THE FUTURE DEVELOPMENTS OF NANOTECHNOLOGY IN MEDICINE

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ABSTRACT

Nanotechnology is the science of manipulating molecules at the nanometre scale. We are beginning to see uses in many areas such a material science and new manufacturing methods. However, the promises don't just end there as current research shows that Nanotechnology's biggest benefits could come from the field of Medicine, for example, new forms of Cancer Treatments and new ways to deliver drugs directly to where they are needed in the body. Nanotechnology is not without its problems as there are key engineering challenges and ethical issues to be resolved. If these hurdles are overcome then the most important benefit to Medicine could be the use of Nano-Robots, to surgically repair the chromosomes with in a cell.

INTRODUCTION

Nearly every technological improvement has been made by making things smaller and more precise than previously. But eventually we get closer to the limits which are set by physics as the scales that we work at become microscopic. The smallest unit of matter we can build with are atoms or molecules. When this scale is reached, we can begin to make products by manipulating individual atoms and molecules exactly where we want to place them. These ideas for molecular manufacturing were first introduced by Nobel Prize winner Richard Feynman more than 40 years ago in his famous speech titled "There's Plenty of Room at the Bottom". This meant that molecular manufacturing would give us endless opportunities to develop new technology.

In 1986, Dr K. Eric Drexler published his book "Engines of Creation: The Coming Era of Nanotechnology" where he proposed his idea of a 'nanoscale assembler' which would be able to build copies of itself. However there were many ethical issues surrounding this idea including trying to find a way of stopping the machines from making too many replicates of itself once the machines were placed inside the body.

Nanotechnology started in the early 1980s with the major developments of cluster science and the invention of the Scanning Tunnelling Microscope (STM). This development then led on to the discovery of fullerenes in 1985 and carbon nanotubes which were discovered a few years later.

Carbon nanotubes and fullerenes are both made of carbon atoms. Each carbon atom is covalently bonded to three other carbon atoms to form hexagonal rings (see Figure 1) leaving the forth electron delocalised. The bonding is therefore similar to that of graphite. They are both fairly unreactive due to the stability of the graphite-like bonds however researchers have been able to increase the reactivity of fullerenes by attaching active groups to the surface of them. They are also good electrical insulators due to the restricted movement of delocalised electrons.

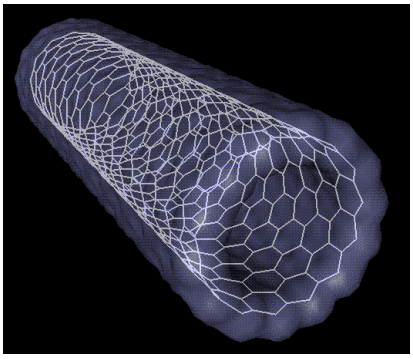

Figure 1

Their hollow structures allow them to hold other atoms inside of them, which is particularly useful in Medicine when binding specific antibiotics to the structure of fullerenes in order to target resistant bacteria and even certain cancer cells such as melanoma.

Carbon nanotubes can trigger similar toxic responses to asbestos fibres when they are roughly 20µm or longer. They have the ability to persist in the body and they have dangerous effects. Macrophages that try to engulf the nanotubes will suffer from cell ruptures and die. However this is not the case with nanotubes smaller than 20µm as they have different properties to longer nanotubes. The smaller nanotubes are not dangerous or toxic when they are inhaled as they do not remain in the body.

There are many possible uses of nanotechnology. Nanoparticles can consume very low amounts of energy and this could make it an important alternative to the current methods of supplying power. Nanotechnology is already used in stain-resistant and anti-wrinkle clothes but it could also be used to monitor a person's heart rate in 'smart clothing'. Filtration is also another possible use of nanotechnology. This is because the surface and volume of some particles can change when they are nanoparticles so that they have a large surface area. The advantage of this is that more reactions can occur on the surface of the particles. This can allow new kinds of filtering including water for drinking or light for solar energy.

