The research of nanotechnology and the ways in which it could dramatically change medicine.

By
Timothy Morris

PASS

RESEARCH PAPER
BASED ON
PATHOLOGY LECTURES
AT MEDLINK 2010

Abstract

With billions of dollars being spent on nanotechnology research each year, it is the largest scientific initiative since the Apollo mission [1]. Nanotechnology is the study of manipulating matter on an atomic and molecular scale (10^{-9} m, a billionth of a meter). Generally, nanotechnology deals with structures sized between 1 and 100 nanometres and involves developing materials or devices within that size range. This paper will explore the main areas of research currently being undertaken and the effects this research may have on the medical profession in the future; with the main focus being on how nanotechnology could dramatically change the treatment of cancer and help to minimise the invasiveness of most treatments.

Introduction

Nanotechnology holds the promise of an entirely new stage in scientific development and will have a profound effect on many areas of our everyday lives and, more importantly, on the medical care we all receive. Nanotechnologists try to copy nature and nanotechnology is all about building from atoms upwards in a process called miniaturisation. Machines and computers will become a lot smaller and more sophisticated. Nanotechnology will revolutionise the way in which doctors carry out detection, diagnostics and treatments of many illnesses and diseases. It will catapult drug delivery systems, in vivo imaging, surgery and disease prevention into an entirely new dimension [2]. Imaging will be a lot more precise and reliable so doctors can target the exact affected area, within the range of 100-1000 cells, and then nanosurgery could be carried out using lasers, as well as nano devices that could be programmed to perform some surgical functions and remove the affected tissues. This would also benefit the patients greatly as nanotechnology would enable many treatments of the various illnesses and diseases to be non-invasive and painless. As a result more people would be willing to be treated in the first place as many suffer, at least a little, from belonephobia (the fear of needles) and tomophobia (fear of surgeries and/or surgical operations). Men would also be more willing to visit their local GP for minor ailments (a traditional problem) if the treatment was quick and simple, for example, swallowing a tablet etc.

Nanotechnology is especially important to the medical profession as it deals with things on the smallest treatable level possible, at the cellular level. The fact that cancer is caused by the uncontrolled growth of a group of cells is a perfect example of the scale that doctors have to work at in order to treat such diseases and how much of an impact nanotechnology could have on these treatments. One way in which scientists believe we could treat diseases on a molecular level in the future is by the use of nanobots. Nanobots are small autonomous robots, primarily made out of silicon, that are designed to work either individually or in very large numbers to complete a certain task, they are self-fuelling or can use the particles released by decaying atoms to power themselves. Nanobots are made of silicon, primarily because it is durable, conducts electricity and can be manipulated reasonably easily. However, the primitive nanobots will probably have to be, at least partially, of biological nature before nanobots can be produced that are made entirely out of electromechanical components [3]. Nanobots have such a large amount of potential as they have the capabilities of carrying out a large number of functions such as identifying and destroying malignant tumours, removing any harmful substances from the bloodstream and even curing victims of auto-immune diseases such as AIDS (in a similar way to what is shown in Figure 1). Another way in which nanobots are so special is that they have the potential to remove damaged or malfunctioning components of a cell and replace them with similar biological ‘machines’ or mechanisms before tumours

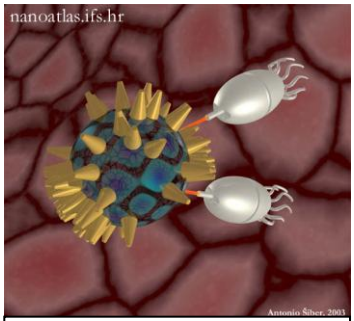

Figure 1. Nanobots attacking a virus

even start to grow, thus removing the cause and not the symptoms. This is an exciting prospect as these nanobots could be so precisely built that they could be integrated into the body without any adverse side effects and could stay in the bloodstream for some time without being rejected by the body. However, at the present moment, there is no way of building the nanobots in a way that would not cause adverse effects on the body as research into nanotechnology's affect on the body suggest that they could cause significant damage to the body by unravelling, or changing DNA molecules [4].

Drug delivery systems are also a very important aspect of nanotechnology being researched extensively. Nano-sized drug delivery systems are such an important advance in nanotechnology because they can be designed to target specific tumours to deliver the cancer drugs and can then be passed out of the body without causing any adverse effects. Nano-sized drug delivery systems are made out of carbon and are part of the fullerene group. They are cylindrical in shape and are composed entirely of sp^2 hybridised orbitals with bonds similar to that of graphite. They naturally align into rope-like structures because of the Van Der Waals forces that hold them together, making some nanotubes into folded sheets. These physical properties result in the nanotubes being extremely flexible, 100 times stronger than steel and a sixth of the mass.

