Nanotechnology:

Latest Research and Future Uses

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PASS WITH MERIT

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Abstract

Nanotechnology currently has a huge potential to revolutionize medical diagnosis. In this paper, I will be researching into the depths of nanotechnology and its strong link with medicine, both in patient treatment and research of medical conditions and pathogens. I will explore the possible areas of advancement within the medical field along with its ecological and ethical implications.

Introduction

Nanotechnology is the ability to control materials and devices at the atomic and molecular level. It is enabling revolutionary changes. The idea of nanotechnology was first introduced in 1959. Richard Feynman, a physicist at Caltech, gave a talk called "There's Plenty of Room at the Bottom" and although he never directly mentioned the word "nanotechnology", he did prophesise that we would eventually be able to arrange atoms in the way we desire and do chemical synthesis by mechanical manipulation. The tern "nanotechnology" was first used by Professor Norio Taniguchi of the Tokyo Science University in 1974, on his paper, "On the Basic Concept of Nano-technology." The origin of the word "nano" lies in Greek; it means midget. However, a more contemporary definition is it that it is a billionth of a metre. In 1985 a spherical molecule called Buckminsterfullerene, $C_{60,}$ was discovered by Professor Sir Harry Kroto and two Rice University Professors, Dr Richard Smaller and Dr. Robert Curl. The "Buckyball" is truncated icosahedron and each of the sixty carbon atoms in the "Buckyball" has one delocalised electron, enabling the Buckminsterfullerene to conduct electricity. This, along with its size, makes it a vital component in nanotechnology and in 1999 the first Nanomedicine book, written by Robert A. Freitas Jr., was published.

The chemical properties of nanoparticles are very difficult to predict because of the Quantum Size Effect. The Quantum Size Effect is a phenomenon observed when atoms or molecule in a nanoparticle form behave differently to atoms or molecules in bulk form. This is due to the fact that van der Waal's forces along with hydrogen bonding have a higher influence on the physical properties of nanoparticles compared to other physical forces such as gravitational field strength. It is due to the Quantum Size Effect that limitations are imposed on the use of nanotechnology in the medical field. For example, macroscale molecules which are non toxic could become toxic whilst in nanoscale form due to the Quantum Size Effect.

Despite these limitations there have been many medical advances due to the application of this new technology, for example:

Drug Delivery

Many drugs are not water soluble, which makes drug delivery very difficult. Nanospheres are involved in the transport and release of drugs and proteins needed by the body. In this day and age many medicines are taken orally and although this may be an effective method, it is not necessarily the most effective method as the drugs may not reach their destination before they are broken down and digested. The University of Texas is, therefore, developing a way of using nanospheres so that drugs can be release in a controlled manner in oral delivery. Given their small size, nanospheres are able to enter human tissues and cells quickly, therefore ensuring an effective treatment.

An example of this is in the form of contact lenses. According to New Scientist, on the 29th October, scientists in Singapore created contact lenses which delivered glaucoma medication (Figure 1). They were made by mixing the drug with a pre polymer liquid. This was then polymerised to create the transparent lens. This offers the patient a wider choice in the method of treatment. Although eye drops are the most commonly used, they are not the most

Figure 1: Contact lens which delivers Glaucoma medicine

efficient method as the majority of the drug ends up in the blood stream instead of around the eye. This usually leads to unwanted side effects as the drug is transported to other tissues it is not designed to work with. The contact lens consists of nano-water filled channels and the drug leaches out if these channels directly to the surface of the eye. This contact lens could then be modified to be lubricant for people who suffer with dry eyes.

New molecules have also been developed called nanoshells. Nanoshells are silicone spheres coated in gold, they locate cancerous cells and bind to them, and they then destroy the cancer cells by using a laser with releases infra-red light which heats it causing it to melt. You can modify nanoshells (Figure 2) by adding surface antibodies. Unlike radiation and chemotherapy, nanoshells minimise the damage to healthy body cells which may surround the diseased cells.

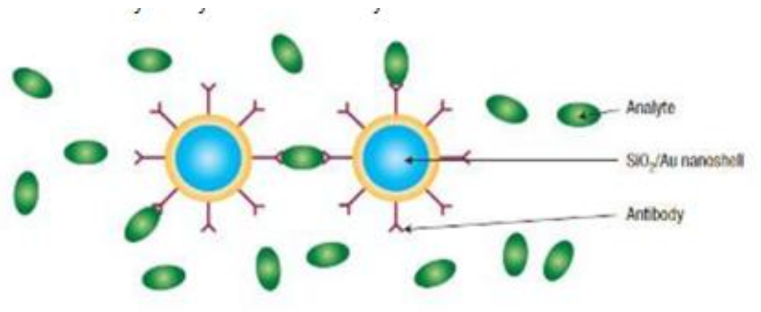

Figure 2: Antibodies on the surface on nanoshells binding to antibodies of the infected cell

Detection of Cancerous Cells and Treatment.