Nanotechnology is very important to Medicine because the Medical field deals with particles at the level. Nano-Robots have a huge potential for medical uses because the small robots could be used to perform a number of functions inside the body as well as outside of it. Damage to the cells in the body is difficult to repair because the cells are so small. However Nano-Robots could manipulate the molecules and the atoms into repairing the cells.

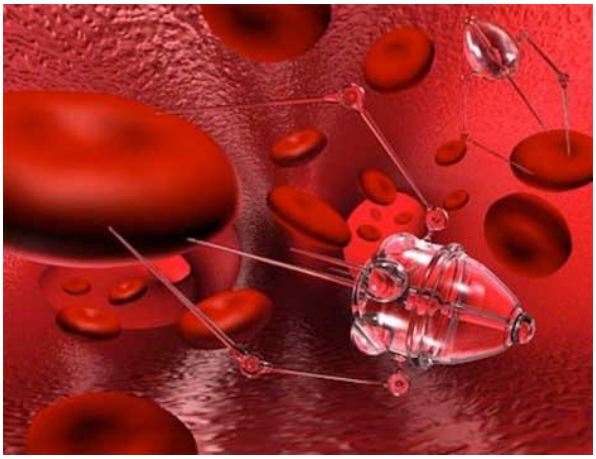

Figure 2

At the moment current technology used to destroy cancer cells also destroys the healthy cells surrounding them. It might be possible to target the cancer cells (see Figure 2) and destroy them with almost no damage to the healthy cells with the use of Nanotechnology. Gene therapy would also be a way of reducing the number of illnesses and diseases. Nanotechnology would have to be small enough to enter the body and possibly reconstruct the Genome. For this to happen we would need to know about the Human Genome a little better. Again Nano-Robots could to swap the abnormal genes with normal genes, as well as performing other functions beneficial to the body.

DISCUSSION

Before this paper discusses the possible future developments of Medical Nanotechnology and the ethical issues surrounding such future developments, it is important to explain the current research.

Drug Delivery

Drug delivery is a method where we can deliver the correct amount drugs, to the correct area of the body in the time that is needed. The most common ways of distributing drugs are the preferred non-invasive methods. These methods include per-oral (through the mouth), topical (through the skin), trans-mucosal (through or across the mucous membrane, as the administration of drugs via the cavity between the cheek and the gum), or inhalation routes.

Drugs might not reach where they are needed using the methods mentioned because they could be exposed to enzymatic degradation. Another reason is that the drugs cannot be absorbed into the blood system efficiently, which is due to the molecular size and charge issues for this to be therapeutically effective. For this reason many peptide and protein drugs must be administered directly into the bloodstream, such as many immunisations which are based on the delivery of protein drugs by injection. There has been a lot of current research into the area of drug delivery, which also includes the development of targeted deliveries. The drug is only activated when it is in the target area of the body – this would be useful in cancerous tissues, for example. There is also research into how the drug is released over a certain period of time and in a controlled manner.

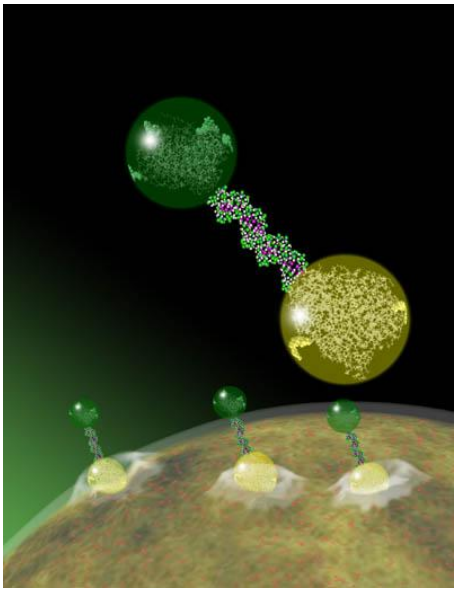

Figure 3

Nanotechnology is an important feature for drug delivery. The nanoparticles are built to be attracted to the diseased cells which can allow direct treatment of these cells (see Figure 3). This method is very advantageous at it reduces the damage to healthy cells in the body and it can allow for an earlier detection of the disease. A useful feature of using Nanotechnology means that drugs which are currently given by injections may be able to be taken orally. This is because the drugs are enclosed inside nanoparticles, which helps them to pass through the stomach and into the bloodstream.

