Nanotechnology in Medical and Health Sciences

Imagine an army of nanosensors roaming around in your body, sniffing and destroying cancer cells, bacteria and viruses. Imagine a workforce of nanomachines picking up damaged cells and repairing them instantly. This might sound like a scene from a science fiction movie. Today's dream of nanotechnology may be the reality in the future!

Nanomaterials and Nanotechnology (NT)

Molecular structures with length measurements upto 100 nanometers or less are called nanomaterials. Nanotechnology (NT) is the creation, manipulation, and application of such materials. Nanoparticles do not behave like solids, liquids, or gases we are familiar with. Their behaviour is guided by the laws of quantum physics. Nanoparticles of the same chemical may have electronic, magnetic, and mechanical properties quite different to the larger particles of the same chemical.

Nanomedicine

Nanomedicine is one of the most promising applications of NT. Nanomedicine might sound like scenes from a science fiction movie. Nanobots (nano-robots) in your veins roaming around, sniffing out and killing cancer cells and nanomachines picking up damaged cells and replacing them, may one day become a reality. Perhaps in the future, nanosensors inserted into your body will remain vigilant for organ malfunction and will alert your family doctor remotely. On physician's instructions, orders, transmitted remotely, the implanted molecular-sized pump will deliver the precisely correct dose of the required medicine directly to the target organ. This is what nanotechnology has in store for the medicine in the future. Scientists are looking at developing nanoscale tools and machines, designed to monitor health, deliver medicines, cure diseases, and repair damaged tissues. The built-in nanosensor in your body will constantly monitor your environment and warn you if the exposure to environmental radiation and toxic agents such as organophosphate compounds are reaching dangerous levels. The advantage of such sensor is that it is small, lightweight, inexpensive, and easily operated. Nanosensors will also help to understand the interactions between genes and the environment and to learn how cells communicate with each other.

Compare the sizes with nanoparticles!

White cell in blood	10000 nm
Bacterium	1000 – 10000 nm
Virus	75 – 100 nm
Protein molecule	5 – 50 nm
Nanoparticles	**1 – 100 nm**
Width of DNA	2 nm
Fullerine	**1 nm**
Atom	0.1 nm

Phases of NT development

NT development is in four phases. The first consists of '*passive nanostructures*', which are designed to perform one task only. The second phase, '*active nanostructures*' will include drug delivery devices, new types of transistors and sensors. A third phase would feature '*nanosystems*' with thousands of interacting components. The fourth phase, '*molecular nanodevices*' would be composed of systems within systems operating much like a living cell!

Applications of NT currently in use

- Stain repellent clothing: nanofibres keep water from soaking into fabric
- Stronger, stiffer tennis racquets and golf clubs: Hit the ball harder and more accurately because they flex less
- Antimicrobial wound dressings: nanofibres and particles with medically active coatings get to all parts of the wound
- Bouncier tennis balls: Less heat loss in flexing means more energy is restored to the bounce
- Skin care cream: Nanoparticles carry moisture deeper into pores
- Better sunscreen: nanoparticles provide a more even skin coverage
- Car wax: Like skin cream and sunscreen it offers more complete coverage
- Self cleaning windows: Dirt slides down nanoscale coating on he outside of windows
- Tougher paint: Dried matrix is more resistant to impact

Engineered nanoparticles are already being used commercially, in some sporting goods (eg stronger tennis racquets), tyres, building material (eg. self cleaning windows) and in clothing (eg. stain resistant clothing) industry. Newer sunscreen creams contain nanoscale titanium dioxide or zinc oxide particles. Unlike commonly available opaque white sunscreen creams, NT based ones are transparent, but still block ultraviolet rays effectively. Fullerenes are used in many products ranging from pharmaceuticals and semiconductors to coatings used for bowling balls.

