Nanotechnology: the next big thing in Medicine.

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PASS

(300 words over limit)

Research Paper based on pathology
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Abstract

"Nanotechnology will affect everything" says William Atkinson. Recent years have witnessed an unprecedented growth of nanotechnology. In this essay I will delve into the science behind nanotechnology and its future impact on the world. There is increased optimism that nanotechnology that is applied to medicine will bring increased advances in diagnosis, treatment, and prevention of disease. This interest has grown to such a significant extent that there has been an emergence of a new field, nanomedicine. Nanomedicine may improve our understanding of basic behaviours of disease, it may provide more effective therapies and it may help us prevent disease from an early stage. Nanotechnology will be the science that dominates the rest of the 21st Century and it will have many effects on our lives; increasing the health span and life quality of humans in various ways such as early prevention of disease, quicker repair of damaged bones and organs etc. and an opportunity to understand how diseases operate at a cellular level. To give you a perspective of the size of a nanoparticle: a nanoparticle is one nanometer, DNA is ten nanometers, a bacterium is one thousand nanometers and a human is one billion nanometers.

Introduction

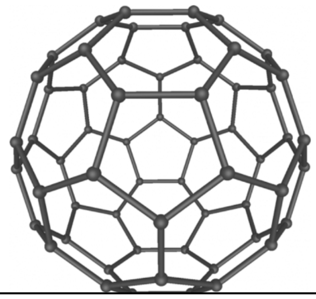
Cloude Levi Strauss; "The world began without man, and it will complete itself without him". In this essay, I will explain exactly what he meant by this. In 1959, little did he know, Richard Feynman was opening up a whole new dimension to science when he spoke; "There's plenty of room at the bottom". Nanotechnology is the closest we can get to the "bottom", merely because we are currently unable to make things out of entities smaller than atoms. Therefore, the scale nanotechnology is used in ranges from 1 nanometre to 100 nanometres. In order to fully investigate the issues concerning nanotechnology we must understand what it is; "Nano" comes from the Greek word for dwarf, and nanotechnology as a whole is defined as "the engineering of functional systems at the molecular scale." It is important to understand the reason nanotechnology is so highly looked upon is because most diseases and abnormalities occur at cellular level and at the moment doctors can only cure on a macroscopic level. All viruses and bacteria are nanosize therefore one would think that it makes sense to fight back at nanosize. Fortunately, at the moment cells within our bodies contain a self- regenerative ability that takes over once medical treatment has been administered, by being able to work at the cellular level we could replace this regenerative process, and make it more effective and help the process to work quicker. Albert R Hibbs said "...it would be interesting in surgery if you could swallow the surgeon." As strange as this idea may be, it does spark some interest as surely if we were able to partake in surgery at nanosize the precision of cuts and incisions would be far greater and by using a machine we would minimise the risk of human error. Another fundamental principle that should be understood is that when materials are reduced to the nano state their properties change relative to what their properties were at a macroscopic level; for example insoluble materials, such as gold, become soluble, stable materials, like Aluminium, become combustible. It is these changes of these phenomena that distinguish nanotechnology from microtechnology (versions of materials at the macroscopic level are just minimised in size without change to their properties). The reason these changes occur is down to the increased surface area to volume ratio of the molecules therefore other elements such as hydrogen bond to the molecules on the surface of the material and their properties therefore change. In nanotechnology, tiny differences in size can build up to massive difference in function. Ted Sergent, author of The Dance of the molecules, says "matter is tuneable at nanoscale like a string on a guitar; change the string and the note changes; change the size of a quantum dot and you change their rainbow of colours from a single material". Think of it as the sand on a beach one grain is insignificant ,you could easily walk past without noticing it, but millions make a whole new feature; a beach.

