Applications of nanotechnology in medicine

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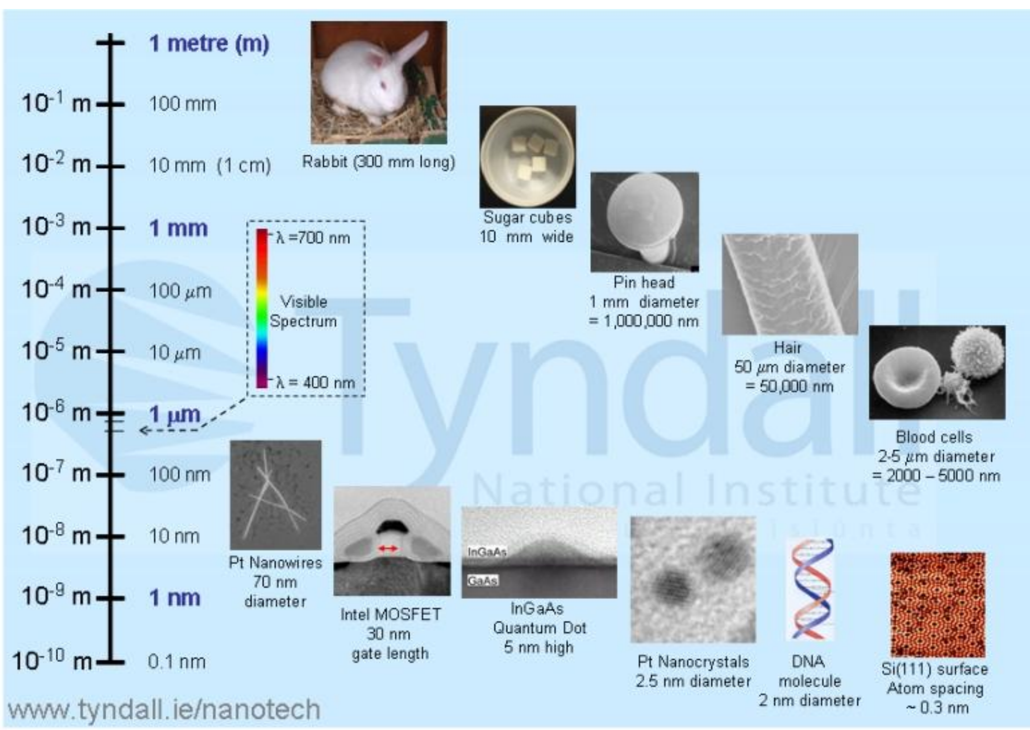
ABSTRACT

This paper is about the application of nanotechnology in many different aspects of medicine; such as the treatment of disease, surgical techniques and possible forensic pathology using nanotechnology. The paper includes some background information about nanotechnology, current research of nanotechnology in medicine and what possible future developments there could be using nanotechnology in medical applications. Ethical issues around the medical use of nanotechnology are also discussed.

INTRODUCTION

For many years man has tried to enhance life by revolutionising technology and taking science one step further. There have been amazing developments in materials, electronics, transport, fuels and medicine over the past centuries. But only in the last 50 years have scientists thought about building technology from the ground up. This means that due to advances in computing, electronics and physics, individual atoms can be manipulated and controlled. This field of science is called nanotechnology. Nano comes from the Latin nanus, which means dwarf, however today the prefix nano is in the International System of Units, multiplying the unit by 10^{-9}. Figure 1 shows the size of nano objects in context with everyday objects in order to compare this dimension. Atoms range in radii length between 0.031nm to 0.26nm, so manipulating and building technology from these is called nanotechnology.

