NANOTECHNOLOGY IN MEDICINE-OVERVIEW

1,**Debjit Bhowmik***,Chiranjib,Niladry,Shobharam,2R.Margret chandira B.Jayakar
1.Rajiv Gandhi college of pharmacy,Nautanwa,Uttar pradesh
2.Vinayaka missions college of pharmacy
Vinayaka missions university
Salem-636008,Tamilnadu
debjit_cr@yahoo.com

Abstract

Nanotechnology is the engineering of functional systems at the molecular scale. This covers both current work and concepts that are more advanced. Nanotechnology enhanced materials will enable a weight reduction accompanied by an increase in stability and an improved functionality. Biomedical nanotechnology, bionanotechnology, and nanomedicine are used to describe this hybrid field. The prefix "nano" refers to one-billionth. When applied in the metric scale of linear measurements, a nanometer is one-billionth of a meter. The term "nanotechnology" is now commonly used to refer to the creation of new objects with nanoscale dimensions between 1.0 and 100.0 nm.
Functionalities can be added to nanomaterials by interfacing them with biological molecules or structures. The size of nanomaterials is similar to that of most biological molecules and structures; therefore, nanomaterials can be useful for both in vivo and in vitro biomedical research and applications. Thus far, the integration of nanomaterials with biology has led to the development of diagnostic devices, contrast agents, analytical tools, physical therapy applications, and drug delivery vehicles. Nanotechnology is also opening up new opportunities in implantable delivery systems, which are often preferable to the use of injectable drugs, because the latter frequently display first-order kinetics (the blood concentration goes up rapidly, but drops exponentially over time). This rapid rise may cause difficulties with toxicity, and drug efficacy can diminish as the drug concentration falls below the targeted range. Nanotechnology can help to reproduce or to repair damaged tissue. This so called “tissue engineering” makes use of artificially stimulated cell proliferation by using suitable nanomaterial-based scaffolds and growth factors. Tissue engineering might replace today’s conventional treatments like organ transplants or artificial implants Much of nanoscience and many nanotechnologies are concerned with producing new or enhanced materials. Nanomaterials can be constructed by 'top down' techniques, producing very small structures from larger pieces of material.

Introduction

Nanotechnology is the study, design, creation, synthesis, manipulation, and application of materials, devices, and systems at the nanometer scale (One meter consists of 1 billion nanometers). It is becoming increasingly important in fields like engineering, agriculture, construction, microelectronics and health care to mention a few. The application of nanotechnology in the field of health care has come under great attention in recent times. There are many treatments today that take a lot of time and are also very expensive. Using nanotechnology, quicker and much cheaper treatments can be developed. By performing further research on this technology, cures can be found for diseases that have no cure today. We could make surgical instruments of such precision and deftness that they could operate on the cells and even molecules from which we are made - something well beyond today's medical technology. Therefore nanotechnology can help save the lives of many people. Nanotechnology, when used with biology or medicine, is referred to as Nanobiotechnology. This technology should be used very carefully because the lives of human beings are being dealt with. If used properly, it can be very effective in providing treatments with minimal side-effects. Nanomedicine, an offshoot of nanotechnology, refers to highly specific medical intervention at the molecular scale for curing disease or repairing damaged tissues, such as bone, muscle, or nerve. A nanometer is one-billionth of a meter, too small to be seen with a conventional lab microscope. It is at this size scale – about 100 nanometers or less – that biological molecules and structures inside living cells operate. Nanotechnology involves the creation and use of materials and devices at the level of molecules and atoms. Research in nanotechnology began with discoveries of novel physical and chemical properties of various metallic or carbon-based materials that only appear for structures at nanometer-sized dimensions. Understanding these nanoscale properties permits engineers to build new structures and use these materials in new ways. The same holds true for the biological structures inside living cells of the body. Nanotechnology in medicine currently being developed involve employing nano-particles to deliver drugs, heat, light or other substances to specific cells in the human body. Engineering particles to be used in this way allows detection and/or treatment of diseases or injuries within the targeted cells, thereby minimizing the damage to healthy cells in the body. Nanotechnology can be defined as the science and engineering involved in the design, synthesis, characterization, and application of materials and devices whose smallest functional organization in at least one dimension is on the nanometer scale or one billionth of a meter. At these scales, consideration of individual molecules and interacting groups of molecules in relation to the bulk macroscopic properties of the material or device becomes important, since it is control over the fundamental molecular structure that allows control over the macroscopic chemical and physical properties. Applications to medicine and physiology imply materials and devices designed to interact with the body at subcellular (i.e., molecular) scales with a high degree of specificity. This can potentially translate into targeted cellular and tissue-specific clinical applications designed to achieve maximal therapeutic affects with minimal side effects. In this review the main scientific and technical aspects of nanotechnology are introduced and some of its potential clinical applications are discussed.