There is a belief that nanomedicine has five main sub disciplines. Diagnostics- the early recognition of disease; this is the research into how diseases can be diagnosed and therefore treated quicker. This is further separated into two further categories; in vitro- in glass and in vivo- in living bodies. In vitro diagnostics is using human tissue samples and looking at them with nanodevices at a sub cellular level. In vivo diagnostics is having devices inside the body to identify the early presence of disease. Regenerative nanomedicine (such as bucky balls and nanoshells) this is the maintenance of cells, tissues, and organs by applying cell therapy and tissue engineering methods with the help of nanodevices, and it also incorporates new ways of delivering drugs. As mentioned above, this sub discipline looks at the way that the current cell regenerative process works and how we can improve it. Applications in medicine: such as nano robots and nano computers, we are trying to make programmable nanrobotic devices that would allow physicians to perform precise interventions at a molecular level. This would further improve the ability to diagnose diseases and would reduce the uncertainty that can be produced at macroscopic level- increased speed of diagnosis equals increased speed of recovery. Analytical and Imaging tools, such as atomic force microscopes and laser tweezers, is the use of nanoparticles to make machines to produce analytical images. Nanotech probes can offer signals that are severalfold brighter and hundred times more stable than other techniques. Nanotech probes are as Michael Berger puts it; "nanoprobes and nanosensors have the potential for a wide variety of medical uses at the cellular level. The potential for monitoring *in vivo* biological processes within single living cells, e.g. the capacity to sense individual chemical species in specific locations within a cell, will greatly improve our understanding of cellular function, thereby revolutionizing cell biology." Safety and toxicology- for example whether nanotechnology could harm humans. This is one of the main obstacles in the path of nanotechnology as with such an expansive and theoretical subject, there are so many theoretical problems; for example what would happen if the nanorobots in our body malfunctioned? And in fairness there are many possible, theoretical problems with nanotechnology which is the reason for such long clinical trails and pre-clinical trials

To be able to understand how nanotechnology may affect the future we should acknowledge that there are two main approaches in nanotechnology. Firstly, there is the bottom- up approach, which is in fact the most common; it is the building up of molecular components from nano size parts- imagine building lego blocks one block at a time onto each other to make a tower. The small molecules (lego bricks) assemble themselves chemically by the principle of molecular recognition ("The ability of biological and chemical systems to distinguish between molecules and regulate behaviour accordingly"). The other approach is the top down (essentially the breaking down of a system to gain insight into its compositional sub-systems) approach which is when nano- objects are constructed from larger entities without atomic-level control- taking our previous analogue it is like getting a lego block from taking the tower apart. However one must realise that it is the bottom- up approach that is most often used.

Finally, in my opinion, the most fundamental thing to understand is that most of the research for nanotechnology has derived from the study of similar mechanisms in nature. In fact, nature's mechanisms and the mechanisms involved in nanotechnology run parallel lines (for example, both use the principle of molecular recognition), and I will be using this link in my discussion to make unique yet not impossible hypotheses.

Discussion



The structure of buckminsterfullerene

Nano medicine has many applications already related to it and the number is only going to increase over the next 10-20 years. First to predict what may occur in the future we must assess what has occurred in the past; there are currently many applications of nanotechnology which each fit into different groups with different jobs. There are applications for the diagnosis of disease; in terms of medical imaging, scientists have discovered that we can use iron oxide nanoparticles to improve MRI images of cancer tumours. The nanoparticles are coated in peptide that binds to a cancer tumour; once the nanoparticles are attached to the tumour the magnetic property of the iron oxide enhances the images. Also in terms of early diagnosis of diseases Buckminsterfullerene- aka Bucky Balls; can be used to trap free radicals (a molecule or atom with an unpaired electron) generated during an allergic reaction, and therefore they can block the inflammation that results from an allergic reaction. The

Bucky Balls have the structure similar to all other fullerenes and therefore they work by neutralising these free radicals and stopping the inflammation, by giving an electron to the free radicals and forming a carbon bond between the bucky ball and the free radical. Nanoparticles can be inhaled to stimulate immune response to fight respiratory d diseases; such as influenza – it works by inhaling an aerosol spray containing tiny protein cages that will activate an immune response in their lungs. The cages work by reacting to the new presence of the microbes and set off a response, this immune state can occur for a month. And a nanoparticle cream has been shown to fight staph infections- there is nitrogen oxide gas in the nanoparticles which is known to destroy bacteria. There have been studies concerning this cream on mice and has resulted in the infection being significantly reduced. An example of the success is shown by the research which was published in the Journal of Investigative Dermatology writing: "NO-containing nanoparticles could clear up superficial skin infections caused by MRSA". Nanoparticles can attach to proteins allowing detection of disease in vitro very early on in its development. This was researched by Stanford researchers and there research showed that magnetic nano tags detected cancer in mice earlier than other methods. They report that these sensors are 1000 times more sensitive and can search sixty four proteins simultaneously. There are several other efforts to develop nanoparticles disease detection systems; including some using gold nanoparticles. Quantum Dots may be used for locating cancer tumours in patients and in the near term for performing diagnostic tests in samples. Probes can be attached to a protein or receptor to monitor it and see what other molecules it interacts with, what part of the cell it is in and what signalling pathways the protein may use for performing normal cell functions and abnormal functions that may result in cancer.