Normally when drugs are injected into the body, a percentage of it is absorbed by healthy cells. This may lead to side effects from the drug if too many healthy cells are absorbing the drug. Therefore more of the drug must be injected so that enough of the drug will reach the damaged cells. Nanoparticles protect the drug so that it is not broken down before it reaches the damaged cells. Less of the drugs need to be injected into the body and so there is less risk of suffering from side effects. A lot of money can be saved because the drug is more available and so it can be given to more people.

Therapy Techniques

The allergic reaction is one of the leading causes of chronic situations and while there are a number of treatments to control the allergy, no cure has been found yet. Buckminster-fullerene balls (or Bucky balls) could be used to trap the free radicals which are produced during a reaction to block the inflammation.

The current problems we have in Cancer Therapy today is that the radiation used can damage healthy cells whilst killing the cancer cells. Nano-shells might be used to concentrate the heat from infra-red light in order to destroy the cancer cells with the smallest amount of damage to the surrounding healthy cells. Nanospectra Biosciences has developed a treatment using the Nano-Shells which are illuminated by an infra-red laser and has been allowed for a trial with human patients. However, the infra-red light must be shone onto the affected tissues which might involve an invasive procedure. Therefore a non-invasive method would be preferred, such that it could be possible to find a Nano-Shell which can concentrate ultrasonic sounds or magnetic fields to destroy the cancer cells.

Alternatively, Nanoparticles could be used for cancer therapy so that when they are activated by x-ray radiation, they produce electrons that destroy the cancer cells, which the nanoparticles have attached themselves to. This is expected to be used in the place of radiation therapy as there is less damage to the healthy cells. Nevertheless x-rays can still be harmful to healthy cells due to the amount of x-ray radiation which is exposed to the patient. This could be resolved by either trying to find a method using an alternative source of radiation which is less harmful or by using nanoparticles which can be activated by using very minimal amounts of x-ray radiation.

Bleeding in the body occurs when the body is not able to make blood clots. Sometimes there is so much bleeding that the blood clots are not able to be formed. So far only medical gauze has been used to try to stop bleeding. Medics can only place the medical gauze into the wound and hope that the bleeding will stop – this medical gauze is similar to the gauze used in World War 1. Aluminosilicate nanoparticles can be used in medical gauze to reduce bleeding in trauma patients very quickly by absorbing the water. This causes the blood in the wound to clot quickly. As well as being used in medical gauze, aluminosilicate nanoparticles could also be incorporated into the Soldiers' uniform therefore they would be able to use their uniform to stop the bleeding if they are injured and this could potentially save more lives.

Cartilage unlike bone does not grow back and therefore clinical strategies in order to remake this tissue are of great interest. Damaged cartilage can lead to joint pain and the loss of physical function and eventually osteoarthritis. Researchers at Northwestern University were the first people to design a bioactive nanomaterial that helps with the growth of new cartilage inside of the body (in vivo) and also without the use of expensive growth factors. This is a minimal invasive method as the therapy activates the stem cells in the bone marrow to produce natural cartilage. In the future the use of Nanomaterials could be used to trigger stem cells to produce other cells such as the cells the retina.

Many respiratory infections such as influenza are caused by viruses. The symptoms (i.e. a

blocked nose or a sore throat) only occur after the virus has attacked. In other words, you do not know when a virus is attacking but you cannot keep taking medicine continuously otherwise you may suffer from the side-effects. People would be able to prepare themselves for a respiratory infection by inhaling an aerosol spray that contains small protein cages. These protein cages are then able to activate an immune response inside the lungs, which can last for more than a month and is good against most respiratory virus. Less time would have to be spent waiting for scientists to analyse new viruses, develop vaccinations against them, distribute them and administer the vaccine. Less money would have to be spent on drugs as the same aerosol spray could potentially be used against most of the viruses. The protein cages are also constantly checking for new respiratory infections and getting rid of them quickly. Therefore there is less chance of suffering from the symptoms. The nanoparticles would also be useful because they would work against more than one virus such as swine influenza and avian influenza. The future developments of these protein cages could be for them to work for a longer period of time and adapt themselves to get rid of any new types of respiratory infections.

