

**NEUROMORPHIC ENGINEERING – HOW THE
CONDUCTING AND SENSORY PROPERTIES OF SOME
NANOPARTICLES ARE USED TO BUILD ARTIFICIAL
SYNAPSES AND NANO ELECTRODES, WHICH COULD
TREAT DISORDERS ASSOCIATED WITH PARTS OF THE
NERVOUS SYSTEM.**

BY

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PASS WITH MERIT

**RESEARCH PAPER
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ABSTRACT

This paper shows how large an impact advances in nanotechnology could have on medicine. It has focused primarily on nanotechnology's role in neuromorphic engineering (the building of circuits mimicking those involved in the nervous system) and presents ideas concerning how these advances could treat problems associated with the nervous system, specifically Alzheimer's, Huntington's, Parkinson's and depression. This paper is about these ideas as diseases which affect people's minds can be more distressing than physical illness, and yet I think their effects are underestimated. This paper concludes that improvements in treating such diseases are much needed and so the ideas suggested hold promise for the future, but that nanotechnology is surrounded by ethical issues which need to be addressed at the same time as the science is developed.

INTRODUCTION

Nanotechnology, from the Greek 'nano', meaning dwarf, is the study of manipulating individual atoms or molecules, on a scale of 1-100 nanometres (1-100 billionths of a metre) - smaller than the wavelength of visible light. It is the, "engineering of functional systems at the molecular scale." Roughly 3 atoms measure 1nanometre; therefore working at nanoscale, even with nanotechnology in its infant years, means scientists can study and control the molecular basis of structures and organisms, by taking control of atoms individually, manipulating them and putting them to use with an extraordinary degree of precision and impact.

Nanotechnology is so important because when working at nanoscale, it is possible to build new beneficial structures (molecular manufacturing), which will be the focus of this paper, but also, particles show different properties than when they are grouped together in larger quantity, due to quantum mechanics. Therefore with nanotechnology we can exploit novel properties, and put them to use in our daily environment (nanoscale technology). These two abilities are particularly important for medicine due to the size of the particles nanotechnology works with and the relative size of cells, for example a red blood cell is 6000-8000 nanometres in diameter. Even minor adjustments could be made to individual cells, when working on a 1-100 nanometre scale, and this could have a huge impact if made to every problem cell in an organism.

One particle already having an impact on the medical field, with beneficial properties on the nanoscale, is nano-silver. Measuring 25 nanometres, nano-silver has antibacterial and antifungal properties, as nano-silver ions block microbes' cellular respiration. It is already used in, for example, some antibacterial wipes and bandages, but there is current research into how it can be used to stop the larger scale problems of septicaemia due to antibiotic-resistant bacteria, such as MRSA, which will become more common in the future. Clearly this will be crucial in shaping the future of the medical field.

Nanotechnology, in particular molecular manufacturing, was foreshadowed in Feynman's 1959 speech. He suggested that "There's Plenty of Room at the Bottom"; that a set of precise tools could build and operate a smaller set, which would in turn operate a smaller set, and so on until it should be possible to build machines small enough to manufacture objects with atomic precision. Feynman made clear that small scale forces, such as van

der Waals intermolecular forces and surface tension, rather than the stronger covalent bonds scientists were used to working with, would be the most important to consider and work with and against.