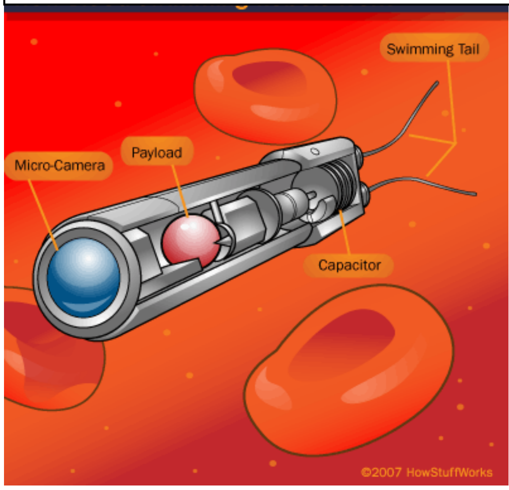
Nanoparticles are also used for the delivery of drugs; Nanocapsules containing antibiotics can be used to coat burn dressing. If an infection occurs the harmful bacteria stimulate the nanocapsules to release the antibiotics. This results in much quicker treatment and much more effective treatment. Oral administration of drugs is now possible for many wider treatments, as for those who dislike having injections can now take the drug enclosed in a nano capsule, which helps it pass through the stomach to deliver the drug into the bloodstream. Many companies are now investigating ways as to test for drugs for more diseases such as one company is at the clinical stage of testing a drug for systematic fungal disease; this particular type of diseases use a nanoparticles called cochleate. The development that has sparked the most optimism is the development of nanoparticles that deliver drugs directly to cancerous cells without harming other cells and allowing earlier detection of the disease. The nanoparticles work by being programmed to be attracted to diseased cells.

Nanoparticles also give useful applications to trauma medicine; Nanofibres- can stimulate the production of cartilage in damaged joints. The therapy activates the bone marrow stem cells and produces natural cartilage- this is a huge break through as cartilage does not grow back like bone does. Aluminosilicate nanoparticles can reduce bleeding in trauma patients much more quickly by absorbing water, causing blood in the wound to clot quickly. Z-Medica, a company interested in the development of nanotechnology also known as Quick Clot, are producing a medical gauze that uses aluminosilicate nanoparticles. And one of the earliest applications of nanoscience was the use of nanocrystaline silver for the treatment of wounds.

Finally, nanoparticles can be used to kill or repair diseased cells without affecting the cells around the diseased cell; Nanorobots could in the future be programmed to repair specific cells, functioning in a similar way to antibodies, as I will further mention later on in this document. Some nanoparticles when activated with X-Rays generate electrons that cause the destruction of cancer cells to which they have attached themselves. This is in place of radiation therapy and causes much less damage to the surrounding tissue. Nanobiotix, the company further researching this treatment, has released pre clinical results for this technique. Nanoshells may be used to concentrate the heat from infrared light to destroy cancer cells with minimal damage to surrounding. Therefore there are less drastic side effects such as hair loss with chemotherapy. Nanoshells are being pilot trialled with human patients; in vivo. Other nanoparticles are also being used to deliver drugs, heat, light or other substances to specific types of cells (such as cancer cells).