Buckyballs are another form of fullerene (buckminsterfullerene) and could transform the way in which drugs are delivered. All living cells are protected by either a cell membrane or a cell wall (or both) that form, almost a protective cocoon around the rest of the cell. Scientists and researchers at Rice University (Houston, Texas) have discovered a way in which to maximise the effect of drug delivery systems through the use of Buckyballs. "Drugs are far more effective if they're delivered through the membrane, directly into the cell," said lead researcher Andrew Barron. "Viruses, which are often toxic, long ago developed ways of sneaking through cell walls. While we're mimicking some techniques used by viruses, we're using non-toxic pieces of protein, and we're incorporating Buckyballs as a passkey." [5]

Discussion

With over 7.5 million people dying of cancer each year [6] and the chances of you having cancer at some point in your life at an astonishing 1 in 3 [7] ratio it is not surprising that researchers are focusing much of their work on how nanotechnology could treat cancer. The treatment of cancer is, at the moment, a very traumatic ordeal. Many forms of cancer require invasive surgeries that attempt to fully remove the affected tissues, which are often unsuccessful. Both before and after this surgery all cancer patients are subjected to the harsh treatments of chemotherapy for a set amount of time. Chemotherapy is, emotionally, one of the worst, if not the worst, treatment for any disease as it targets any fast dividing cell, the main characteristic of cancer cells. As a result of the body being subjected to such harsh chemicals in the chemotherapy they suffer from alopecia, immunodeficiency, nausea and many other unpleasant side effects caused by fast dividing cells being destroyed. However, chemotherapy is needed as it is a very good treatment, in the fact that it is effective in destroying at least some of the cancerous cells. They then have to go through radiotherapy and other unpleasant treatments.

This doesn't have to be the case however as the use of nanotechnology could change the treatment entirely. With the prospect of fluorescence in vivo imaging, (using nanoparticles), advancing all of the time to produce an imaging system that is incredibly accurate (within 100-750 nm), sensitive, multimodal, lifetime based and of high resolution; the treatment of cancerous cells will become extremely specific and concentrated. As a result the treatments will be a lot less traumatic and a lot more effective. One way of using nanotechnology to destroy cancer cells could be through the use of the EPR effect (Enhanced Permeability and Retention Effect) which helps to

explain how nanotubes can act as a drug delivery system to only the specific tumour you want to destroy and not other cells or normal tissues, like chemotherapy does.

When a tumour grows it has a 'leaky' blood vessel and so allows relatively large (but still nano-sized) drug delivery systems to enter and destroy it. Because normal tissues don't have a 'leaky' blood vessel, the relatively large drug delivery systems cannot enter the tissue and so cannot destroy the normal tissue. An example of this 'leaky' blood vessel can be seen in Figure 2.

Buckyballs are another way in which drug delivery systems could revolutionise cancer treatment. As mentioned above Buckyballs could offer the possibility of delivering drugs directly into the cell. As the drugs become more effective if applied straight to the cell, through the cell membrane, tumours can be destroyed more easily. Because Buckyballs are geodesic in shape they can act as storage components, this can be seen clearly in Figure 3. When Buckyballs attach to peptides they form Bucky amino acids, or Baa's, which are based on the amino acid pheylalanine. A certain sequence of amino acids can attach to the cell membranes of cancer cells and then penetrate it, very much like viral proteins, in order to deliver the drugs directly into the cell itself. This can be seen in Figure 4. In the meantime however, scientists could optimise some of the latest research carried out and simply maximise the effectiveness of chemotherapy by enhancing the flow of blood to the tumours. They could do this by lowering the fluid pressure in and around the tumours as this high fluid pressure is why chemotherapy is so unpredictable in how effective it is going to be. The reason for this is that the high fluid pressure makes it extremely difficult for the chemotherapy drugs to leave the bloodstream and attack the target area. They could change the 'leakiness' of the blood vessels surrounding the tumour by targeting the collagen matrix around the blood vessels. This would mean that the drugs could be more effective in treating the tumour as they could target them more easily and stay in the tumours longer. [8]