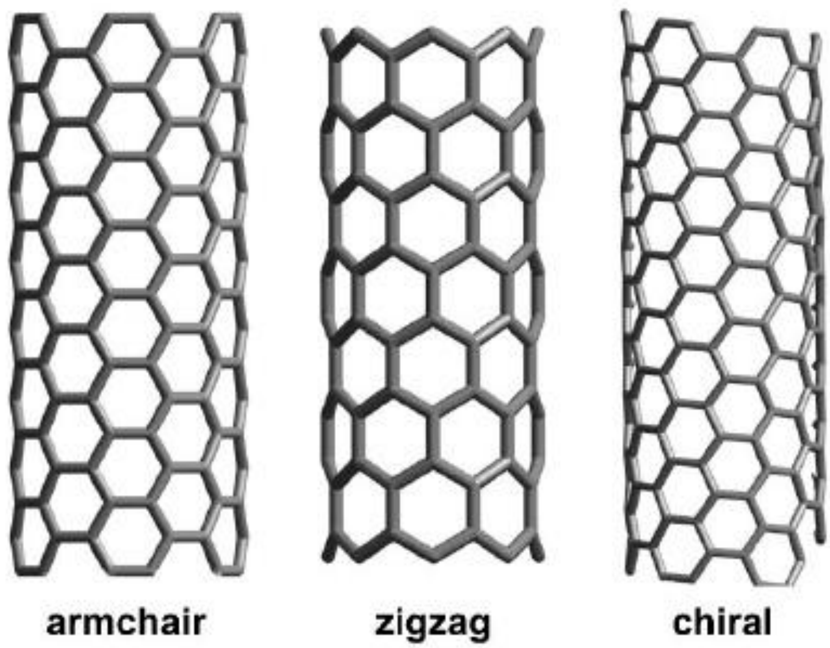
Figure 1



Some everyday examples of nanotechnology are self cleaning windows, where a layer of microcrystalline titanium oxide is deposited on the window. Dirt sticks to the window but because part of the layer is photo catalytic it breaks down the dirt and then water on the window takes the dirt with it as it runs down the window.

Another application of nanotechnology is nanobatteries, which are fabricated batteries that use carbon nanotubes which have organic molecules attached to align the lithium ions to increase the power density of the battery by 10 times compared to a normal lithium battery. Carbon nanotubes came from the work of Sumio Iijima, a Japanese scientist who was using simple arc-evaporation apparatus where he discovered fullerene-related carbon nanotubes in 1991. He found that these tubes contained at least two layers and were closed at both ends. Once he had discovered how to make carbon nanotubes other scientists developed and improved the carbon nanotubes until a new class of carbon nanotubes was discovered with only a single layer. There are three types of carbon nanotubes; armchair, zigzag and chiral, as can be seen in Figure 2. There are three types due to the possible arrangements of hexagons in the nanotube. The properties of carbon nanotubes vary because of the various attached molecules, lengths, and arrangement of hexagons. Carbon nanotubes can be 5 times as stiff as steel according to its Young's modulus, and much lighter.

Figure 2



One of the most developing areas of nanotechnology applications is in medicine. Ever since the 1800's when antiseptics, anaesthetics and hygiene for public health were invented and discovered, we have wanted to improve medical techniques, equipment and treatment to prolong and improve life. So when nanotechnology was introduced to the modern world, medical applications were thought of almost straight away. At the moment, there are a few applications in medicine of nanotechnology such as drug delivery systems. This is where a drug is placed inside a Bucky ball, a form of the element carbon which has many carbon atoms joined in one "ball". The most common type of buckyball or fullerene is buckminsterfullerene which has 60 carbons. The drug is only released by the ball at the point where it is needed in the body. This dramatically reduces side effects as almost all the cells affected by the drug are the ones targeted. Nanotechnology has so many possibilities for medicine because disease and many illnesses are at the cellular level and if we can make and manipulate things smaller than the cells themselves, we could theoretically target certain antigens and/or get inside damaged cells to make a positive change.

Another application in medicine is diagnostics, where magnetic nanoparticles can be bound to an antibody and are used to label micro-organisms, structures and molecules. This can be used to identify a disease or an illness. Cancer treatment is a new development where nanoparticles with quantum dots are placed inside the body of the person diagnosed with cancer. The nanoparticles then move to the cancer inside the body where they attach to the antigens of the cancerous cells showing exactly where the tumour is and how big it is using sensor test chips. Then the nanoparticles can be heated or "cooked" with radio waves, only killing adjacent cells, the cancer cells. This could be a future alternative to chemotherapy.