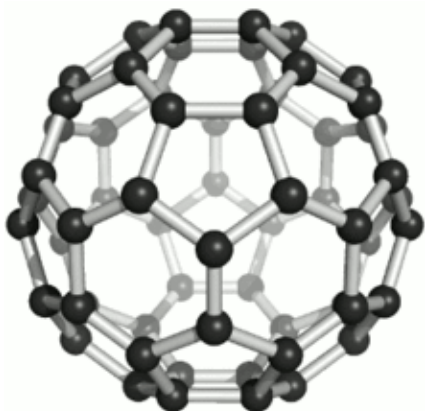


Figure 1 - buckminsterfullerene

Feynman inspired more interest in the atomic future ahead of us. In his 1974 paper, Professor Taniguchi defined nanotechnology as, “the processing of, separation, consolidation, and deformation of materials by one atom or by one molecule.” Following this, in 1985, Smalley discovered buckminsterfullerene (Figure 1), the first fullerene (hollow balls which are allotropes of carbon), largely thanks to the 1981 development of the STM (scanning tunnelling microscope). Carbon nanotubes (Figure 2) were discovered a few years later. The 1988 AFM (atomic force microscope) has further aided discovery and manipulation of similar structures as it allows for individual atom manipulation.

Taniguchi’s definition forms the basis of Drexler’s work, which was essentially the invention of molecular manufacturing. As introduced by Drexler’s *Engines of Creation* (1986), molecular machines could be used to control the manufacture of complex products and *Nanosystems* (1992) showed how molecular carbon lattices, “diamondoid”, such as carbon nanotubes, could be the structure to construct these machines from. A carbon nanotube is a sheet of graphite rolled into a tube of diameter 1.3 nanometres, and is suitable for molecular manufacturing as they display properties such as extreme strength relative to their density, and efficient conductivity of electricity and heat.

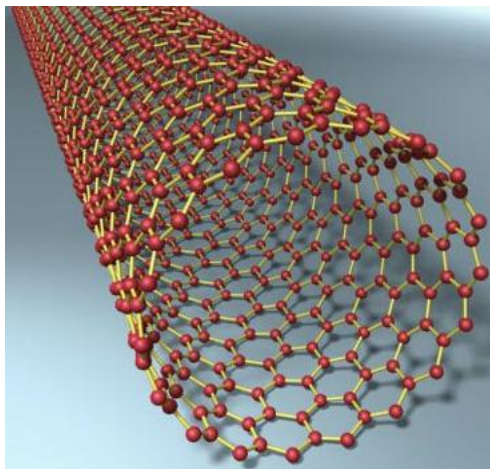


Figure 2 – carbon nanotube

The other development in nanotechnology which will be central to molecular manufacturing is the creation of nanowires, which will be the focus of this paper as these nanoparticles are currently being used in neuromorphic engineering. These are solid rods of silicon, nanometres thick, which are semiconductors. Their size means electrons flow along, rather than across, the wire, so the direction of the flow of impulses can be easily anticipated and controlled. They could be accurate sensors as well as efficiently converting waste heat to electrical impulses.

Research concerning nanotechnology is currently going into drug delivery techniques to aid treatment of: heart disease by detecting and removing arterial plaques; and cancer as nanoshells (silicone spheres coated in gold) can deliver drugs to specific cancerous cells

and destroy them. However, this paper is going to focus on nanoparticles with conducting and sensory properties, and how these could impact on disorders related to the malfunctioning of electric impulses (of the nervous system) in our body. In particular this paper will look at how: artificial synapse connections and nanoelectrodes could provide a form of treatment for Alzheimer's, Huntington's, and Parkinson's; depression could be treated using controversial techniques where areas of the brain associated with pleasure are stimulated; and the issues surrounding these developments.

Moreover, this paper will attempt to show how nanotechnology can 'copy nature', by manufacturing molecules using a 'bottom up' approach (selecting and arranging molecules atom by atom) rather than the normal manufacturing process of breaking things apart to create smaller molecules, and how copying nature has the potential to revolutionise our future. As Richard Dawkins said in *The Selfish Gene* (1976), our bodies are, "survival machines," built and selected for by nature, to ensure the survival of our genes as, "their preservation is the ultimate rationale for our existence." Through copying nature we can make better these survival machines artificially. However, the potential impact copying nature, this speeding up of evolution - if you like - could have on the medical world, particularly on disorders involving the nervous system, probably cannot yet be anticipated.