Application of Nanotechnology in Medicine

1. While most applications of nanotechnology in medicine are still under development nanocrystalline silver is already being used as a antimicrobial agent in the treatment of wounds.
2. Qdots that identify the location of cancer cells in the body.
3. Nanoparticles that deliver chemotherapy drugs directly to cancer cells to minimize damage to healthy cells.
4. Nanoshells that concentrate the heat from infrared light to destroy cancer cells with minimal damage to surrounding healthy cells. For a good visual explanation of nanoshells, click to see this slide.
5. Nanotubes used in broken bones to provide a structure for new bone material to grow.
6. Nanoparticles that can attach to cells infected with various diseases and allow a doctor to identify, in a blood sample, the particular disease

Nanomedicine: Future Applications

Nanomedicine refers to future developments in medicine that will be based on the ability to build nanorobots. In the future these nanorobots could actually be programmed to repair specific diseased cells, functioning in a similiar way to antibodies in our natural healing processes.

1. The elimination of bacterial infections in a patient within minutes, instead of using treatment with antibiotics over a period of weeks.
2. The ability to perform surgery at the cellular level, removing individual diseased cells and even repairing defective portions of individual cells.
3. Significant lengthening of the human lifespan by repairing cellular level conditions that cause the body to age.

Uses Nanotechnology in Medicine:

Nanotechnology is set to increase rapidly over the coming years. Researchers are developing customized nanoparticles the size of molecules that can deliver drugs directly to diseased cells in your body. When it's perfected, this method should greatly reduce the damage treatment such as chemotherapy does to a patient's healthy cells. Nanomedicine refers to future developments in medicine that will be based on the ability to build nanorobots. In the future these nanorobots could actually be programmed to repair specific diseased cells, functioning in a similiar way to antibodies in our natural healing processes.

Nanotechnology in Drug Delivery System

Today, most harmful side effects of treatments such as chemotherapy are a result of drug delivery methods that don't pinpoint their intended target cells accurately. **Researchers at Harvard and MIT** have been able to attach special RNA strands, measuring about 10 nm in diameter, to nanoparticles and fill the nanoparticles with a chemotherapy drug. These RNA strands are attracted to cancer cells. When the nanoparticle encounters a cancer cell it adheres to it and releases the drug into the cancer cell. This directed method of drug delivery has great potential for treating cancer patients while producing less.

Medical Applications of Nanotechnology in Drug Research

The National Institutes of Health Bioengineering Consortium, or BECON, held a symposium in 2000 entitled "Nanoscience and Technology: Shaping Biomedical Research“. At the conference, eight areas of nanoscience and nanotechnology were addressed that were believed to be most pertinent to research in biomedicine. These areas included synthesis and use of nanostructures, applications of nanotechnology to therapy, biomimetic nanostructures, biologic nanostructures, electronic-biology interface, devices for early detection of disease, tools for the study of single molecules, and nanotechnology and tissue engineering. For example, nanoscale polymer capsules can be designed to break down and release drugs at controlled rates and to allow differential release in certain environments, such as an acid milieu, to promote uptake in tumors versus normal tissues. Substantial research is now designed for creating novel polymers and exploring specific drug-polymer combinations. Nanocapsules can be synthesized directly from monomers or by means of nanodeposition of preformed polymers. Nanocapsules have also been formulated from albumin and liposomes. Implantable drug delivery systems that are being developed will make use of nanopores to control drug release