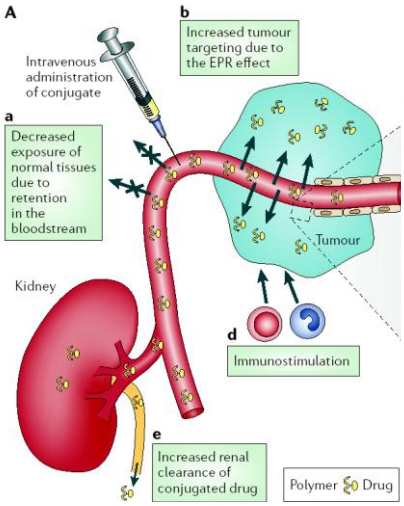

Figure 2. Shows how nano-sized drug delivery systems can be designed to target only tumours and not other healthy cells as well.

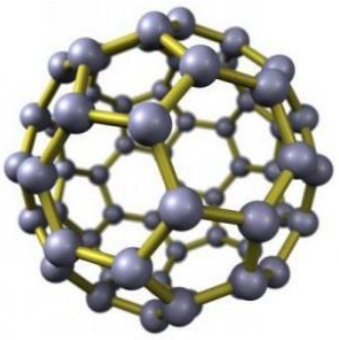

Figure 3. A Buckyball (C_{60})

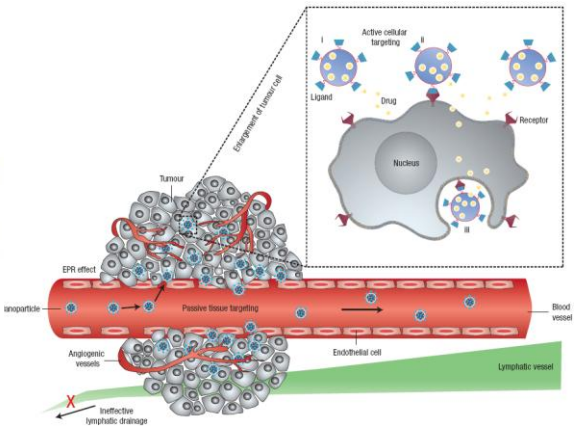

Figure 4. A closer look at the effected area and how the drug delivery systems destroy the effected cells

These procedures are some of the prospective treatments for cancerous cells; however these techniques may be a little primitive in the sense that they destroy the cancerous cells. Surely a better way of treating cancerous cells is to use nanobots to repair damaged/malfunctioning parts of the cell which are causing the cell to rapidly divide at an uncontrollable rate? Scientists could use the nanobots to produce molecular machines that could repair the malfunctioning parts of the cell by manipulating individual atoms so that

the cell could function correctly again. They could carry this manipulation out by the use of laser tweezers. The use of nanotweezers could even be advanced enough to manipulate the DNA itself, more specifically the genome. This gene therapy would automatically change how the cell functions and could therefore stop it malfunctioning. However this would be a very advanced way of repairing cells and we would need to understand more about how the human genome works to truly produce gene therapy. Also the nanobots would have to contain nanocomputers that could work efficiently and on very little energy.

Another way in which the nanobots could repair damaged cells is by tissue engineering. This would work in a similar way to scaffolding. The scaffolding would be made with nanotubes that would fit/slot together perfectly and be held by Van Der Waals forces. This is a perfect example of how we could copy nature in order to create techniques of repairing cells at a molecular level. However if scientists are unable to create such sophisticated nanobots they may be able to replace the cancerous cells that have been destroyed with specialised stem cells. These specialised stem cells would be modified by less sophisticated nanobots using nanotubes to help the adult stem cells morph into the desired type of cell. This specialised stem cell would copy the cancerous cell's function before it started to malfunction and as a result the body system it was part of could begin to function correctly again and no damage would have been done.

An experiment has been carried out by the University of Oklahoma which could hold the answer to a way of treating cancer. However this would not be a treatment at all as this technology could hold the answer to preventing some cancers altogether. The experiment was carried out on rats. Researchers injected cerium oxide nanoparticles into the rats and found that cerium oxide nanoparticles may be effective in inhibiting cell death caused by ROI's (reactive oxygen intermediates). As a result of this cerium oxide nanoparticles could be the key to treating many degenerative diseases such as cancer and Alzheimer's. This technique would be most effective in stopping brain tumours and cancers of the eye such as choroidal melanoma's [9].