DISCUSSION

Possible developments due to neuromorphic engineering using nanotechnology

Currently scientists are working on neuromorphic engineering; where systems containing electric circuits mimicking structures present in the nervous system are developed. This field involves copying nature, and therefore benefits from the 'bottom up' approach, so has been attempting to make use of nanotechnology. The conducting and sensory properties of particles such as carbon nanotubes and nanowires also make them obvious choices for such circuits.

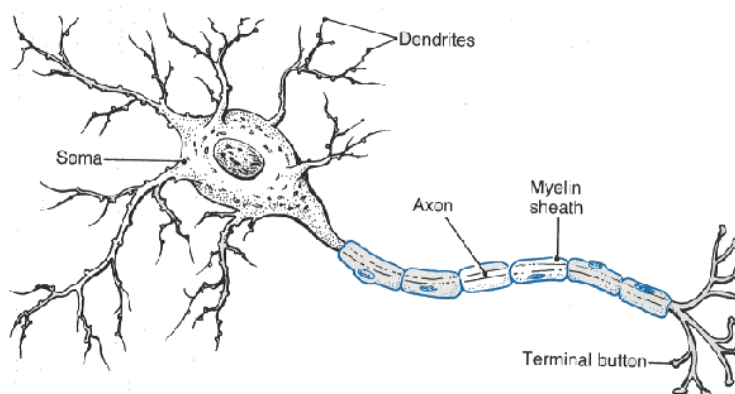


Figure 3 – structure of a neuron

The nervous system contains a network of neurons (Figure 3) which transmit impulses (electrochemical waves called action potentials) along their axons, and is responsible for coordinating organisms' actions in response to stimuli. The central nervous system (CNS) of vertebrates consists of the brain, spinal cord and retina. The

peripheral nervous system consists, on a basic scale, of sensory, motor and relay neurons, and synapses to link the three together.

Sensory neurons conduct impulses from sensory organs to the CNS. Relay neurons in the CNS connect sensory neurons to motor neurons. The motor neurons then conduct impulses from the CNS to effectors (muscles and glands) which perform a response to the stimuli. Synapses (Figure 4) are

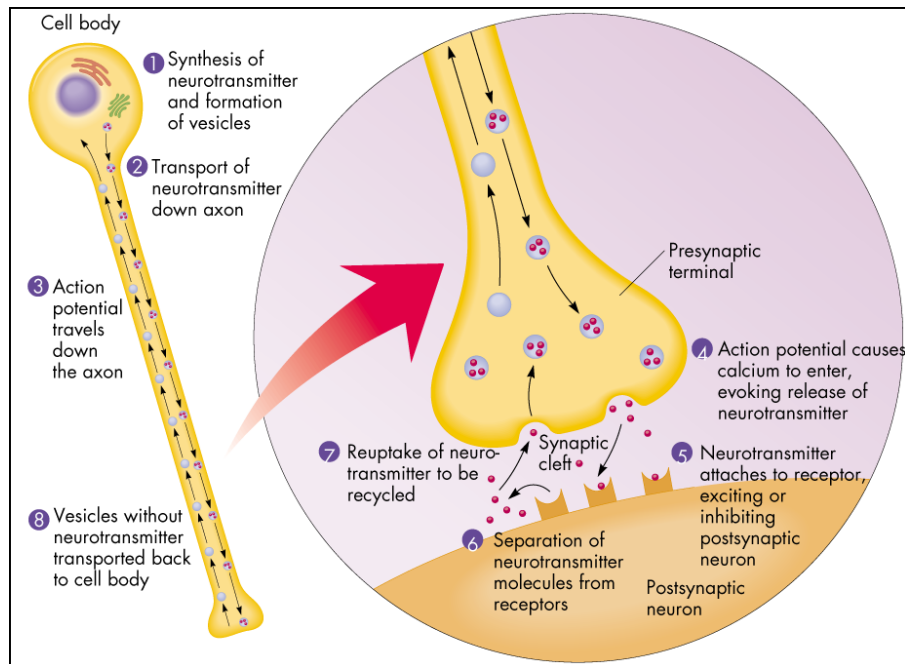


Figure 4 – action of a synapse

regions where impulses are transmitted from one neuron to another or from the motor neurone to the effector. In the synapse the arrival of an impulse results in a neurotransmitter being released as action potential causes calcium to enter the neuron. This neurotransmitter diffuses across a gap to the next neuron and the arrival of the chemical causes the next neuron to produce its own impulse.

