDS.

Introduction

In a nutshell, nanotechnology is the study of manipulating matter on an atomic and molecular scale.

It is the engineering of tiny machines, providing the ability to build things from the bottom up. This manufacturing revolution will ultimately enable control of material at the nanometer scale using mechanochemistry.

But exactly how nano is this technology?

1 nanometer= 1 billionth of a meter= the width of three or four atoms.

The average human hair is around 25,000 nanometers wide.

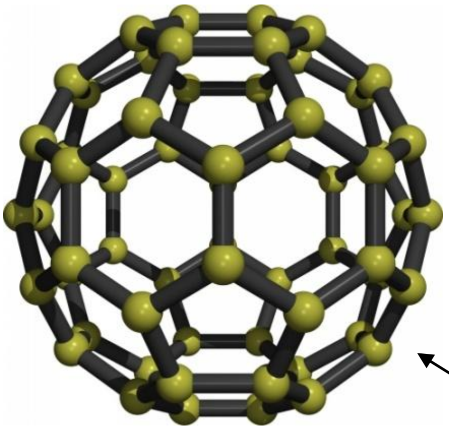
The idea of nanomedicine is a modern day phenomenon, exclusive to the 20th century due to the existence of atoms only being uncovered towards the end of the 19th century. The first implications to the concepts of nanotechnology can be found within the famous 1929 essay written by J.D Bernal:

> *'The stage should soon be reached when materials can be produced which are not merely modifications of what nature has given us in the way of stones, metals, woods and fibres, but are made to specifications of a molecular architecture.'*

The concept was pioneered in 1959 with a presentation by physicist Richard Feynman, titled "There's plenty of room at the bottom", exploring the theoretical capabilities of building substances at the atomic and molecular scale, imagining the entire Encyclopedia Britannica written on the head of a pin.

After decades of ideologies, Donaldson, in 1976, offered the first detailed record of theoretical biological techniques which seemed necessary in order to achieve cell repair which might prove feasible. A remarkable feat considering that the time when this was written predated many current aptitudes such as protein sequencing and synthesis, including large areas of knowledge of restrictions on cellular developmental pathways and genetic programmes and networks.

The actual use of the term nanotechnology was popularised by K. Eric Drexler in the early 1980s when nanoscience uncovered two major developments; the birth of cluster science leading to the invention of the scanning tunneling microscope (STM); the development of which led to the discovery of Buckminsterfullerene in 1985, also known as "fullerene" or "buckyball", named after Richard Buckminster Fuller's geodesic dome. The buckyball is a spherical molecule with the formula C_{60} with the amazing ability to be twice as hard as diamond when compressed to 70% of its original size.



The C_{60} "buckyball" fullerene

Its discovery not only lead to a Noble Prize, but also to the invention of carbon nanotubes in 1991. These are allotropes of carbon, and have proven important in medicine with multiple uses such as alternate drug delivery to patients.

In another development, the synthesis and properties of semiconductor nanocrystals was studied which then led to a fast increasing number of metal and metal oxide nanoparticles and quantum dots.

From there, nanoscale materials technology has found widespread use in medicine, including surgical and dental practices, nerve cell research using intracellular electrodes, biostructures research and biomolecular research using near-field optical microscopy, scanning-probe microscopy and optical tweezers.

Discussion

HIV And Nanotechnology

What is HIVs?

Human Immunodeficiency Virus, i.e. HIV, is a lentivirus which consequently causes Acquired Immunodeficiency Syndrome, i.e. AIDS, and therefore results in the immune systems failure. Figure 1 shows an animated version of the cell from the virus. HIV primarily infects vital cells in the immune system such as T-cells, macrophages and dendrites cells, which leads to low levels of CD4+ T cells via three ways; direct viral killing of infected cells; increased rates of apoptosis in infected cells; killing of infected CD4+ T cells by CD8 cytotoxic lymphocytes, therefore, infected cells cannot be recognised.