In the future we should be able to construct micro-scale materials from parts on the nanometre scale, complex nanodevices will be made and nanorobots will be made, at first they will be made from biological materials and then maybe from more useful, biodegradable and cheaper materials. There are several protagonist characters that are needed for example we would need an assembler; in my opinion, and this may just be a long shot, nanotechnology is acting in a very similar way to the way that we evolved from simple blocks of DNA- and as stated above, there are many aspects of nanotechnology that we look at that are similar to those in nature. There are molecular machines that act as replicator cells (molecular assemblers) and replicate to form new more complex structures, like we evolved from tiny amoeba. This may mean that we are literally right at the very top of the iceberg in terms of the depth of nanotechnology. These molecular assemblers will position random molecules bringing them together to form new materials; exactly like replicator cells did in the primeval soup (which made up most of the early earth) according to Richard Dawkins' book "The Selfish Gene". The assemblers will control how the molecules react and therefore make much more complex structures; like humans relative to the amoeba. These molecular machines (assemblers) are being researched heavily although some say that there are structures present in nature that could construct such an object. For example, a line of sigma bonds can act as a hinge; conformation (changing proteins) can serve as sources of motive power for linear motion; the reversible motor of the bacterial flagellum can serve as a source of motive power for rotary motion. These molecular machines may produce a second- generation machine which will be able to partake in general synthesis of three-dimensional molecular structures. It may take a very long time to in fact build one of these molecular machines but if we are able to there will be a revolution in medicine with new tools and computers which will bring surgical control to the molecular level. Another major necessary component are nano-computers which would undertake the role of activating, controlling and deactivating the nanomechanical devices. Presumably we would need to have sensors (nanoelectronic biosensors) in order to have nanodevices that can detect changes in the conditions inside the body; such as the process of cell repair. These would have to be connected to the nanocomputers as they would have the "mission plans" and the information for the sensors to sense. There is currently ongoing research into the class of nanogenerators; making a new class of self powered implantable devices that by converting mechanical energy from body movement, muscle stretching and water flow into electricity, therefore sensors could be powered.

A theoretical image of what a nanorobot may look like



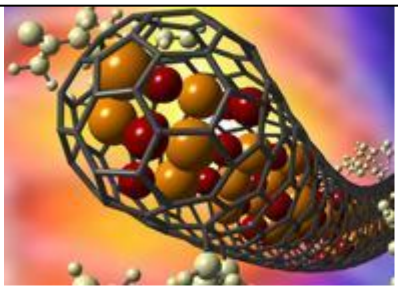
Nanotechnology and biotechnology can be used together to create ingestable systems that will be able to tell medics the exact location and type of disease that they are dealing with. The United Nations Convention on Biological Diversity defines biotechnology as: "Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use." If we combine biotechnology principles with the principles of nanotechnology we can create these "processes" at a molecular level. There are currently a few applications of biotechnology in nanomedicine; drug production, gene therapy, genetic testing, and pharmacogenomics (Pharmacogenomics is the study of how the genetic inheritance of an individual affects his/her body's response to drugs). However we may not need to carry out these processes at a molecular level as, it is thought that at one stage in the future disease and genetic defects will be eliminated through alteration, using nanoparticles, at atomic level; effectively recoding the DNA of a person.

Nanorobots, as mentioned numerous times above, could easily be the most innovative and fundamental creations in the future. At circa 2.5 micrometers, nanorobots have many possible future applications; the elimination of bacterial infections in a patient within minutes; the ability to perform surgery at cellular level, removing individual diseased cells and even repairing defective portions or individual cells; significant lengthening of the human life span by repairing cell level conditions that cause the body to age. They will be like having your very own army against disease. Imagine robots patrolling through your body killing "trespassers" (diseased cells). Their structure is likely to be mostly based around the element carbon due to carbon's 4 free electrons and natural properties exhibiting strength and other useful characteristics. The nanorobots would be specialised on computers for their jobs; they will be specified to specific organs and be programmed to recognise specific diseases. The nanorobots could be used to change defects more efficiently and more controversially they might be able to be used to change people's physical appearance and even their capabilities. There are obviously several theoretical problems with nanorobots and they shall be discussed later on in the essay.

In the future we can use nanoparticles as "the middle man"; in other words we can use them as carriers to carry drugs and other materials in a nano capsule. They have attracted the attention of researchers all over the world as they provide an opportunity for the controlled efficient release of drugs.

The future application of nanoparticles drug delivery systems is an exciting prospect with many new advantages due to the increased precision the nanoparticles operate under such as the reduction of side effects, wastage, and increased bioavailability. (The main objective of current research is to increase the bioavailability of the drugs in humans. Bioavailability refers to the presence of drugs where they are needed most in the body). However the biggest advantage of these "nanocarriers" is the size factor; the problem with drug capsule delivery at macroscopic or even microscopic level is that they are too big to be absorbed into the bloodstream of the body where as nanoparticles are incredibly small and are able to do this. One of the most promising nano-related inventions possible in the future is the possible "triggered response" of the nanocapsules to release the drugs when they are told to by an impulse. The capsules can be functionalised, by attaching or inserting substances with particular necessary properties (including the property that causes the release of the contents of the cell in response to a particular biomolecule) into the wall. This is how they "know" when to release the contents.