Nanotechnology and Drug Bioavailability

Drug bioavailability is a related problem with potential nanotechnology solutions. Again, biodegradable polymer capsules show promise. Hydrophobic drugs such as paclitaxel or 5-fluorouracil can be encapsulated in polymers or liposomes with nanoscale cavities that improve drug absorption and bioavailability. The opportunity exists to systematically look at both successful and failed drugs to see which ones might benefit from novel delivery vehicles. In some cases, reformulation of a drug with smaller particle size may improve oral bioavailability. Nanotechnology is being used to create new diagnostic pharmaceuticals for use in medical imaging. The class of compounds known as superparamagnetic iron oxides (SPIOs), also known as monocrystalline iron oxide nanoparticles, or MIONs, have shown promise for a number of magnetic resonance (MR) imaging applications both as naked particles and as magnetic labels

Salient Feature of Nanotechnology in Medicine and Cosmetics

- Nanotechnology involves manipulating properties and structures at the nanoscale, often involving dimensions that are just tiny fractions of the width of a human hair. Nanotechnology is already being used in products in its passive form, such as cosmetics and sunscreens, and it is expected that in the coming decades, new phases of products, such as better batteries and improved electronics equipment, will be developed and have far-reaching implications.
- One area of nanotechnology application that holds the promise of providing great benefits for society in the future is in the realm of medicine. Nanotechnology is already being used as the basis for new, more effective drug delivery systems and is in early stage development as scaffolding in nerve regeneration research. Moreover, the National Cancer Institute has created the Alliance for Nanotechnology in Cancer in the hope that investments in this branch of nanomedicine could lead to breakthroughs in terms of detecting, diagnosing, and treating various forms of cancer.

- ***Nanotechnology,*** "the manufacturing technology of the 21st century," should let us economically build a broad range of complex molecular machines (including, not incidentally, molecular computers). It will let us build fleets of computer controlled molecular tools much smaller than a human cell and built with the accuracy and precision of drug molecules. Such tools will let medicine, for the first time; intervene in a sophisticated and controlled way at the cellular and molecular level. They could remove obstructions in the circulatory system, kill cancer cells, or take over the function of subcellular organelles. Just as today we have the artifical heart, so in the future we could have the artificial mitochondrion. Often hailed as a revolutionary new technology, nanotechnology has the potential to impact almost every area of society.

APPLICATION IN MEDICAL SCIENCE

This section discusses the applications of nanotechnology in the field of health care. These applications can remarkably improve the current treatments of some diseases and help save the lives of many.

A. Drug Delivery System

Nanobots are robots that carry out a very specific function and are just several nanometers wide. They can be used very effectively for drug delivery. Normally, drugs work through the entire body before they reach the disease-affected area. Using nanotechnology, the drug can be targeted to a precise location which would make the drug much more effective and reduce the chances of possible side-effects.

Figure 1 - device that uses nanobots to monitor the sugar level in the blood.

B. Disease Diagnosis and Prevention

Diagnosis and Imaging

Nanobiotech scientists have successfully produced microchips that are coated with human molecules. The chip is designed to emit an electrical impulse signal when the molecules detect signs of a disease. Special sensor nanobots can be inserted into the blood under the skin where they check blood contents and warn of any possible diseases. They can also be used to monitor the sugar level in the blood. Advantages of using such nanobots are that they are very cheap to produce and easily

C. Preventing Diseases

a. H*eart-attack Prevention*

Nanobots can also be used to prevent heart-attacks. Heart-attacks are caused by fat deposits blocking the blood vessels. Nanobots can be made for removing these fat deposits (Harry, 2005). The following figure shows nanobots removing the yellow fat deposits on the inner side of blood vessels.