The development of HIV occurs in three stages; acute infection (also known as primary infection); the latency stage; the final stage - being AIDS. Primary infection lasts for several weeks and could potentially include symptoms such as fever, swollen lymph nodes (lymphadenopathy) , sore throats (pharyngitis), muscle pains (myalgia), depression, and mouth and esophageal sores. The latency stage shows no/few symptoms and can last from two weeks to twenty years or even beyond. The final and fatal stage of infection, AIDS, is defined by low CD4+ T cell counts (fewer than 200 per microliter), various opportunistic infections, cancers and other conditions.

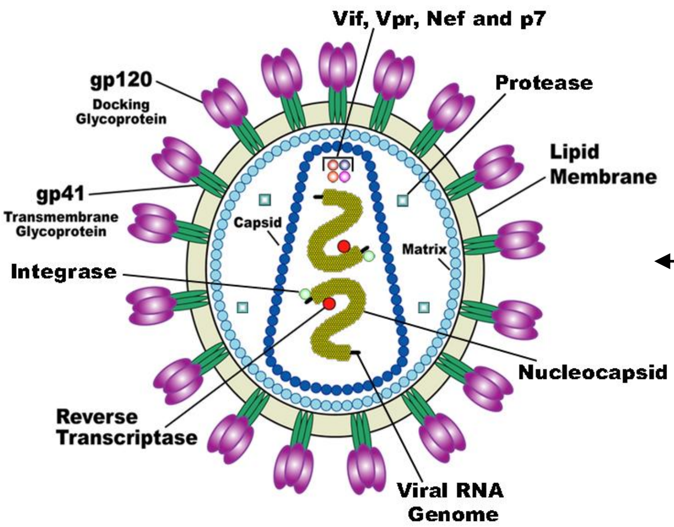


Figure 1

Traditional treatment such as antiretroviral medication reduces both mortality and morbidity of the HIV infection. However, not all countries have access to this life saving treatment, especially the poverty ridden countries, such as Africa, who happen to have extreme rates of HIV infection.

On average, this infection results in the death of 8219 people daily, meaning that statistically, one person dies every 20 seconds. Currently, 0.6% of the world suffers from HIV, with more than 25 million people being killed by the virus from 1981 to 2006. In 2005 alone, AIDS claimed between 2.4 - 3.3 million lives; 570,000 of those lives being children. Third world countries have been hit the worst by the HIV/AIDS 'pandemic' with continents such as Africa having 60% of the population infected. The UN Secretary General, Kofi Annan, stated:

> *'Between 1999 and 2000 more people died of AIDS in Africa than in all the wars on the continent'*

Presenting the scale of the devastation caused by the virus. Furthermore, UNAIDS 2004 report on the global epidemic quoted:

> *'[2000] began with 24 million Africans infected with the virus. In the absence of a medical miracle, nearly all will die before 2010. Each day, 6,000 Africans die from AIDS. Each day, an additional 11,000 are infected'*

Highlighting the importance of developing cheap, effective and replicable treatments are for the survival of the population of the third world countries.

Diagnosis:

However, before HIV can be treated, detection of the infection must transpire. An existing method of diagnosis uses screening with an ELISA (enzyme-linked immunosorbent assay) to detect antibodies of which correspond to HIV-1. Specimens with a nonreactive result are classed as 'HIV negative'. Conversely, if the specimens are reactive, they are firstly retested in duplicate to verify results, and then undergo confirmatory testing with a more specific supplemental test like Western blot or, less commonly, an IFA (immunofluorescence assay). Only specimens that are repeatedly reactive by ELISA and positive by IFA, or reactive by Western blot, are considered 'HIV positive' and are indicative of HIV infection.

Modern HIV testing is extremely accurate with the chances of a false-positive result in the two-step testing protocol being estimated at 0.0004% to 0.0007%. Nevertheless, this method could take long periods of time due to the different interludes of diagnosis, furthermore, this system of detection could be too expensive for the people of Africa to have access to, so a more applicable, cost-effective method must be used.