Current research in medical applications of mechanical nanotechnology is in tissue repair, where carbon nanotubes are used to create a scaffold around the tissue and allow the tissue to grow to the right shape. More current research is taking place in the repair of damaged nerves. It is being investigated whether nanoparticles can be used to connect neurons around the nerve connections. In surgery many patients have problems with blood loss due to arteries being accidentally cut after a transplant or operation so research is being conducted where a liquid is poured onto both sides of the cut. The liquid has certain nanoparticles in it which a laser then targets to heat and fuse together. This so far has been successful on a piece of chicken meat in binding the meat together, which could prove to make cutting through arteries and blood loss much less of an issue in surgery in the future.

DISCUSSION

Future developments of nanotechnology have no real limit, since we are dealing with the molecular scale and if we can move individual atoms using a scanning tunnelling microscope, then we could theoretically move atoms into structures and all sorts of mechanical devices. In the particular area of nanotechnology in medicine, there is a potential for many new treatments and devices to prolong life. In this section of my paper I am going to discuss my proposed ideas about the possible future of applications of nanotechnology in certain areas of medicine.

Disease

A disease is a specific pathological change caused by infection, stress, etc. producing characteristic symptoms. There are many types of diseases but I am going to discuss infectious diseases. Infectious diseases are caused by pathogens entering the body, multiplying and damaging cells. Tuberculosis is an example of a bacteria caused disease that destroys the immune system and is fatal, unless treated. It is estimated that in 2007, 1.8 million people were killed by tuberculosis in the world. Tuberculosis is treated with antibiotics over 6-24 months, but because of its high resistivity to antibiotics the treatment has to continue to confirm that the bacteria are all gone. Even though the bacteria have a relatively slow replication rate (it divides every 16-20 hours) the presence of any tuberculosis bacteria can still multiply and grow. The antibiotics used to treat tuberculosis are isoniazid, rifampicin, pyrazinamide and ethambutol. Together all of these destroy the bateria unless they are resistant strains of the tuberculosis but can have side effects like causing hepatitis. These antibodies don't fully cure the patient 100% of the time, in fact over 50% of patients with tuberculosis die. I would like to propose a treatment using nanotechnology for tuberculosis and other bacteria related diseases.

My proposed future development in treating bacteria related diseases is to use nanotechnology to build nanobots that locate the bacteria by selectively binding to it or entering the actual bacteria. These nanobots have quantum dots on them to show where the bacteria are on a high resolution MRI scan (magnetic resonance imaging). Quantum dots are nanoparticles which are semiconductors that emit a particular colour when a certain current is passed through them. These nanobots then destroy the bacteria from the inside. Once the bacteria are destroyed, doctors could track the quantum dots which would show the position of the nanobots until they are passed through the body and excreted out, meaning there are no other consequences once the bacteria are gone.

Another very large killer is viruses. Viruses are the smallest pathogen and are the cause of some infectious diseases such as influenza, HIV, AIDS and chickenpox. Even though viruses cause a fewer number of different diseases than bacteria, they still kill a lot of people. Viruses enter cells then multiply inside of the host cell and break free of the cell, damaging the cell or killing the cell. At the moment there is no cure for viral infections as viruses are immune to antibiotics and only antiviral drugs can be given to help the patient deal with the virus itself. There is no treatment that involves killing the virus or getting it out of the patient currently. I think that nanotechnology could be used to first understand more about viruses and their RNA codes, including how to destroy them and secondly use nanotechnology to gain access into viruses to destroy them or to neutralise the ability to replicate and to function. I believe this can be achieved because viruses are bigger than or as big as some of the nanotechnology that has been made and can be made, as seen in Figure 3.