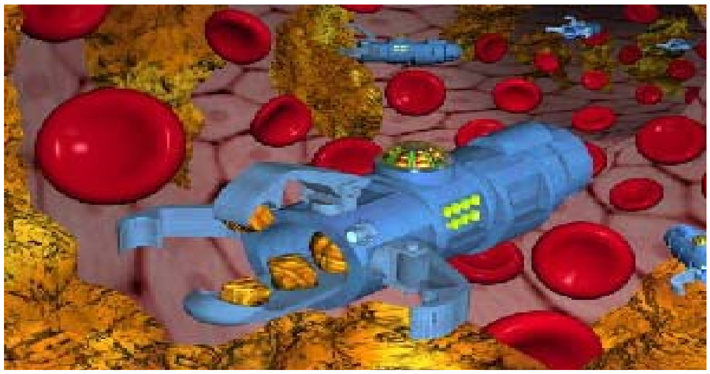

Figure 1. Nanobots Preventing Heart-attacks (Heart View)

b. *Frying Tumors*

Nanomaterials have also been investigated into treating cancer. The therapy is based on "cooking tumors" principle. Iron nanoparticles are taken as oral pills and they attach to the tumor. Then a magnetic field is applied and this causes the nanoparticles to heat up and literally cook the tumors from inside out.

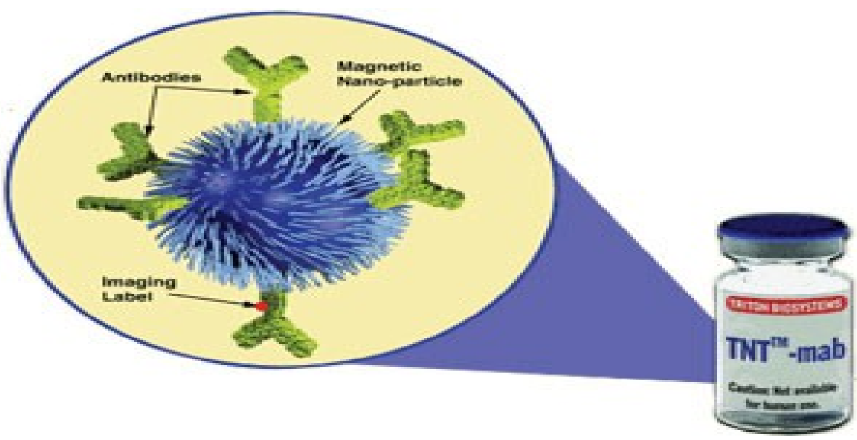

Figure 2. Cancer Cooker- Triton BioSystems is developing an anticancer therapy using antibody-coated iron nanoparticles

c. *Tissue Reconstruction*

Nanoparticles can be designed with a structure very similar to the bone structure. An ultrasound is performed on existing bone structures and then bone-like nanoparticles are created using the results of the ultrasound (Silva, 2004). The bone-like nanoparticles are inserted into the body in a paste form (Adhikari, 2005). When they arrive at the fractured bone, they assemble themselves to form an ordered structure which later becomes part of the bone (Adhikari, 2005).

Another key application for nanoparticles is the treatment of injured nerves. Samuel Stupp and John Kessler at Northwestern University in Chicago have made tiny rod like nano-fibers called *amphiphiles*. They are capped with amino acids and are known to spur the growth of neurons and prevent scar tissue formation. Experiments have shown that rat and mice with spinal injuries recovered when treated with these nano-fibers. (Weiss, 2005)

Figure 3 Miniature Cameras inside Blood Vessels

Expenses in Nanotechnology

Conducting research on nanotechnology is very expensive. An article in the Nanotech Report 2004 claimed that global investment on nanotechnology has reached:

- $8.6 billion: Total investment
- $4.6 billion from government
- $3.8 billion form corporate research and development
- $200 million from venture capitalists (Perkel, 2004).