The usage of nanotechnology is fast becoming a popular method in the diagnosis of viruses, like HIV, with detection periods being just a few minutes. This is done by measuring frequency changes of an infrared laser as DNA/RNA is scattered by it. The changes in the frequency are as discrete as an individual's fingerprint so differentiation of the different frequencies can be easily monitored and measured. Nonetheless, previous attempts to copy this method have failed due to the weakness of the signal produced but with the addition of further nanotechnology, more specifically, nanorods, this signal can be amplified to levels of which can be interpreted by scientists consistently. Moreover, the factors of enhancement are incredible as this method is cheap, reproducible and simple to implement; all factors which satisfy the needs of third world countries diagnosis/detection equipment.

Another way nanotechnology can be used is via quantum dots. Quantum dots tag biological molecules for the recognition of proteins that point out disease/virus status so ultimately, they can be used in the clinical analytic tests to rapidly identify molecules of which have relation to the HIV//AIDS and other diseases/viruses, one being cancer cells. Nanosensors can also be used to detect and monitor HIV molecules (see Nanosensors section below).

Treatment:

Previous attempts to prevent HIV activity in vivo, via the usage of nanomaterials, included that of which modified HIV drugs were combined with gold nanoparticles. This blocked critical stages in the virus' cycle where it combines with the host cell. By hacking off the ends of a failed drug and sticking the resulting molecules onto gold nanoparticles, scientists had created a drug called TAK 779, which successfully prevented HIV from binding to the human's white blood cells. However, the severity of the side effects meant that the drug was ruled out as a possible treatment of HIV. The problem was caused by an ammonium salt at one end of the molecule, removing the salt prevented the side effects but, consequently, the new molecule was not able to bind tightly enough to the virus particles.

A study published in the 'Journal Of Nanotechnology' by the university of Texas and Mexico University found that silver nanoparticles of size 1-10nm, when attached to HIV-1, prevented the virus from bonding to the host cells, thus a leap to treating HIV/AIDS. What makes this method effective is the size of the nanogranules as they impact the virus' 'plans'. Once inside the body, the nanoparticles are able to generate a suspending isolation effect which potentially, could block out the replication of the virus.

Another advantage of these nanoparticles is the great surface adsorption effect owing to their high surface area. This adsorbs the virus's metabolic product and the virus's duplicating parts, and puts an end to them. Rotating cells, from when the nanogranules enter the body, rub against other cells, thus creating a nanorubbing mechanism effect. This can ultimately stop the virus from affixing to the surface of cells, therefore combating the transcription of the virus.

Nanotechnology and the Prevention of Cholera

What is Cholera?

Cholera is an acute infection of the small intestine caused by the bacterium Vibrio Cholerae (Figure 2).

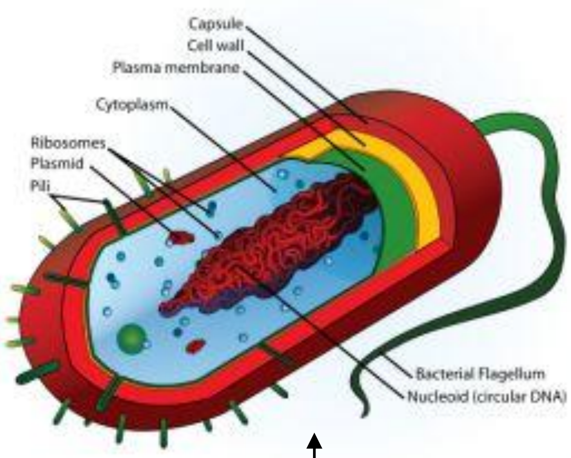


Figure 2

The bacterium releases a toxin that causes excessive release of water in the intestines, leading to severe diarrhoea which, if untreated, would lead to death. It is transmitted via contaminated food or water and therefore is largely present in locations with poor sanitation, crowding, war and famine – a common theme through countries such as Africa, India, Mexico, and South and Central America.

Its symptoms include abdominal cramps, dry mucus membranes or mouth, excessive thirst, glassy or sunken eyes, low urine output, nausea, rapid dehydration, vomiting and sudden diarrhoea.

Current treatment of cholera consists of an oral rehydration therapy developed by the World Health Organisation (WHO) which is cheaper and easier to use than the previously used intravenous fluid. The treatments objective is to replace the lost sugars and electrolytes lost through diarrhoea.