It is clear how crucial neurons are to the functioning of our nervous system. Currently, scientists can, “stimulate neurons with electrical impulses to override the brain’s own signals,” using electrodes. However, using nanotechnology, and the conducting properties of silicon nanowires or carbon nanotubes, they could build brain-penetrating nanoelectrodes to transfer messages to individual neurons.

It is also clear how crucial synapses are to the functioning of our nervous system. Scientists have decided to try to build artificial synapses using nanotechnology in an attempt to scale neuromorphic circuits towards the human brain level. This paper attempts to suggest how they could repair damaged neural circuits.

Harvard researcher Charles Lieber and his team have linked silicon nanowires with axons and dendrites of mammalian neurons, creating artificial synapses between them. It is important to remember that nanowires are suitable for this as they are semiconductors. For this reason it could also be possible to use carbon nanotubes as they conduct electricity.

Memristors, electronic devices with two terminals whose conductance and resistance can be precisely controlled and programmed, before being stored in a similar way to

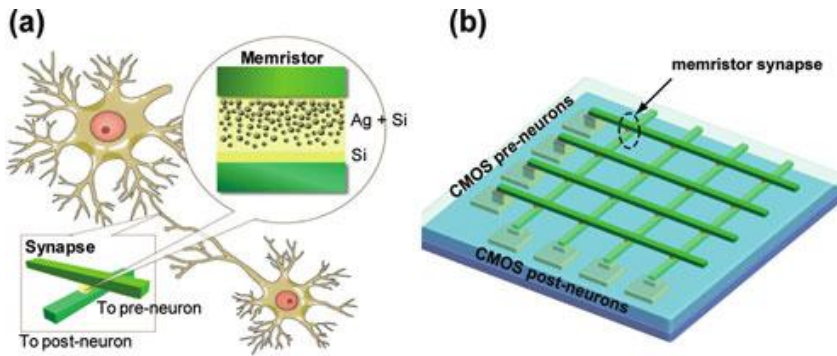


Figure 5 – nanoscale memristors
 (a) Concept of using memristors as synapses
 (b) Structure of a memristor

memories, are also being developed to act as artificial synapses. Therefore they mimic synapses as they are also, “two-terminal devices whose conductance can be modulated by external stimuli with the ability to store (memorise) the new information.” They can ‘remember’ our experiences due to

patterns in signal type and strength. Nanoscale memristors (Figure 5) created by a scientist named Lu, consist of two electrodes on either side of silicon nanowires studded with silver atoms.

Altering of synapse or neuron function can lead to a host of crippling problems. One disease which affects synapse function, which could potentially be treated using artificial synapses created using nanowires or nanotubes, is Alzheimer’s.

Alzheimer’s is the most common form of dementia in the UK. Synaptic dysfunction and failure occurs early in the disease; so artificial synapses such as memristors, could be used as treatment to slow the progression of or stop some parts of the disease from occurring. In sufferers, ‘plaques’ (abnormal clusters of beta-amyloid protein fragments) build up between neurons, and ‘tangles’ (twisted protein strands in dead and dying neurons) develop in the brain (Figure 6), leading to the death of some of the brain’s 100 billion neurons. The ‘plaques’ block synapses and possibly trigger the immune system to devour disabled neurons. So, if artificial synapses produced using nanotechnology, were put in the place of blocked synapses, the effects of the disease associated with nervous system