Diagnostic and Imaging Techniques

Cancer cells are very hard to locate and invasive test such as a biopsy are needed when making a diagnosis. A biopsy can be very painful to the patient and there needs to be enough of the cancer cells in the biopsy in order to make a diagnosis because the current instruments and the processes that are used today are not sensitive enough. Nano-biomarkers can be used to build very sensitive instruments to provide a much earlier detection with a smaller amount of cancerous cells. Quantum dots (qdots) may be used in the future to locate cancer tumours in patients and possibly performing diagnostic tests inside the samples. The qdots have a peptide coating which disguises them with a protein-like cover that allows them to target specific molecules. It could be possible in the future to use different peptide coatings on the qdots to detect other problems in the body such as blood clots which can occur in blood vessels.

Magnetic resonance imaging (MRI) can be very useful for detecting a tumour in the body without turning to surgery. The MRI scans uses pulses of magnetic waves to identify the different types of tissue in the body, distinguishing bone from muscle, fluids from solids and so on. However it can be difficult to determine cancerous tumours from normal healthy cells. Scientists have discovered that peptide-coated iron oxide nanoparticles (magnetic nanoparticles) can be helpful when locating cancerous cell clusters in MRI scans. The magnetic nanoparticles are able to find the tumour cells and attach themselves to them. Once the nanoparticles have bound themselves to these cancer cells, the particles are able to work like radio transmitters, which help with the MRI's detection.

Anti-Microbial Techniques

Normally a bacterial infection is treated with anti-bacterial drugs. The drugs must be given to the correct area as soon as the infection is detected. In any case, bacteria will eventually become resistant to the drugs, so drugs companies have to invest a lot of money into producing new anti-bacterial drugs. The use of Nano-Crystalline silver is used to kill bacteria. Scientists have developed minuscule nanoparticles that can carry nitric oxide, which helps in the body's natural immune response to infection. This method has been topically applied on mice. The particles release the nitric oxide that travel deep into

the skin, clearing up the infections and helping to heal the tissue by killing the bacteria.

Abscesses are deep skin infections that often resist antibiotics and may require the need of surgical drainage. Nanocapsules containing antibiotics can be placed inside burn dressings. This means that if an infection starts the harmful bacteria in the wound causes the Nanocapsules to break open and release the antibiotics which are enclosed inside. This is a quicker treatment of an infection and it reduces the number of times that the dressing has to be changed. These Nanocapsules can be incorporated into the uniform which firemen and soldiers wear and it could even be put into the suits of racing car drivers. This means that the antibiotics are released as soon as an injury occurs but before an infection can develop.

Nano-Robots in Medicine

Some cells in the body may have damaged chromosomes which mean that the cell will not be able to function properly. Genetically damaged cells could eventually cause problems in other cells during cell division (mitosis) or in future generations. One possible way of repairing the chromosome is to take out the entire chromatin content in the nucleus of a living cell and replace it with a new set of pre-made chromosomes that have been artificially produced as defect-free copies of the original chromosomes.

This may not necessarily work in adults, but it could be more reliable in a blastocyst or in the embryo before the baby has fully developed. A Nano-Robot could also check for genetic problems in egg cells in the ovaries and the sperm cells in the testicles before fertilisation so that the egg cells and the sperm cells which contain damaged chromosomes can be replaced with the pre-made chromosomes before they are used in fertilisation.

The Future for Nanotechnology

Tissue engineering could be done with the use of Nano-Materials. Tissue engineering would make use of artificially stimulated mitosis by using suitable Nano-Material based growth factors. Advances in nanotechnology based tissue engineering could ultimately lead to a longer life expectancy in humans and other animals.