An alternative way of preventing cancer, and indeed all diseases, is to have nanobots that are permanently in your body and could monitor your health and body systems, then send a feedback to a computer or other device. These nanobots/ nanochips would mean that treatment could begin as soon as possible. As a consequence if a cell is malfunctioning it won't cause much, if any, damage and your medical records would be a lot more efficient as these nanobots could send information to your health care providers as well. This increased efficiency of electronic medical records would mean that medical care could be a lot more suited to the individual as doctors would know more about how your body systems function and could pinpoint the proper treatments that you need. Treatment plans could also be altered according to the individual's needs and responses. This would almost eradicate any chance of doctors making errors with treatment plans, for example treating a patient with a drug that they are allergic to. It would also make the treatments a lot more effective as doctors would know exactly what is wrong with the patient.

Conclusion

To conclude, nanotechnology holds an immense amount of potential for development in all areas of our lives; but we suspect that in no field will it have such a profound impact as in the medical profession. This future technology will save countless lives and will revolutionise most treatments. However we are not there yet, and in order to create such sophisticated and miniaturised technology, we need to have a much greater understanding of how the human body works, especially at the cell and genome level. This will take many more years of research and billions of dollars worth of funding. Nevertheless, even when we do achieve such an understanding there are still many problems that need to be overcome in order for nanotechnology to be universally used. Probably the largest hurdle that needs to be overcome is the cost and efficiency of producing such sophisticated and miniaturised technology since companies will not fund such programmes if they are losing out financially, especially if the economy stays in such a dire state. Besides the financial problems that will have to be overcome, there are also many other aspects of nanotechnology that will need to be altered in order for the universal use of nanotechnology to be accepted. An example of one of these problems is that many of the nanobots, that are crucial to many of these ideas to become reality, are made of silicon which is non biodegradable; as a result nanotechnology would be a source of yet another drain on the earth's dwindling resources. Not to mention the fact that there is evidence to suggest that some nanoparticles (especially buckyballs) may have severe adverse effects on our body. However, Swedish and American scientists have discovered that carbon nanotubes can be broken down by an enzyme, myeloperoxidase, which is good news as the nanotubes could be used in many nanoparticles and then be broken down biologically into harmless components after they have completed their tasks. [10] Another major problem associated with nanotechnology is that it will increase everybody's lifespan which will then cause population booms throughout the world. If nanotechnology does, indeed, rapidly expand and become universally accepted, there will need to be tight restrictions in place to ensure that it doesn't expand a lot quicker than other industries that will also need to increase substantially in order to support this growth in population. If this restriction of the growth of nanotechnology is not carried out it will mean that industry and food production will have to be increased too dramatically, too quickly, which, if advances in technology are not applied to these areas also, could cause increased emissions of greenhouse gases and damaging chemicals. As a result of such failures to control it's growth, nanotechnology may be one step too far in scientific development and cause the destruction of the earth as the ozone layer would be diminished. This would consequence in the end of the human race through natural disasters and increased temperatures. It may not get to that point however, since nanotechnology could also be used in acts of destruction and death by terrorists or on the black market. These acts would cause untold damage and billions would die since the technology had fallen into the wrong hands. These are just some of the hurdles that will have to be overcome in order for nanotechnology to be introduced into everyday life. However, if these problems were overcome, nanotechnology could bring with it untold wonders and prosperity.

References

[1]= http://www.enableipc.com/nanotechnology.html

[2]= http://mritechnicianschools.net/2010/25-ways-nanotechnology-is-revolutionalizing-medicine/

[3]= http://nanogloss.com/nanobots/what-nanobots-are-made-out-of/

[4]= http://www.rxpgnews.com/biotechnology/Buckyballs_Deform_DNA_-_Surprising_Simulation_Find_2973_2973.shtml

[5]= http://www.medicalnewstoday.com/articles/61145.php

[6]=http://wiki.answers.com/Q/How_many_people_die_from_cancer_in_the_world_each_year

[7]= http://westernlivingbenefits.com/blog/ (November 8, 2008 article)

[8]= http://www.technologyreview.com/biomedicine/24757/

[9]= http://www.physorg.com/news81622244.html

[10]= http://insciences.org/article.php?article_id=8670

Image References

Figure 1= http://www.nanotech-now.com/images/Art_Gallery/AS-nanobot.jpg

Figure 2= Duncan, R. Nature Reviews Cancer 2006, 6, 688-701

Figure 3= http://images.sciencedaily.com/2008/05/080527091910.jpg

Figure 4=Peer, D, et al. Nature Nanotechnology 2007, 2, 751-760