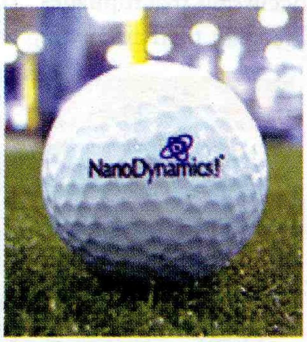

Fig 1 NT engineered golf ball

Immunoisolation

Application of nanotechnology will, in the future, enable the doctors to cure diabetes. Insulin-secreting, islet cells taken from the pancreas of a pig can be transplanted under the skin of a diabetic patient, to correct the lack of insulin. A major problem in this kind of tissue or cell transplant is that the recipient of the transplant developing an immune response against the foreign tissue, and rejecting it. To overcome this, a variety of drugs (immuno-suppressives) are used to curb the immunity. These drugs have the disadvantage of causing infections and cancers. NT engineering can be used to encapsulate the cells, and evade the immune response and rejection. This will protect the transplanted tissue while avoiding the need for toxic, immunosuppressive drugs. Transplantation of encapsulated will be an effective way of treating enzyme or hormone deficiency states in the years to come.

It may also be possible to implant encapsulated neurons in to the brain and then electrically stimulate them to release neurotransmitters. Such an approach would open up new avenues in treating diseases such as Parkinson's Disease (a condition where there the limbs become stiff and hands become shaky) and Alzheimer's disease (a disabling condition, where there is gradual memory loss).

Nanoshells

Nanoscale systems, called the nanoshells, designed to deliver drugs to target tissues, have been developed. A nanoshell is slightly larger than the polio virus. The drug that has to be delivered to the target tissue, for example to the tumour, is incorporated into the nanoshell. These nanoshells are injected and made to accumulate near the tumour cells. An infrared laser beam is then applied. The nanoshells selectively absorb the specific infrared frequency. The polymer gets dissociated and the drug is released to accurately on the tumour tissue. Antibody-attached gold nanoshells have also been developed for immunoassays, a technique used in diagnosing diseases. These nanoshells are capable of detecting subnanogram quantities of antibodies in blood, within 10 to 30 minutes of sample collection, allowing rapid bed-side diagnosis.

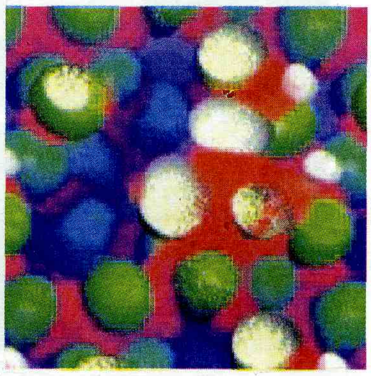

Fig 2 Computer-generated model of the interaction of nanoshells with the target molecules

Nanosieves

Ion transport can be controlled by modifying physical characteristics such as voltage gating, pore size, shape, and the charge. Nanosieves can filter out molecules with different characteristics with great precision. This degree of precision is valuable in certain applications in medicine.

Nanopores in ultrafast DNA sequencing

Nanopores can rapidly differentiate between pyrimidine and purine segments in a single RNA molecule. This allows them to discriminate between DNA chains of similar length and composition even if they differ by only one base pair. Such techniques will be a boost to scientists working in the field of genetic engineering.

Single virus detectors

Detecting even a single virus particle with great accuracy is possible with advances in NT. Within the next few years, diagnostic tools incorporating nanotechnologically engineered single virus detectors may be available to the practicing doctor.