There is also the possibility of bacterial infections in a patient that could be eliminated in minutes by using Nano-Proteins instead of using antibiotics, which need to be taken over a period of weeks. This means that there is less of a chance of getting side effects from the Nano-Proteins.

With nanotechnology, minute surgical instruments and robots could be made to perform microsurgeries on any part of the body. This means that instead of damaging a large amount the healthy cells, these instruments would be precise and accurate, targeting only the damaged cells. The visualisation of surgery can also be improved. Computers can be used to control the Nano-sized surgical instruments instead of a surgeon and Nano-cameras can be used to provide a close up of the surgery. This means that there would be less chance of any mistakes or flaws occurring and so surgery could be done on tissue, genetic and cellular levels.

The Ethical Issues of Nanotechnology

There are many ethical issues which nanotechnology faces. Bioethical researchers believe that Nanomedicine could be manipulated to harm the body instead of healing it.

What if the nanoparticles were used for terrorism purposes? The nanoparticles are so small that they can't be seen or controlled easily. They could also be used to deliver harmful substances such as toxins into the body. Nanotechnology could also allow us to create more powerful weapons. Therefore scientists and Politicians are urged to examine all the possibilities of nanotechnology before they start to design these powerful weapons.

Elements behave differently than they do in their mass form and there is some concern that some nanoparticles could be toxic. Nanoparticles are so tiny that some doctors are concerned that the nanoparticles may be small enough to cross the blood-brain barrier (a membrane which protects the brain from harmful chemicals in the bloodstream). This is very important especially if we plan on coating everything such as our clothes and our roads with nanoparticles. We need to make sure that these nanoparticles will not poison us before we start to use them.

Another question is who would control the technology that is place inside of human beings? Would it be the government, the businesses who developed the technology or the doctors? Would controlling the technology mean that you have the power to change human evolution?

Nanotechnology is currently being funded by private companies and the government, but when the breakthrough of nanotechnology does eventually arrive, not everyone will be able to afford it. If only a minority of people can afford this technology, what does this mean to the majority of the population?

In theory nanotechnology could make us stronger, smarter and give us other abilities such being able to heal ourselves very quickly. Could we therefore still call ourselves human or would we become transhuman. Since almost every technology starts off expensive, could this create two races of people – a wealthier race of modified humans and a poorer population of unaltered people.

Many experts believe that the interest into transhumans are very advanced however, nanotechnology will definitely continue to affect us as we learn more and more about the potential use of the nanoscale.

CONCLUSION

There are a number of challenges which nanotechnology would need to overcome before it can be placed inside of human beings. These include how to program the nanoparticles into doing their correct job or how to control the nanoparticles and how to keep them working once they are inside of the body. However an important challenge is what would happen to the nanoparticles once they have completed their particular function inside of the body. Would there be a way of getting the nanoparticles out of the body once they have completed their particular function or would they stay in the body? Only after these questions are answered can nanotechnology then be tested on humans.

The most likely use of Nanotechnology would be the medical gauze containing aluminosilicate nanoparticles. This is medical gauze is currently being tested on trauma patients. Recent tests have shown that this medical gauze has decreased blood loss and improved the chances of survival.

The most beneficial use of Nanotechnology would be cancer therapy. So far there is for cure to cancer and the methods that are used today can damage healthy cells whilst killing the cancerous cells. By using Nanotechnology in cancer therapy not only would the body's healthy cells not be damaged but Nanotechnology could also reduce the chance of getting a relapse.

Probably, the field of Nanotechnology which has the greatest potential would be the use of Nano-Robots, such as replacing damaged chromosomes in a cell. This could have the most potential for the future because it could mean for example that no one would develop any cancerous diseases or any deformities.

Nanotechnology does have its drawbacks such that we don't know for sure how the human body will react to the nanoparticles. However the amount of research into nanotechnology is promising and should not be stopped despite the ethical issues and the challenges facing this topic.

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