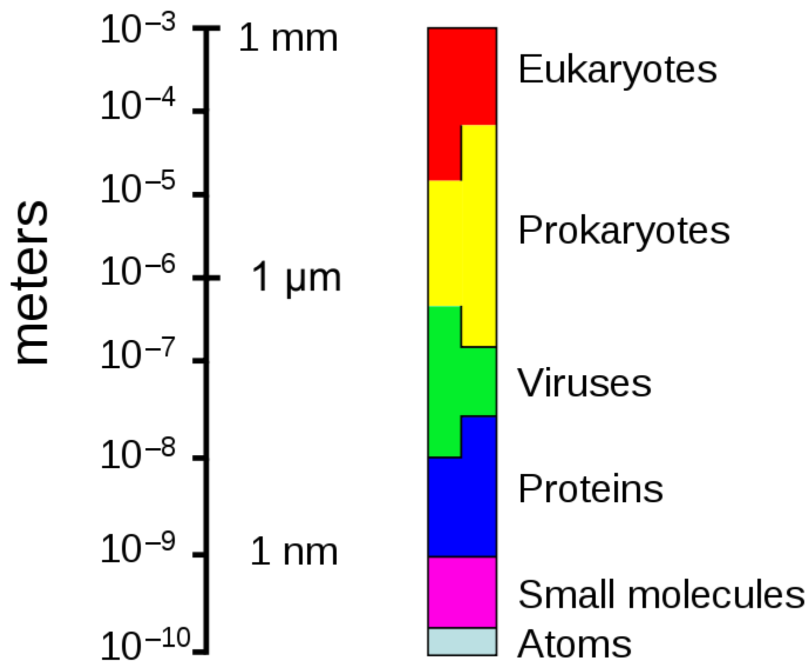


Figure 3

If viral infections are understood and can be manipulated using nanotechnology in the future then many people could survive and/or recover from infectious diseases. I think that the genes of the virus are the key factor and if there is a way to know what proteins the virus has then they can be inhibited or destroyed by certain drugs or by nanoparticles.

Some diseases are caused by too much of a substance such as coronary heart disease, where a variety of factors contribute such as; too much cholesterol in the diet, smoking, too many low density lipoproteins due to an unhealthy diet with too many saturated fats,. These fats can build up in the coronary artery to form an atheroma or plaque which narrows the lumen of the artery, as seen in Figure 4. Then blood clots behind it, stopping the oxygen reaching the heart muscle, leading to an insufficient oxygen supply to the heart. This then means the heart muscle dies, so the heart does not pump as strongly as required meaning that vital organs die and the body dies.

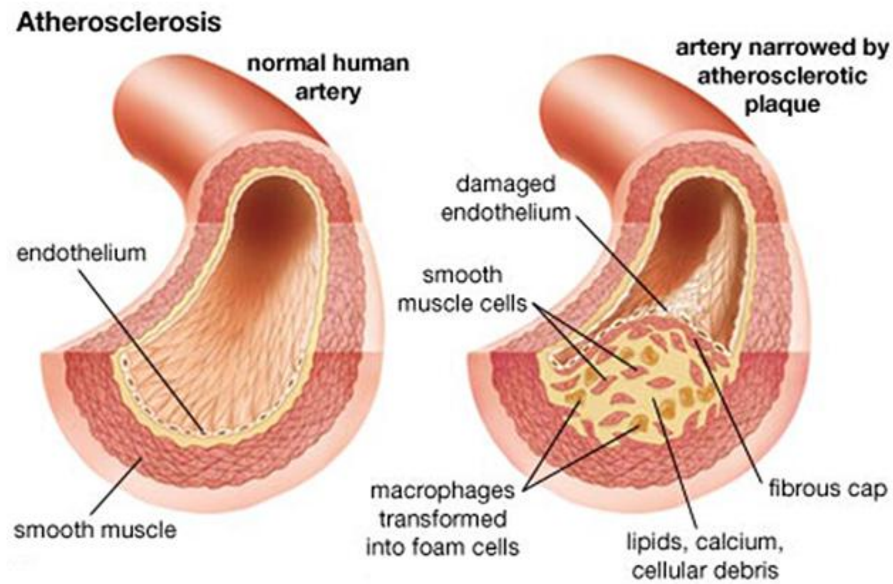


Figure 4

If there was a preventive method to stop the build up of cholesterol and low density lipoprotein (LDL) in the arteries, then less people could die of it in the future. Coronary heart disease is mainly down to lifestyle choices such as diet, smoking and consuming alcohol but more often than not those at risk from coronary heart disease are not aware that they are very likely to be diagnosed with it. To prevent this, nanotechnology could be used to screen a possible patient for cholesterol or LDL build up in their arteries. Nanoparticles could be made that have an affinity with relatively large amounts of cholesterol and/or LDL or nanoparticles that bind/bond to cholesterol/LDL could be injected or ingested in the body and tracked using quantum dots and MRI scanning techniques. The nanoparticles would collect at the site of cholesterol/LDL and be seen on the scan. The doctor can then offer a diagnosis and necessary lifestyle changes that have to be made in, and/or treatment in order to not get coronary heart disease and for it to develop into the worst case scenario of death.