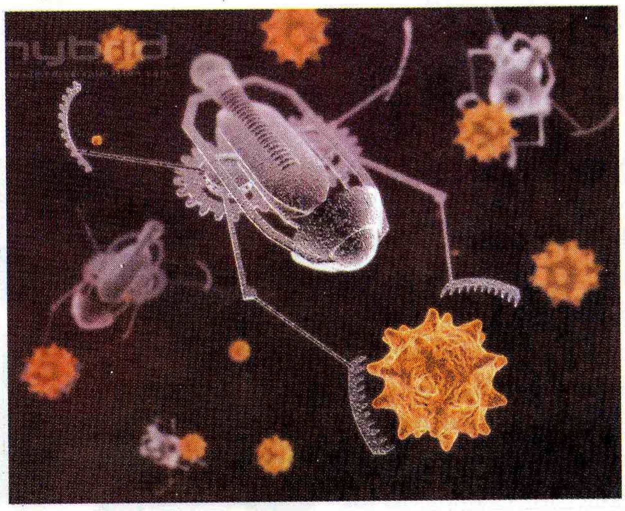

Fig 3 An artist's impression of a virus detecting nanorobot

Biological robots

With as little as 300 genes, it is now possible to engineer bacterial 'biorobotic' bacteria. These 'synthetic' microbes could be designed to produce vitamins, hormones, enzymes, or cytokines used to treat patients. Bacterial biorobots capable of absorbing harmful substances such as poisons and toxins and metabolizing them into harmless products will be possible with advances in NT.

Radio-controlled biomolecules

Tiny radiofrequency antennas, using 1.4 nm gold nanocrystals less than 100 atoms, can be attached to DNA. This will make it possible to control gene expression in living systems via remote electronic switching. Gold nanoparticles are attached to specific nucleotides and added to a sample of DNA. This would then bind to complementary gene sequences and block the activity of specific disease-causing genes.

Respirocytes

An artificial, 'mechanical' red blood cell, called the 'respirocyte' is undergoing development. It is a spherical structure powered by glucose in blood, and capable of delivering nearly 240 times more oxygen to the tissues than the natural red blood cell. In the future, it will be possible to inject oxygen-carrying 'respirocytes' to an accident victim who has lost a large amount of blood, without waiting for blood transfusions.

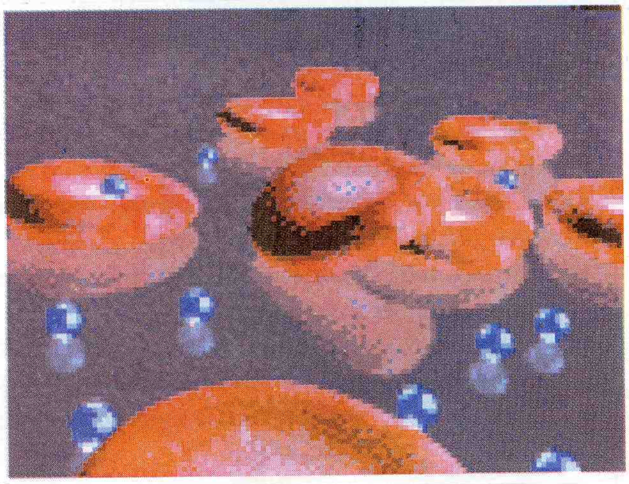

Fig 4 An artist's impression of respirocytes

Microbiovores

An artificial mechanical white blood cell, called a 'microbivore', has been developed. It uses a '*digest and discharge*' protocol to destroy microorganisms. These are predicted to be 80 times more efficient than the naturally occurring macrophages. These would also have a longer life span than circulating white blood cells. Microbivores