A theoretical image of what a nanocapsule may look like.



Future nanoapplications are going to be represented very much in the treatment of cancer. One of the scientific reasons that nanotechnology is looked upon as such a large stepping stone into the future of cancer research is due to their large surface area to volume ratio- this empowers a large number of functional groups to attach to a single nanoparticles, which can then seek out and bind to dangerous cells. One of the most disgusting treatments of cancer is the novel cancer treatment methods which are likely to be used often in the future. The nano particles are attached to cancer cells and then they literally cook the tumours with the help of radio frequency waves that heat the tumour attached to the nanoparticle causing the tumour to burst. These may be used in the future in place of chemotherapy and radiotherapy.

Another interesting development in nanotechnology is the development of nanovaccines; in the future researchers believe that we shall be able to use oil based emulsions as vaccines that are placed in the nose and provide vaccination for the nasal cavity and the bloodstream. The emulsion of soybean oil, alcohol, water and detergents are mixed with the dead part of the disease causing microbe; the vaccination can occur in exactly the same manner as with an injection i.e. by stimulating a "fake" immune response.

The process of repairing broken bones can also be helped by nanoparticles, Laurie B Gower has been researching bone formation- she is examining biomimetic methods of constructing a synthetic bone graft substitute that matches the natural bone; so that it would be accepted by the body and guide cells toward the mending of the bone.

There are however problems with the rapid development of nanotechnology. The lack of knowledge about how nanoparticles might affect or interfere with the biochemical pathways and processes of the human body is particularly troublesome. Scientists are primarily concerned with toxicity, characterization and exposure pathways. Toxicology- The nanoparticles may be toxic- silver nanoparticles that our used to make socks smell less. When the silver nanoparticles are washed away they get rid of the useful bacteria which break down the organic matter in waste treatment plants. The Group “Center for Responsible Naotechnology” have advocated that nanotechnology should be specifically regulated by governments. Ethical problems- There are also other more specific problems such as the ethical problems behind choosing your capabilities. There are also issues with human safety as because we know so little about nanotechnology we are unsure of the consequences that may be caused such as what if the nanorobots start attacking healthy cells. Lastly there are economical issues concerning nanomedicine as the costs are going to pile up; costs of parts, manufacturing costs, implantation costs- let alone the cost of further research.

Conclusion

With 6.8 billion pounds spent on nanomedicine in 2004 and with over 200 companies and 38 products worldwide, nanotechnology is only going to increase and become more fundamental in medicine. Furthermore this paper supports the utilisation of nanotechnology as although some may argue that nanotechnology could change the world as we know it by; making more cheap products available that turn the economy of the world into turmoil, or the increase in threat of terrorists, or the dangers of human toxicology. The future applications of nanotechnology if they occur could change the world for better reasons; humans may live longer and more healthily, mammoth diseases may be stopped in their tracks and save millions of people’s lives. And despite the arguments that “it will increase the population even more”, I am certain that the majority of people would rather have these treatments to reduce the suffering of either themselves or their loved ones.

The excitement shown by so many researchers all over the world further amplifies how interesting and thought provoking the topic of nanotechnology is and how it may in fact provide “escape routes” for many people in the future, in terms of disease.

In conclusion as mentioned various times above, the continuation of the development of nanotechnology, is going to depend on our ability to make nanorobots and in my view nanoreplicators (nanoselfassemblers). The development will also be hindered by ethical and economical issues such as funding for such research and the devices, which I assume, will cost “an arm and a leg”. However taking all this into account I think that nanotechnology will be the basis of many people’s jobs and lives in the future, and not just in nanomedicine. To give a firm idea of development of other non-medical devices; there are nanoparticles in sun cream that reflect U.V. light. There are silver nanoparticles in socks which stop the odour of the socks, coatings on tennis balls made from nanoparticles to make them last longer. Future desktop and laptop computers are likely to be very much more powerful, at least times ten to the three times more powerful.

Overall, we must do everything to further support the development of nanotechnology as it is something new and innovative that may make a difference in the future. And I hope now that you can understand why and with what evidence Cloude Levi Strauss said; “The world began without men, and it will complete itself without men.

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