Currently nanotechnology research seems to show a great focus on the treatments of cancers found throughout the body. Many nanomaterials have been created that could potentially be used in cancer treatment. One creation is the "quantum dot" (Figure 3). Phil Chamberlain described the quantum dot as, "a crystalline compound between two and ten nanomentres wide with electrical and optical properties." The quantum dot surrounds the damaged tissue and once under visible light it emits infrared light. Thus pin-pointing on the body the areas affected by cancer. The use of the quantum dot reduces the need for biopsies and unnecessary damage

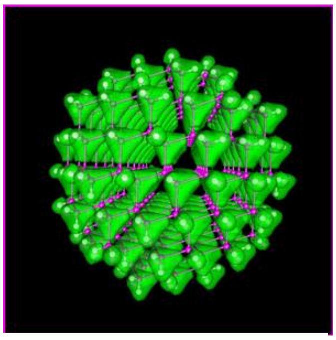

Figure 3: Quantum Dot

Imaging

Quantum dots are very useful in tracking cells and drugs that are distributed around the body. Quantum dots bind to the cancerous cells and effectively lighten then up for the scanner. Nanotechnology enables doctors to visualise the extent of the cancer and therefore allow them to make a correct diagnosis of the stage of cancer.

Screening

Nanotechnology also enhances the screening process for cancer. Biomarkers in tissues and fluids need to be identified in order for the patient to be diagnosed. As different types of cancers can differ from each other, several biomarkers may need to be detected simultaneously. Quantum dots emit different colours of light depending on their size, this, therefore, enables the simultaneous detection of multiple biomarkers.

Surgery

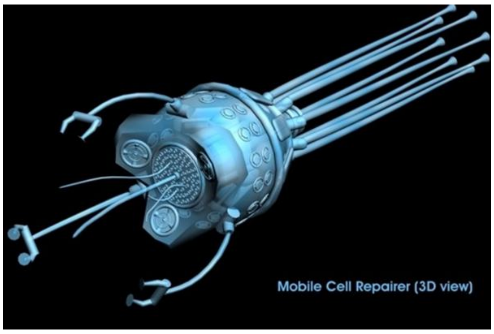

Figure 4: Diamondoid cell-repair nanorobot

One of the most important applications of nanomedicine is within cardiovascular sciences, Nanoscience provides the technology to design and develop surgical instruments that are not only smaller in size but also more effective. Robotic surgical systems (Figure 4) provide surgeons with unprecedented control over instruments and enable then to carry out surgical procedures with complete precision. Instead of using surgical instruments, surgeons use joystick handles to control the arms of the robot that are inserted into the patient and view the robot arms by using MRI scanning technology (Figure 5). The large movements made by the surgeon on the joystick are converted into miniature movements by the arms of the robot to ensure complete precision. Nanoinstruments reduce the risk of the central nervous system being disturbed and the risk of gastrointestinal problems occurring. This makes it a safer procedure compared to normal surgery, particularly for elderly patients.

This could reduce surgical costs in the future as nanorobots could be used in monitoring tissues for any signs of disease. This intern would decrease the amount of people who become seriously ill due to the disease as the disease would hopefully be detected at an earlier rate so therefore treatment could be given at a quicker rate.

Nanoshells are also used in kidney and heart transplants. Infra-red radiation is used to melt the nanoshells to “weld” the cut arteries together. This reduces the risk of blood leakages which could potentially result in a blood clot.

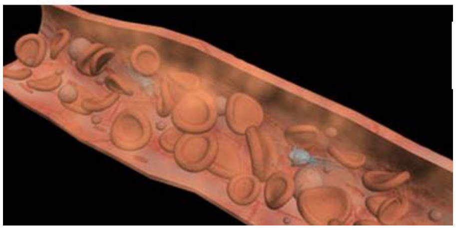

Figure 5: Nanorobot in a blood stream

Discussion

Nanotechnology is the future of medicine. Systems are currently being developed to monitor the internal environment of patient’s bodies for any symptoms of disease. The benefit of this is drugs are delivered directly to the site that requires them; this means that the risk of side effects is reduced and as a result the drug is more effective. This could therefore reduce the amount of money spent on these drugs. People with diabetes are a group of people that could benefit by this research. For example, a device could be created that monitors the levels of insulin in the blood and when the level of insulin is below the required level insulin is automatically released into the blood stream.