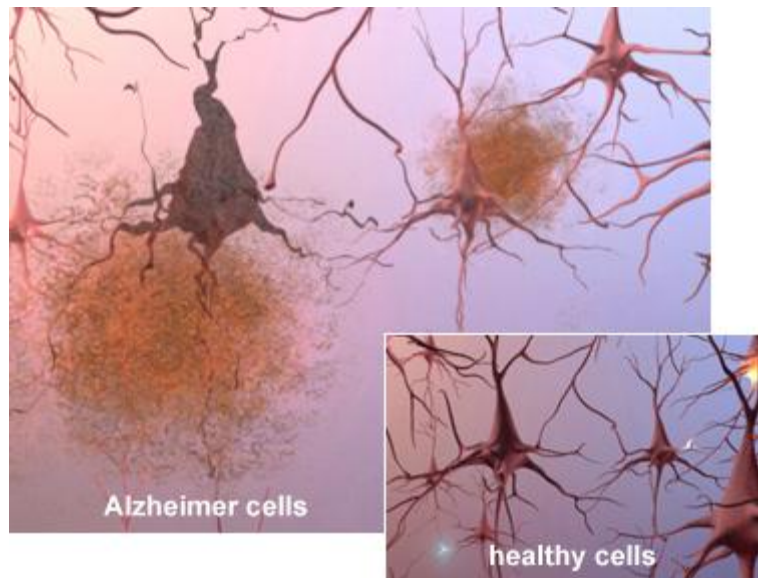


Figure 6 – ‘plaques’ and ‘tangles’ leading to the altering of neurons

function such as degeneration of speech, memory and coordination, could be slowed down at the very least.

Another factor of the nervous system impacted upon by Alzheimer's, is neurotransmitters. Sufferers have reduced synthesis of the neurotransmitter acetylcholine, which, "plays a key role in memory, learning and many other brain functions." Nanotechnology could therefore treat Alzheimer's using nanoelectrodes programmed to tell individual neurons to produce more acetylcholine, potentially leading to lessened memory loss.

A second disease which affects the nervous system is Huntington's disease. Some symptoms include: involuntary, jerking movements; memory problems; and personality change. It is inherited due to a genetic abnormality on the fourth chromosome, where cytosine, adenine and guanine occur in a repeated sequence, forming the abnormal gene 'huntingtin'. The protein formed due to this gene, stops neurons from protecting themselves against the toxic waste products of body processes, and therefore neurons and synapses which control movement are often damaged. Nanoelectrodes or artificial synapses could be useful here in stimulating the sending of signals to protect against damage from toxins.

It is useful to note that symptoms of Huntington's are similar to those of Parkinson's, particularly those which occur later in the disease (slowness of movement and muscle rigidity). These similarities suggest that Parkinson's could also have future treatments involving nanotechnology. Indeed, the movement problems encountered are due to the damage or death of neurons which produce dopamine, a neurotransmitter associated with smooth muscle movement, emotions, learning and memory. This causes neurons to fire impulses randomly, leaving sufferers struggling to control their movement. Therefore nanoelectrodes or artificial synapses could treat Parkinson's as they could stimulate the sending of signals to produce dopamine.

The final problem associated with the nervous system that this paper will explore is depression. Symptoms vary between sufferers; from sleep and appetite changes, to irritability, concentration problems, and feelings of worthlessness. These seriously impact on their lives and the lives of others around them, can lead to suicide and self-harm, yet are very hard to treat.

In the BBC Four documentary, *The Brain: A Secret History* (2011), scientists suggested that electrodes could be implanted in the brain to stimulate regions associated with pleasure, as a treatment for depression. This controversial idea was tested using electrodes that were too large so stimulated too large an area of the brain. Nanotechnology could solve this problem, and therefore treat depression through stimulating areas of the brain associated with pleasure, as nanoelectrodes can target individual neurons so would not over stimulate non-target areas of the brain.