At present the tools for developing nanotechnology are very basic and we still need more investment to reap the benefits of this great technology.

Nanomedicine and Nanoparticle in Drug Delivery system

> Nanomedicine is the medical application of nanotechnologyThe approaches to nanomedicine range from the medical use of nanomaterials, to nanoelectronic biosensors, and even possible future applications of molecular Nanomedicine research is directly funded, with the US National Institutes of Health in 2005 funding a five-year plan to set up four nanomedicine centers. In April 2006, the journal Nature Materials estimated that 130 nanotech-based drugs and delivery systems were being developed worldwide nanotechnology

The small size of nanoparticles endows them with properties that can be very useful in oncology, particularly in imaging. Quantum dots (nanoparticles with quantum confinement properties, such as size-tunable light emission), when used in conjunction with MRI (magnetic resonance imaging), can produce exceptional images of tumor sites. These nanoparticles are much brighter than organic dyes and only need one light source for excitation. This means that the use of fluorescent quantum dots could produce a higher contrast image and at a lower cost than todays organic dyes used as contrast media. The downside, however, is that quantum dots are usually made of quite toxic elements.

Researchers at Rice University under Prof. Jennifer West, have demonstrated the use of 120 nm diameter nanoshells coated with gold to kill cancer tumors in mice. The nanoshells can be targeted to bond to cancerous cells by conjugating antibodies or peptides to the nanoshell surface. By irradiating the area of the tumor with an infrared laser, which passes through flesh without heating it, the gold is heated sufficiently to cause death to the cancer cells

One scientist, University of Michigan’s James Baker, believes he has discovered a highly efficient and successful way of delivering cancer-treatment drugs that is less harmful to the surrounding body. Baker has developed a nanotechnology that can locate and then eliminate cancerous cells. He looks at a molecule called a dendrimer. This molecule has over one hundred hooks on it that allow it to attach to cells in the body for a variety of purposes. Baker then attaches folic-acid to a few of the hooks (folic-acid, being a vitamin, is received by cells in the body). Cancer cells have more vitamin receptors than normal cells, so Baker's vitamin-laden dendrimer will be absorbed by the cancer cell. To the rest of the hooks on the dendrimer, Baker places anti-cancer drugs that will be absorbed with the dendrimer into the cancer cell, thereby delivering the cancer drug to the cancer cell and nowhere else (Bullis 2006)

Cancer

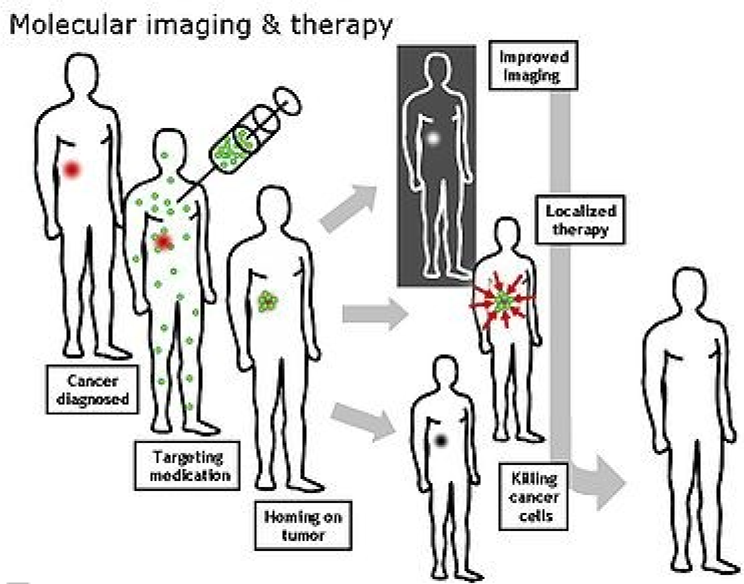

Figure 4 A schematic illustrations showing how nanoparticles or other cancer drugs might be used to treat cancer.