Another possible area of advancement in nanomedicine is bone cell regeneration. This gives people all around the world a method of recovering from degenerative bone diseases without the need of having major surgery.

Current research places a high regard for finding a cure for cancer. Currently the most effective treatment for cancer is chemotherapy. Chemotherapy is used to treat a variety of cancers – from bone cancer to lung cancer. Chemotherapy is used in five different ways:

1. ***Neoadjuvant Chemotherapy*** – this is used in conjunction with radiotherapy and is given prior to surgery in efforts to shrink the tumour.
2. ***Induction Chemotherapy*** – this is usually used first. In lung and stomach cancer chemotherapy may be given first and then followed by surgery or radiation therapy.
3. ***Adjuvant Therapy*** – chemotherapy is either given alone or along with radiation. It is designed to kill the cells that have been metastasized (Figure 6).
4. ***Primary Therapy*** – this is used for patients with lymphoma or leukaemia or any other cancers where there is no hope for a possible cure. Chemotherapy is given to help control the symptoms.
5. ***Combination Chemotherapy*** – two or more chemotherapeutic agents are used at the same time. This allows each medication to enhance the action of the other or for the two to work synergistically.

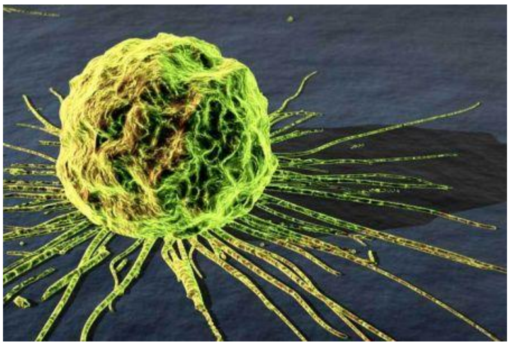

Figure 6: metastasizing cancer cell

Chemotherapy can therefore be very draining for the patient and so by combining the techniques of drug delivery and imaging the method of cancer treatment could be made more comfortable and therefore, it reduces the emotional strain on the patients and their families.

Chemotherapy involves one of over 50 drugs being administered into the body depending on the extent and type of cancer. These drugs can be administered in a variety of ways:

1. ***Intravenous Chemotherapy*** – a think needle is inserted into a vein on the hand
2. ***Orally*** – the drug is given as liquid form, a capsule or a pill
3. ***Intramuscularly*** – Injection into the muscle
4. ***Subcutaneously*** – Injection under the skin into fatty tissue
5. ***Intralesionally*** – Injection directly into the cancerous areas of the skin
6. ***Topically*** – the drug is applied to the surface of the skin.

The main method of administering these drugs is by Intravenous Chemotherapy. Here the drug passes directly into bloodstream and made to circulate around the body so that it can reach all the cancer cells and prevent them from dividing. The problem with this is that if the vein is particularly fragile it may rupture and blood may leak into surrounding tissue. This can lead to edema, causing pain and tissue damage and in some cases necrosis. By healthy bodily cells also taking up the drug, it reduces the efficiency of the drug and high quantities need to be administered because not the entire quantity of drug supplied is going to the desired region. This, therefore, increases the amount of money spent on developing these drugs.

As a result chemotherapy triggers a lot of side effect, for example:

- Hair Loss – the lining of the mouth, stomach and the hair follicles are very sensitive because their cells multiply rapidly just like cancer cells. Some people find this a very traumatic and upsetting experience.

- Loss of Appetite, Nausea and Vomiting – lost sense of taste and increased sensitivity of the digestive system.
- Anaemia – decrease in the production of blood cells leading to low blood count.
- Cystitis and Hemorrhagic Cystitis – a result of chemotherapy is given directly to the bladder.
- Insomnia – chemotherapy drugs cause patients to feel drowsy and therefore patients on chemotherapy can end up napping during the day thus making it difficult to sleep at night. Stress and tension of cancer can cause sleep deprivation.
- Low White Blood Cell Count – chemotherapy drugs temporarily stop cells dividing.
- Numbness
- Skin Colour changes
- Stomach sores
- Some chemotherapy drugs may increase the risk of developing other cancers, such as leukaemia, later in life

To help reduce the risk of side effects nanotechnology could be used to carry chemotherapy drugs directly to the malignant cells. This would mean the drug would only target the malignant cells thus making the drug more efficient. Therefore, the person could continue to go about their daily activities whilst having treatment. This improves patient's lives and makes, what is already an unpleasant experience, a little less stressful.