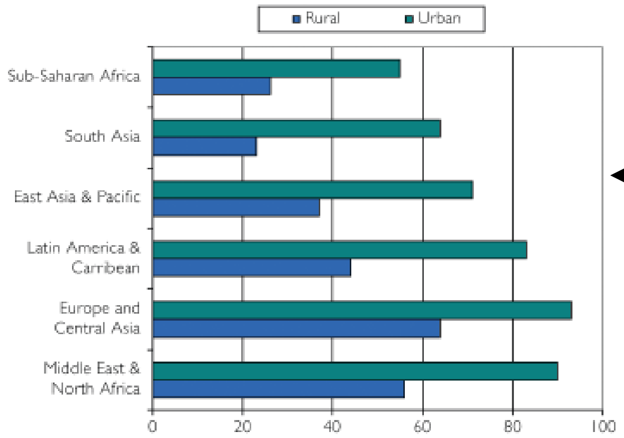
Nanotechnology and its adaptation to water treatments could be key to the prevention of cholera.

The Need for Water Treatment:

With water and poverty becoming more and more closely linked, pressures on government authorities to ensure people living in the developing countries have access to water are ever increasing. But ultimately, water resources must be handled in a sustainable manner in order to maintain the environmental, social and economical functions it provides in contributing towards different groups of people.

In 2002 alone, 1.1 billion people did not have access to a reliable water supply and 2.5 billion people - the majority of which lived in Africa/Asia - lacked access to adequate solutions. This consequently, means that illnesses such as cholera, are major killers, especially in children in the developing countries. This issue is having a knock on effect with children not receiving an education due to schools not being able to provide adequate water/sanitation facilities. This then leads to more children turning to crime in order to attain the basics needed in order to survive.

Figure 2: Share of Population with Access to Adequate Sanitation, 2002 (%)



Source: World Bank, 2005.

Figure 3:
Presenting the percentage of the population throughout the world with access to adequate sanitation.

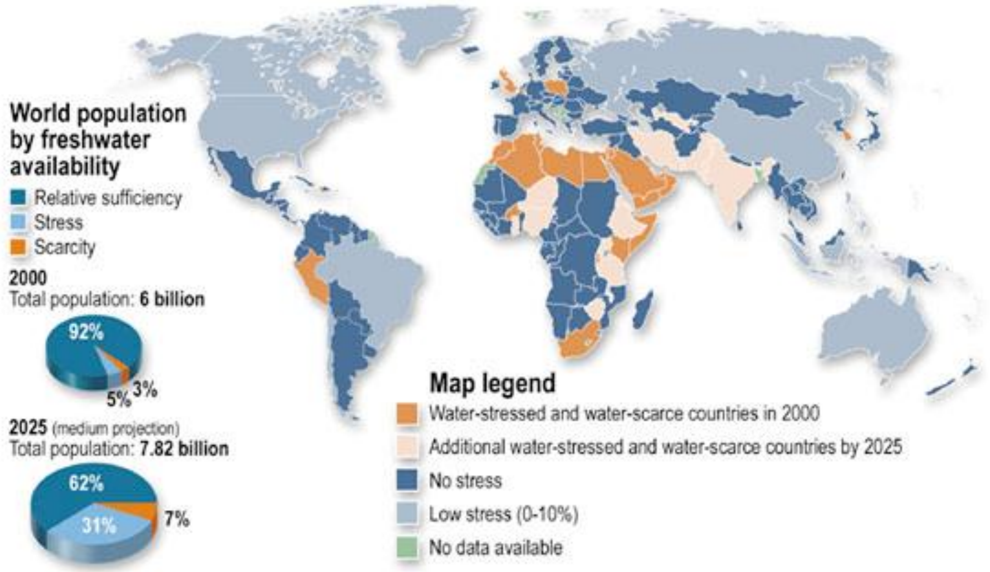


Figure 4

Access to 'potable' water would transform the lives of many people in the developing countries for good. Figure 4 shows 2000's figures of the world population by freshwater availability, also including the predicted 2025 figures. The usage of nanotechnology is being implemented to remove contaminants from drinking water and to ultimately increase the availability of fresh water but, like the majority of nanotechnology, there is still a long way to go.