Nanoparticle Targeted Drug Delivery System

It is greatly observed that nanoparticles are promising tools for the advancement of drug delivery, medical imaging, and as diagnostic sensors. However, the biodistribution of these nanoparticles is mostly unknown due to the difficulty in targeting specific organs in the body. Current research in the excretory systems of mice, however, shows the ability of gold composites to selectively target certain organs based on their size and charge. These composites are encapsulated by a dendrimer and assigned a specific charge and size. Positively-charged gold nanoparticles were found to enter the kidneys while negatively-charged gold nanoparticles remained in the liver and spleen. It is suggested that the positive surface charge of the nanoparticle decreases the rate of osponization of nanoparticles in the liver, thus affecting the excretory pathway. Even at a relatively small size of 5nm, though, these particles can become compartmentalized in the peripheral tissues, and will therefore accumulate in the body over time. While advancement of research proves that targeting and distribution can be augmented by nanoparticles, the dangers of nanotoxicity become an important next step in further understanding of their medical uses.

Molecular nanotechnology

Molecular nanotechnology is a speculative subfield of nanotechnology regarding the possibility of engineering molecular assemblers, machines which could re-order matter at a molecular or atomic scale. Molecular nanotechnology is highly theoretical, seeking to anticipate what inventions nanotechnology might yield and to propose an agenda for future inquiry. The proposed elements of molecular nanotechnology, such as molecular assemblers and nanorobots are far beyond current capabilities.

Nanorobots

The somewhat speculative claims about the possibility of using nanorobots in medicine, advocates say, would totally change the world of medicine once it is realized. Nanomedicine would make use of these nanorobots (e.g., Computational Genes), introduced into the body, to repair or detect damages and infections. According to Robert Freitas of the Institute for Molecular Manufacturing, a typical blood borne medical nanorobot would be between 0.5-3 micrometres in size, because that is the maximum size possible due to capillary passage requirement. Carbon would be the primary element used to build these nanorobots due to the inherent strength and other characteristics of some forms of carbon (diamond/fullerene composites), and nanorobots would be fabricated in desktop nanofactories specialized for this purpose. Nanodevices could be observed at work inside the body using MRI, especially if their components were manufactured using mostly ^{13}C atoms rather than the natural ^{12}C isotope of carbon, since ^{13}C has a nonzero nuclear magnetic moment. Medical nanodevices would first be injected into a human body, and would then go to work in a specific organ or tissue mass. The doctor will monitor the progress, and make certain that the nanodevices have gotten to the correct target treatment region. The doctor will also be able to scan a section of the body, and actually see the nanodevices congregated neatly around their target (a tumor mass, etc.) so that he or she can be sure that the procedure was successful.

Nanonephrology

Nanonephrology is a branch of nanomedicine and nanotechnology that deals with 1) the study of kidney protein structures at the atomic level; 2) nano-imaging approaches to study cellular processes in kidney cells; and 3) nano medical treatments that utilize nanoparticles and to treat various kidney diseases. The creation and use of materials and devices at the molecular and atomic levels that can be used for the diagnosis and therapy of renal diseases is also a part of Nanonephrology that will play a role in the management of patients with kidney disease in the future. Advances in Nanonephrology will be based on discoveries in the above areas that can provide nano-scale information on the cellular molecular machinery involved in normal kidney processes and in pathological states. By understanding the physical and chemical properties of proteins and other macromolecules at the atomic level in various cells in the kidney, novel therapeutic approaches can be designed to combat major renal diseases. The nano-scale artificial kidney is a goal that many physicians dream of. Nano-scale engineering advances will permit programmable and controllable nano-scale robots to execute curative and reconstructive procedures in the human kidney at the cellular and molecular levels. Designing nanostructures compatible with the kidney cells and that can safely operate in vivo is also a future goal. The ability to direct events in a controlled fashion at the cellular nano-level has the potential of significantly improving the lives of patients with kidney diseases.