A slightly less controversial way of using nanotechnology to treat depression, would be using nanoelectrodes to send signals to neurons to release endorphins. Endorphins are

chemicals released during, for example exercise, excitement and pain, which, “produce a feeling of well-being.” An endorphin rush after pain can prevent neurons from releasing more pain signals. Therefore if the release of endorphins was stimulated in a depressive, using nanoelectrodes, many of the symptoms involved could be treated, such as feeling helpless or worthless.

Issues to be considered before the proposed developments could take place

To say that these and other future developments in nanotechnology, will be entirely beneficial to medicine, and the rest of our world, is an extremely bold statement. There are ethical issues concerning any such developments; the impacts they will have, need to be discussed and researched before any development is put into use.

Particularly when discussing nanotechnology impacting on the nervous system, and crucially the brain, there are numerous ethical issues to be considered. Firstly, should we be attempting to act as nature does? ‘Playing God’ in this way could anger some religious people in society as some believe preserving life in this fairly artificial way is going against ‘God’s will’.

In addition, there are ethical issues and social stigmas, if the altering of nervous pathways and brain activity, were to be regarded as a version of ‘mind control’; free-will is one of our most basic human rights. Is taking someone out of depression ‘mind control’? Does interfering with an organisms’ brain and nervous pathways alter their level of free-will? And if it does, could it be right that scientists do interfere with free-will, if it leads to a depressive choosing against suicide? There are no correct answers to these questions, and consequently, it will be hard to make laws concerning these topics.

The potential social effect is another issue to be considered. More accurate diagnosis by nanomachines will mean less human capital required in diagnosing processes, so less human errors and wider healthcare access. This could increase the standard of living, but also lead to increases in population size and ageing populations, causing problems such as limited government resources and consumer goods having to be spread between more people, and the working population having to support more pensioners. Many economists have also suggested that nanotechnology will widen the gap in income distributions.

As well as this there will be other effects to economies. Currently many economies are dependent on oil and less-durable products are sold as firms are profit maximisers. However, how will the economy change if nanotechnology rids industry’s dependence on fossil fuels (as predicted in Canton’s, *The Strategic Impact of Nanotechnology on the Future of Business and Economics*)? How will businesses change to adapt to people wanting to buy durable products made from super-strength carbon nanotubes? Nanotechnology has the potential to revolutionise the way economies work.

Another issue which makes some people concerned about nanotechnology is the unknown effects of particles of this size. It is thought that some nanomaterials can migrate through the skin as they are so small, and cause health problems. This could be

lethal if this is the case as we are using nanoparticles of, for example zinc oxide, which reflect UV rays and are transparent, in sun creams.

Another potential unknown effect is environmental problems. Nanotechnology, “promises to reduce by orders of magnitude the inputs of energy and materials and associated environmental discharges required to produce a device,” as it has almost 100% efficiency, as explained by Fiona Moore in a paper. It could potentially revolutionise the way we monitor and attempt to ‘save’ our environment. However, there has been no life cycle analysis of nanoparticles; it is unclear whether they will be detectable after release into the environment, meaning that if they do cause damage, it could be hard to get rid of them and so we may be left with this damage and its repercussions, on a permanent basis.

Furthermore, carbon nanotubes have information gaps concerning their safety. There is data showing that their size means, under certain conditions, they can cross the skin’s membrane barriers and cause reactions such as inflammation. There is also suggestion that they could be toxic as their structure is similar to the fibre-shaped structure of asbestos. However, while this is a concern, it is unclear whether or not all asbestos-shaped materials will behave like asbestos. What is perhaps a more realistic threat from carbon nanotubes with our current information, is that their absorbed environmental contaminants will be released into an organism once it has absorbed or inhaled the nanotubes.