Existing Water Treatments:

Currently, a range of water treatment devices, including some of which incorporate nanotechnology, are already on the market and others are in advanced stages of development. Established methods of water treatment range from desalination to filtration to chemical treatment; whereas, nanobased technologies include a variety of different types of membranes and filters based on carbon nanotubes, nanoporous ceramics, magnetic nanoparticles, nanosensors and other nanomaterials.

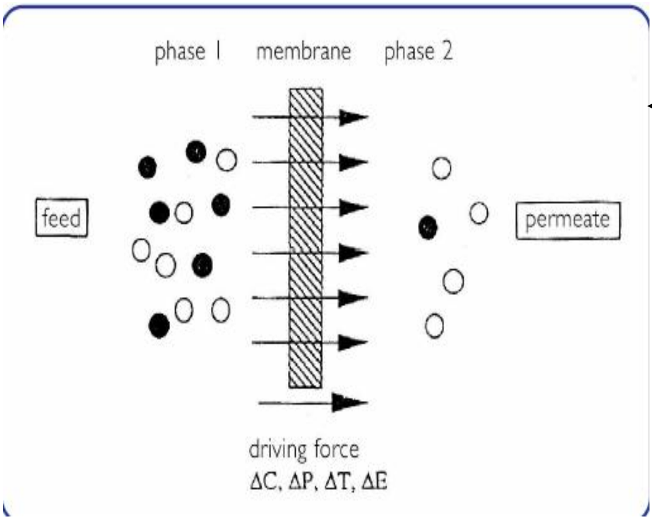


Figure 5

Membrane processes are considered a key component of advanced water purification and desalination around the world. The essential part of the technology is the membrane which is a barrier that separates two homogenous phases. It allows some solutes to pass through but rejects the penetration of others. It achieves the separation of solutes of a fluid mixture when a 'driving force' is applied. This 'driving force' could be a pressure difference (Æp), concentration gradient (Æc), temperature difference (ÆT), or electrical potential difference (ÆE). The basic principle of operation is illustrated in Figure 5. Phases 1 and 2 are generally the feed water and the product water or permeate, respectively. The basis of separation is that each membrane has unique characteristics for the selective permeation and rejection of different solutes. Two major membrane processes used in industry to purify water is via nanofiltration and reverse osmosis.

Nanofiltration removes dissolved salts (desalination) from brackish (salty) water, micro-pollutants (arsenic etc), and softens water through the removal of calcium and magnesium ions. Reverse osmosis membranes are also used for the desalination of brackish water, ocean, and seawater.

In a recent study in South Africa, tests demonstrated that nanofiltration membranes can generate potable water from the brackish groundwater. As expected, the reverse osmosis membranes isolated about 99% of all the solutes, but the concentrations of essential nutrients, such as calcium and magnesium ions, were condensed to levels that were beneath the specifications of the World Health Organization standard for drinking water. The product water therefore, had to be spiked with these nutrients to provide drinking water of the compulsory quality.

Nanobased Water Treatments:

As talked about in the previous section, membrane processes are considered key components of advanced water purification and desalination technologies. However, nanobased materials such as carbon nanotubes, nanoparticles, and dendrimers are contributing to the development of more efficient and cost-effective water filtration processes.

There are two types of nanotechnology membranes that could be effective: nanostructured filters, where either carbon nanotubes or nanocapillary arrays provide the basis for nanofiltration; and nanoreactive membranes, where functionalised nanoparticles aid the filtration process.