Nanotechnology can also be used in the treatment of breast cancer. Nanodevices such as nanorobots could be used as an alternative to biopsies and surgeries in the detection process of breast cancer. After detection chemotherapy is required to ensure complete removal of the tumour. One of the possible breast cancer chemotherapy treatments is AC. This consists of two separate drugs – doxorubicin and cyclophosphamide. Both these drugs work by interfering with the DNA in rapidly dividing cells. This is usually administered through a drip or injection. A fine tube is inserted into the vein, usually in the back of your hand (cannula). The treatment is given as a course of several sessions over a period of a few months. Excessive amounts of doxorubicin may cause changes in heart function.
In order to make treatment as safe as possible, modification could be made using nanotechnology, for example:

1. Currently cyclophosphamide fluid is made by dissolving a powder and therefore it may be possible to contain the powder in nanoshells. However, cyclophosphamide is a "prodrug" and inactive when administered. It only becomes function chemotherapeutic drug when it is oxidised in the liver by enzymes. Therefore, in order for the new method of treatment to have any effect, cyclophosphamide would be needed to be converted into its active form before administration. "Prodrugs" are very useful as they ensure the maximum amount of the drug reaches the required area; because the cyclophosphamide would be contained within nanoshells there would be no difference in the quantity that would be delivered to the site.

2. Doxorubicin is normally a liquid drug; it can be developed into an encapsulated form called Doxil. This encapsulated form may cause less damage to the heart as the drug is surrounded by a fatty coat. This fatty coat is designed to prolong the release of the drug inside so that it remains in the blood for a longer period of time. However, nanoshells could be used to contain this drug and as gold is a fairly unreactive metal it could be used to coat the drug.

3. After containing the drugs in nanoshells, you could bind antibodies and quantum dots to its surface so that when it is inject it could be easily tracked within the body and bind

directly to the malignant cancerous cells. This reduces the risk of side effects as the drug would have a lower chance of coming into contact with healthy cells.

4. By shining ultraviolet light on the body and by using imagining method for the internal body, the quantum dots within the bloodstream could then be traced and monitored. Quantum dots remain fluorescent for a long period of time, so it would be easy to see when they bind to the surface of the cancerous cells. In order to release the drug, gentle doses of infrared radiation could be used to meet the nanoshells thus releasing the drug in close proximity to the cancerous cell. This reduces the effect of the drug on healthy cells surrounding the cancer cells.

This method could reduce the trauma suffered by patients who undergo chemotherapy and increase the efficiency and effectiveness of treatment by greater specificity. Side effects such as hair loss, nausea and vulnerability could be greatly reduced therefore increasing their quality of life. The modification that could be made to breast cancer treatment could be replicated for other types of cancer treatment; cancer tumour location and its proximity of sensitive areas will need to be taken into consideration.

<u>Ethical and Environmental Considerations</u>

As with any medical advancement there are ethical issues. Often the main issue is that we should not be interfering with “God like powers”. The full extent of nanotechnology is unknown, nanoparticles may be taken up by the cells and therefore able to enter the food chain. They may even be able to reproduce and as a result able to take over the running of the human body thus causing harm to vital organs in the long run.

The moral and ethical issues associated nanotechnology is very important as everything is on a very small scale and so keeping track of is advances is very difficult. Cyclophosphamide has a half life of three to twelve hours. Cyclophosphamide is excreted renally and therefore present in urine. Doxorubicin has a half life of between twelve to eighteen hours, which give it plenty of time to get into a water supply and cause contamination when excreted as faeces. Due to small size of the particles nanoparticles may still be present in water supplies even after purification. If toxic chemicals infect the environment this could cause massive disruption to the ecosystem. For example, fish which have been exposed to soluble fullerenes over a period of several days resulted in brain damage due to lipid oxidation (Figure 7).