Possibly the most famous issue with nanotechnology is Drexler’s ‘gray goo scenario’, concerning the problems of exponential growth of self-replicating nanosystems if they became out of control. His ideas raised public concern to such an extent that it probably influenced the NNI (National Nanotechnology Initiative), established in 2000 in the US, in their decision to fund nanoscale technology over molecular manufacturing. However, many do not think this a problem; currently nanobots do not have self-replicating capabilities and they may never do. It was the debate of whether this was a cause for concern or just a, “widespread misinterpretation of Drexler’s work,” that led to Drexler and Smalley debating in 2003, and Smalley accusing Drexler of, “hav[ing] scared our children” with, “such monster[s] as the self-replicating mechanical nanobot.”

Finally, as well as saving lives, nanotechnology in the wrong hands, has the potential to destroy lives. Miniaturizing current weapons would have a deadly impact. However, nanotechnology also has the future possibility of: ‘disassembler’ bullets which would attack organisms at a molecular level; and selective bio-weapons of mass destruction which, for example could only affect people with certain genetic makeups. Therefore as well as killing people, this could provoke wars based on race etc.

Clearly, although we do not know if there are any adverse effects at all, people are right to be cautious as nanotechnology has not been around for a long enough period of time. Effects have to be monitored over lifetimes before a definite health and environment statement on any effects of these particles can be proved beyond reasonable doubt.

All of these ethical issues have led to debate on how intensely nanotechnology should be regulated. However, even if governments decide to closely regulate nanotechnology, this will be a difficult task, as: “nanoparticles are complex to classify because their properties depend on their chemical composition, their size and form, their crystallographic structure, their surface properties, etc. These properties are not all routinely considered when evaluating their health impacts (for example, particle size does not play a role in current chemical regulations)”. Clearly an approach considering many complex factors will be needed to come to a conclusion about how best to regulate nanotechnology.

CONCLUSION

It is important to note that a limitation of this paper is that it is a ‘gedankenexperiment’, so no practical research has been carried out by me; all of the research behind the thoughts and suggestions in this paper has been collected and put together with limited time and resources.

A practical problem with some of the material in this paper is how the developments mentioned previously would be made viable as treatments; how the artificial synapses and nanowires are going to be implanted into the body, on such an intricate level. However, nanotechnology may solve this problem itself. Current drug delivery techniques being used for heart disease could be used to take the artificial synapses, or other components of circuits, to the target site in the body. In addition, nanosurgery using the future possibility of nanobots, promises non-invasive surgical procedures, which could be used to implant nanoelectrodes into the brain.

Overall, the methods of using nanotechnology in neuromorphic engineering, specifically to create artificial synapses and nanoelectrodes, needs to be perfected, but has the potential to lead to more effective treatment of problems associated with the nervous system, including the four discussed in this paper. It is a shame that these advances are surrounded by so much controversy. Questions such as: “Can the human race survive as we are forever?”; “Should the human race continuously try to improve the world for the benefit of humanity?”; and, “How much nano-prosthesis will make one non-human?” as asked in R Smith’s book (2001) *Social, Ethical and Legal Implications of Nanotechnology* all have different interpretations and answers, meaning there will be much disagreement surrounding advances of this type due to nanotechnology. It means that any sort of breakthrough will take more time to become readily accessible, if at all, because people are reluctant to believe that nanotechnology works and is not dangerous.

This really is the nature of the problem to be solved; society has to be convinced to trust in nanotechnology, and kept informed while ethical issues are researched and discussed, while at the same time scientists develop techniques and uses of nanotechnology that prove the benefits outweigh any drawbacks. One such benefit would be the potential saving and enriching of lives, if the treatments discussed previously reached sufferers of crippling nervous system problems, as they occur due to errors at cellular level, which was previously hard to access on such an intricate basis. These potential effects are so great that it is clear this treatment should not to be overlooked or underestimated.

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Figure 6 - <http://www.alz.org/brain/10.asp>

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