However even those patients who do have coronary heart disease can be treated with my idea of using the same principal as the nanoparticles having an attraction or affinity towards the cholesterol/LDL, I think that nanobots or nanoparticles could be made to dislodge the plaque build up by controlling them externally, once they are at the site. These nanobots would break up the atheroma, then individually absorb the different parts of the plaque inside the nanoparticle such as a "Bucky ball" or place it inside the nanoparticle so the atheroma components can be moved and taken out of the body so that the coronary heart disease is no longer a risk factor if the patient's lifestyle is improved significantly.

Genes

Last century Watson and Crick discovered the double helix shape of DNA, deoxyribonucleic acid, which is the building block of all life, since proteins are synthesised from the nitrogenise bases which code for amino acids. Certain sequences make primary structures of proteins etc, and proteins are needed for all organisms to live. Even though we understand a lot more about the science behind organism development and why organisms have certain traits and characteristics, scientists have yet to sequence the human genome. In current research, conducted by many different teams of scientists lead by David Deamer, Hagan Bayley, Stuart Lindsay, Radomir Zikic, they are trying to show how nanotechnology can sequence the human genome. They think this is possible by using graphene, a one layer thick carbon sheet, to be used as a layer for the DNA to pass through. Salt solution will be immersed above and below the graphene, and two electrodes will be placed either side. Changes in the ion current distinguish individual bases, read by the sensor in the experiment. However this present method is flawed because the changes in the ion current mean nothing to the scientists since there is no standard base to compare against. Additionally the DNA double helix could rotate through the nanopore in the graphene, so a certain amount of carbon hexagons would have to be removed to be extremely accurate. But if nanotechnology improves and many more ways of manipulating molecules and nanodevices are discovered I am sure that the human genome will be sequenced very soon. If this does happen, there will be vast improvements in dealing with hereditary diseases and gene therapy, such as understanding why people contract some hereditary diseases after a certain age i.e. Huntingdon's disorder and Parkinson's disease.

Surgery

Many injuries and health problems need surgery to fix and heal the patient, instead of just using drugs. At the moment surgery is improving and becoming less invasive but also more complex such as open heart surgery. However at a cellular level surgery is still very crude and damaging towards cells. So I think that nanotechnology should be implemented in surgery to help the surgeons stop making accidental errors or needless openings in a patient because it is stressful for the patient, more complicated to deal with and can leave patients with unnecessary scars.

My proposition for the use of nanotechnology in surgery is to make nanosugerical tools that can be less crude than current instruments. These tools will work at the cellular level, tissue engineering as mentioned in the introduction and repairing damaged cells by controlling them externally and using them to join capillaries and damaged neurons. I think this would be possible because nanoparticles can be targeted with a laser or other electromagnetic wave device, then a certain wavelength of infrared or radio waves can be used to heat-seal the collagen together. Or at a smaller level, nanobots built can be used to encourage cells to adhere together and/or become part of the extracellular matrix, which would effectively help with tissue damage and help the body heal itself. If this advanced far enough, it could lead to living much longer and benefitting many patients who have lost limbs or have disfigured faces that plastic surgery couldn't help.

Forensic Pathology

Forensic pathology is the part of pathology, the study of disease, which deals with determining cause of death by study of a corpse. Currently there are many problems with finding the time of death of a person when conducting an autopsy. This is nearly always estimated and sometimes proves that the innocent is guilty or innocent in a murder case. I think that nanotechnology could be used to give an exact time of death.

The approach would use a nanotechnology chip inside the brain, and when there are no electrical impulses the chip records the time. I think this could revolutionise the way autopsies are carried out and speed up the conviction of murderers and law cases etc. For this to work everyone in the world or of that country would have to have the chip implanted.