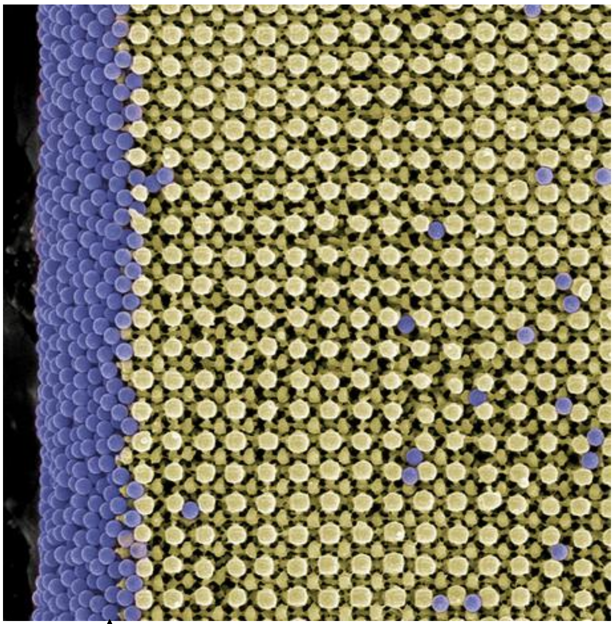


Figure 6

Filters that are structured on the nanoscale offer the promise of better water purification systems. They are cheap to manufacture, long-lasting and can be cleaned. Figure 6 shows a three dimensional polymer nanostructure as a filter element for a microfluidic device. The filter in this case removes tiny suspended beads (colourised to appear blue) from fluid flows directed from left to right. Other similar technologies could absorb or neutralise toxic materials, such as arsenic, that poison the water in many countries, including India and Bangladesh.
Tiny wastewater filters, for example, could filter emissions from industrial plants, abolishing even the smallest residues before they are released into the environment. Related filters could clean up emissions from industrial combustion plants, nanoparticles could be used to clean up oil spills - separating the oil from sand, removing it from rocks and from the feathers of birds caught in a spill. These examples showcase a fraction of the vast uses adaptations of nanotechnology has to offer to the world.

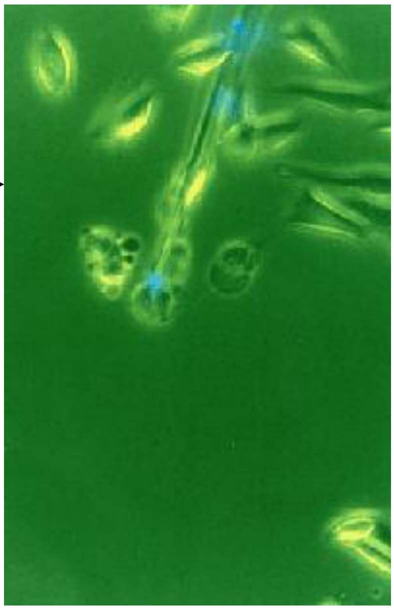
In addition to the nanotechnology membrane processes, chemical engineers have created nano particles out of gold and palladium to break down pollutants in groundwater. The addition of these particles to hydrogen, converts dangerous contaminants like trichloroethylene (a solvent which can potentially cause cancer) into non-toxic compounds. The nanoparticles used are approximately ten thousand times smaller than a human hair. Dr. Wong, one of Smithsonian Magazine's America's Young Innovators, says his reactor will be more efficient and cost less than the carbon reactors being used at this current time.

Nanosensors

What's more, nanotechnology is playing an important role in the development of improving the sensitivity and performance in biosensors due to the nanomaterials being used for construction purposes. As a result of their submicron dimensions, nanosensors, nanoprobes and other nanosystems have allowed simple and rapid analysis in vivo. One important nanobased technique used in water treatment is through nanosensors.

Nanosensors are any biological, chemical or surgical sensory points used to convey information about nanoparticles to the macroscopic world. These can be used in various medicinal purposes, such as monitoring HIV (as stated above) and cancerous cells as shown in figure 6, as well as other environmental uses.

Figure 6:
A nanosensor probe carrying a laser beam (blue) penetrating a living cell to detect the presence of a product indicating that the cell has been exposed to a cancer-causing substance.



Other medicinal uses of nanosensors mainly revolve around the potential of nanosensors to accurately identify particular cells or places in the body. By detecting and measuring changes in volume, concentration, displacement and velocity, gravitational, electrical, and magnetic forces, pressure, or temperature of cells in a body, nanosensors may be able to distinguish between, and recognise, certain cells - most notably those of cancer - at the molecular level in order to deliver medicine or monitor development to specific places in the body. In addition, they may be able to detect macroscopic variations from outside the body and communicate these changes to other nanoproducts working within the body for three reasons:

- To co-ordinate complex, large-scale co-operative activities
- Pass along relevant sensory, messaging, navigational and operational data
- Monitor collective task progress.