Figure 7: Dead fish in contaminated water

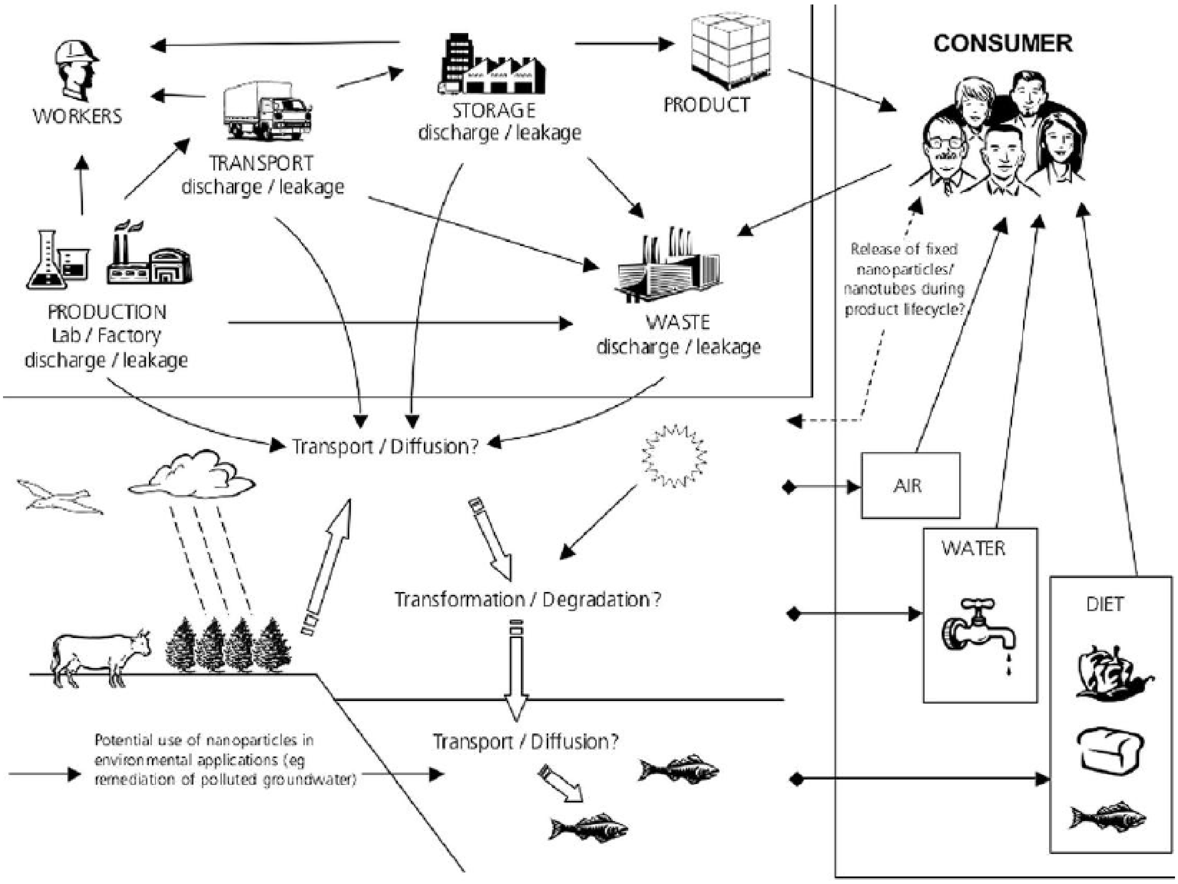

Figure 8: Nanoparticle exposure routes based on the current applications of nanotechnology

It is believed that quantum dots could also have harmful effects on the human body. It is believed that if the quantum dots are contained within the body for a long period of time, they could break down thus releasing cadmium, a very toxic heavy metal that causes pneumonitis and eventually death.

However, with careful research, experimenting and monitoring, the most safe and effective materials can be found and precautions could be developed to ensure safe disposal of the nanoparticles once used.

Nanorobots could also cause many harmful consequences. For example, if control of the nanorobot was suddenly lost midway through a complicated operation it could, not only cause serious damage, but complicate matters further. Due to radioactive power sources the nanorobots could also release alpha, beta or gamma radiation inside the body. This could be detrimental as alpha radiation is very ionising inside the body.

If nanomedicine is not provided for on the NHS, this will create a social divide between the rich and the poor. The rich would be able to afford to pay to get the best treatment; the poor would not be able to benefit from advances in nanotechnology which may be the difference of life and death. “Postcode Lottery” may also be implemented by some local health board, in which some people have to pay for private healthcare whereas others may qualify for free treatment on the NHS depending on where you live.

Before the application of nanotechnology on a public scale, tests would need to be run on a much smaller scale on volunteers. This may mean that finding a suitable number of volunteers may be very difficult as successful outcomes cannot be guaranteed.

Conclusion

In conclusion nanotechnology plays a vital role in cancer diagnosis, treatment and prognosis. Nanotechnology helps significantly in reducing the trauma patients have to endure whilst on chemotherapy. Different techniques can be combined to provide a more successful method of treatment with fewer risks of side effects.

If nanotechnology is developed to an extent that it can be used in treatment I think that it should be offered on the NHS so that people from all walks of life can take advantage of its benefits. Money should not be the main focus when it comes to saving people's life. By providing the treatment on the NHS it may even save money because patients would be treated more efficiently, therefore, patients spend less time in hospital thus reducing the cost. Nanotechnology has the potential to revolutionise medicine and in year to come will be responsible for many life-saving treatments.

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