Problematically this application of nanotechnology has many ethical issues that can be raised, for example the privacy of people. Not everyone would agree to have such a chip implanted, and there could be similar arguments to the control and storage of DNA evidence by governments. The clinical trials of this application would be very difficult and could potentially damage the patient, since the brain is a delicate area and not everything is understood about it.

ETHICS

Nanotechnology is very complex and could dramatically change the world we live in today. So we need to think about the consequences, risks and benefits of nanotechnology applications. For example potentially some or all of the nanoparticles could be toxic to humans, so a build up of these would have harmful affects on the patient and could lead to death. At the current stage of nanotechnology research, the long-term effects of treatment from nanoparticles, or any type of medical nanotechnology, are not known which could be very dangerous in the future. If many people had been treated using a nanotechnology treatment and the long term effect was a fatal disease, then many people could die. Because nanotechnology is not very invasive, it is possible that people could be poisoned with the use of it, such as assassinations or if it was readily available, common deaths. There are no laws at the moment to say that countries should share nanotechnology research which means that it is possible that other countries could harness its uses and applications for biological warfare for which there are no solutions. We also need to think about the implications of nanotechnology, such as if some nanotechnology is made that is self-replicating then we could have a "grey goo scenario" which means that the nanobots or nanoparticles replicate out of control and take up all the space on the earth or become the dominant matter. There might be religious arguments that humans are "playing God" and dealing with matter that should not be dealt with. Money is also a key issue, nanotechnology research is very expensive and because of the current economic climate, grants will be difficult to come by and cuts are being made in scientific research. Also nanotechnology consumes natural materials that may become harder to come by as time goes on. The environmental impact is also an issue, because man-made particles may disrupt natural compounds and other living things. We have no idea how nanotechnology may upset balances of food webs and the carbon cycle or any other key processes essential for life. If this is an issue then nanotechnology may have to be discontinued and be stopped all together.

The placement of nanotechnology in the current world has to be thought about, because the question will be asked whether it should be available within the National Heath Service or not. Depending on this, the wealthier could live longer and the poorer die quicker due to these new nanotechnology treatments and medical developments not being available to all. Whether it is cost effective to be on the NHS is a question the government of the future will have to answer when nanotechnology becomes available for widespread use after clinical trials.

CONCLUSION

Overall, nanotechnology has the potential to be of use in future medical treatments and diagnosis. Potential future developments of nanotechnology in medicine are to build nanobots or nanoparticles that enter bacterium and can show up on MRI scans using quantum dots. Also, it may be possible to build nanoparticles that can target bacteria and enter through their cell wall, and destroy them from the inside. To use nanotechnology to understand viruses better than we do currently by nanobots entering the virus and finding out how to stop them spreading through a person, would be extremely useful in medicine. Once this has happened, nanotechnology could be used to destroy viruses and treat viral related diseases. In the future the human genome and gene therapy will be perfected by use of graphene and other advances at the nano level, which could entail the treatment and possible extinction of hereditary diseases. Surgery could be advanced by using nanotechnology tools and encouraging cell growth in areas controlled externally. Even forensic pathology could be improved by nanotechnology in the use of sensors to indicate the time of death, however this has many ethical problems.

In general, a set of guidelines for the future use of nanotechnology must be written and agreed by the world before nanotechnology research becomes a race to start building weapons. Also I think that it is for the future government to decide on whether or not nanotechnology should be available to everyone on the NHS (if it is still in existence in the future). My personal opinion is that medical applications of nanotechnology should be available on the NHS if it is cost effective. Overall I think that nanotechnology should be further developed for medical applications but only if restrictions and laws are implemented to stop misuse of knowledge and molecular control.

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Image references

Figure 1 Nanometre scale http://www.tyndall.ie/research/nanotechnology-group/length_scales_hires.html
Figure 2 Different forms of carbon nanotube http://www.robaid.com/tech/nanotechnologies-carbon-nanotubes.htm
Figure 3 Virus' comparative size
Figure 4 Atherosclerosis http://www.tappmedical.com/atherosclerosis.htm