Nanosensors and Water Treatment:

Toxin sensors for drinking water are being created in order to combat the contamination of water by blue-green algae which produce cyanotoxins. Scientists from Nanjing University made their sensor to detect the cyanotoxin, microcystin-LR, by assembling gold nanoparticles on nitrogen-doped carbon nanotubes. The Nitrogen-doped carbon nanotubes are less toxic to cells and have better biocompatibility than un-doped carbon nanotubes, making them more suitable for use in biosensors. The nitrogen that bonded with the nanotubes also provides an active site for the gold nanoparticles to anchor onto, much like enzymes forming an enzyme/substrate complex with the complementary substrate. This technology could possibly then be adapted to combat the cholera Vibrio Cholerae bacteria.

Nanosensors and HIV monitoring:

HIV patients can now possibly cut down on the number of their medical check-ups, thanks to a new device slotted for development, show in figure 7**.** This device is believed to monitor, as well as assess, the effectiveness of the treatment of a patient without them having to frequently visit the doctor; additionally, the sensor could monitor the level of the virus in an HIV infected person.

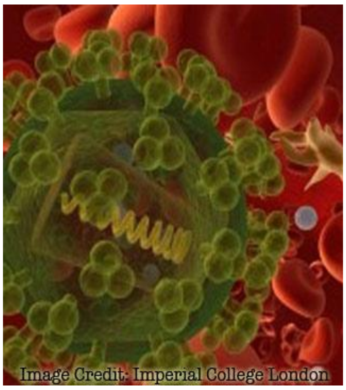


Figure 7

London’s Centre for Nanotechnology scientists, along with researchers from the University College London, Imperial College London Centre for Medical Molecular Virology, the Royal Free Hampstead NHS Trust, Cambridge Medical Innovations, Sphere Medical Ltd and BionanoConsulting are working together for the development of the device**.** The device uses nanoscopic mechanical sensors, called microcantilever arrays to measure HIV and other protein markers that indicate a rise in the level of the virus and the body’s response to it. It is further stated that such a development will help in keeping a regular check on HIV patients and caution them if required. It is further noted that the patients would benefit a lot from this device, as the number of checkups to the doctor would reduce.

Conclusion

As amazing as the technology seems on paper, to date, most of the testing has only been carried out on animals, such as mice; its adaptation to humans is still a hurdle needing to be overcome. Nanosystematic volumetric intrusiveness needs to be taken into consideration for it not to provoke unwanted reactions by physical displacement of critical biological systems or fluids. In particular, its cellular intrusiveness; will cells loose their secretary activity or their ability to divide?

A Finnish study found that two commonly manufactured nanomaterials have the potential to damage human DNA. The scientists cultures human lung cells with nanotubes and graphite nanofibres, and observed alterations in the DNA. Both the nanomaterials caused damage in the cultured cells, also showcasing a direct link between the dose of carbon nanotubes and the amount of damage. Highlighting the importance of appropriate safety tests of the nanotechnology before use.

The environmental risks of nanotechnologies within water treatment must also be taken into consideration as there have been some indications that the unique properties of nanomaterials, such as their size, shape, reactivity and conductivity, may cause them to be toxic.

The prospects of nanotechnology appear endless with breakthroughs within the field seeming exceedingly close. However, with new possibilities and opportunities come new problems consisting not only of the scientific but also social issues. The idea of cell repair machines working molecule by molecule would accumulate to the repair of whole cells, tissues, and organs; ultimately resulting in full restoration of health. With this ability, concepts such as the prevention of ageing enter the equation, raising questions of the boundaries of scientific ability and where they will interfere with the actions of god and the basic laws of nature.

However, the weighing of the risks and benefits has to be taken into consideration and at this stage, and the advantages seem to greatly outweigh the disadvantages. Medicine's aim is to restore health to its maximum potential, and nanotechnology seems to be the path which will lead to that golden goal, in the words of K. Eric Drexler, it will free medicine from reliance on self-repair as the only path to healing.

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