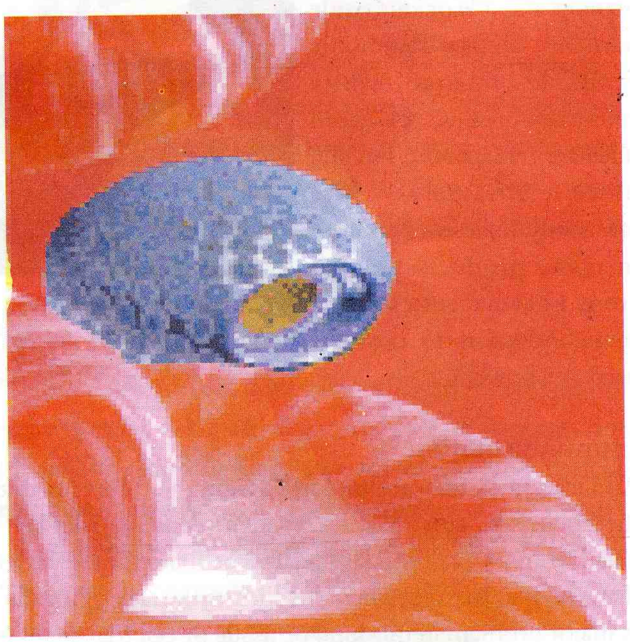

Fig 5 How a microbivore, an artificial white cell may look like!

may be useful to boost defenses against microbes at local sites of infection. Once they have performed their function it would be possible to remove them from the body.

NT for a safer enviornment

NT applications can be used to decrease the generation of pollutants, to 'clean up' existing pollution, and to monitor the environment. Improvements in membrane technology provided by nanomaterials should allow better water filtration, desalination, and wastewater treatment and provide practical solutions to the scarcity of safe drinking water in developing countries.

Health and environmental risks of NT

Potentially large benefits of NT need to be looked at in the context of their possible health and enviornmental risks. The effects of nanoparticles getting into the soil, water, air and into living organisms, either through environmental exposures or by direct applications, remain unexplored. An area of concern is that this NT is moving faster than our ability to evaluate its safety and health risks. Some early research findings are rather worrying. Recent studies suggest nanoparticles may not be as innocent as previously assumed. Some are able to travel readily through the body, get deposited in different organs and even penetrate individual cells. They have the potential of triggering inflammatory responses. Nanoparticles in the environment, known as ultrafine particles, have widely varying shapes, sizes and composition in contrast to engineered nanoparticles which are single, uniform compounds.

Experimental results

In 2004, it was reported that inhaled nanoparticles accumulate in the nasal passages, lungs and brains of rats. When a suspension of carbon nanotubes (one of the most widely used engineered nanoparticles) was placed into mouse lungs, it caused granulomas that interfered with oxygen absorption. When this experiment was repeated in rats, immune cells were found to accumulate around clumps of nanotubes blocking the breathing passages. Oxidative stress (a sign of inflammation) in the brains of largemouth bass exposed to water based fullerenes has raised several health implications.

Safety concerns

It is important that before these products are mass produced and dumped on consumers one needs to be sure they do not cause harm. In 2002, the Action Group on Erosion, Technology, and Concentration (ETC Group), called for a worldwide suspension on research and commercialization of engineered nanomaterials until there are protocols in place to protect lab workers. In the 1990s, the same group has played a key role in the battle against acceptance of Genetically Manipulated Organisms (GMOs).

In summary

Nanotechnology has enormous potential for the benefit of the society. Applications may range from new cancer treatments to new sources of renewable energy. It is vital that different segments of society should work in concert to prevent its true potential being markedly limited or destroyed by real or perceived risks. Problems or questions that are bound to crop up from time to time should to be addressed early and transparently. Past mistakes of rolling out new technology too far ahead of health and safety consideration must be avoided. It is only then that the science of the very small would have a chance of becoming very big.

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For further latest information on Nanomedicine

Read the scientific article (available from the web)
Nanotechnological applications in medicine
Shelton D Caruthers, Samuel A Wickline and Gregory M Lanza

In the journal
Current Opinion in Biotechnology
Volume 18, Issue 1 , February 2007, Pages 26-30.

Some useful websites:

(http://nano.cancer.gov/) (http://nano.cancer.gov/programs/ccne.asp) (http://nano.cancer.gov/programs/nanotech_platforms.asp)
(http://www.nhlbi-pen.info/) of the National Heart, Lung and Blood Institute
(http:/ncl.cancer.gov/) to help facilitate the transfer of nanotechnological research into clinical practice, the NCI, in conjunction with the National Institute of Standards and Technology and the US Food and Drug Administration (FDA) has established the National Characterization Laboratory.