Cell repair machines

- Using drugs and surgery, doctors can only encourage tissues to repair themselves. With molecular machines, there will be more direct repairsCell repair will utilize the same tasks that living systems already prove possible. Access to cells is possible because biologists can stick needles into cells without killing them. Thus, molecular machines are capable of entering the cell. Also, all specific biochemical interactions show that molecular systems can recognize other molecules by touch, build or rebuild every molecule in a cell, and can disassemble damaged molecules. Finally, cells that replicate prove that molecular systems can assemble every system found in a cell. Therefore, since nature has demonstrated the basic operations needed to perform molecular-level cell repair, in the future, nanomachine based systems will be built that are able to enter cells, sense differences from healthy ones and make modifications to the structure.
- The possibilities of these cell repair machines are impressive. Comparable to the size of viruses or bacteria, their compact parts would allow them to be more complex. The early machines will be specialized. As they open and close cell membranes or travel through tissue and enter cells and viruses, machines will only be able to correct a single molecular disorder like DNA damage or enzyme deficiency. Later, cell repair machines will be programmed with more abilities with the help of advanced AI systems.
- Nanocomputers will be needed to guide these machines. These computers will direct machines to examine, take apart, and rebuild damaged molecular structures. Repair machines will be able to repair whole cells by working structure by structure. Then by working cell by cell and tissue by tissue, whole organs can be repaired. Finally, by working organ by organ, health is restored to the body. Cells damaged to the point of inactivity can be repaired because of the ability of molecular machines to build cells from scratch. Therefore, cell repair machines will free medicine from reliance on self repair.
- A new wave of technology and medicine is being created and its impact on the world is going to be monumental. From the possible applications such as drug delivery and *in vivo* imaging to the potential machines of the future, advancements in nanomedicine are being made every day. It will not be long for the 10 billion dollar industry to explode into a 100 billion or 1 trillion dollar industry, and drug delivery, *in vivo* imaging and therapy is just the beginning. Nanomedicine may be defined as the monitoring, repair, construction and control of human biological systems at the molecular level, using engineered nanodevices and nanostructures. Basic nanostructured materials, engineered enzymes and the many products of biotechnology will be enormously useful in future medical applications. However, the full promise of nanomedicine is unlikely to arrive until after the development of precisely controlled or programmable medical nanomachines and nanorobots. Once nanomachines are available, the ultimate dream of every healer, medicine man, and physician throughout recorded history will at last become a reality.

Nanotechnology in Medicine:

Company	Product
CytImmune	Gold nanoparticles for targeted delivery of drugs to tumors
Nucryst	Antimicrobial wound dressings using silver nanocrystals
Nanobiotix	Nanoparticles that target tumor cells, when irradiated by xrays the nanoparticles generate electrons which cause localized destruction of the tumor cells.
Oxonica	Disease identification using gold nanoparticles (biomarkers)
Nanotherapeutics	Nanoparticles for improving the performance of drug delivery by oral, inhaled or nasal methods
NanoBio	Nanoemulsions for nasal delivery to fight viruses (such as the flu and colds) and bacteria
BioDelivery Sciences	Oral drug delivery of drugs encapuslated in a nanocrystalline structure called a cochleate
NanoBioMagnetics	Magnetically responsive nanoparticles for targeted drug delivery and other applications
Z-Medica	Medical gauze containing aluminosilicate nanoparticles which help bood clot faster in open wounds.

Conclution

Nanotechnology provides the field of medicine with promising hopes for assistance in diagnostic and treatment technologies as well as improving quality of life. Humans have the potential to live healthier lives in the near future due to the innovations of nanotechnology. Some of these innovations include:

- Disease diagnosis
- Prevention and treatment of disease
- Better drug delivery system with minimal side effects
- Tissue Reconstruction

Nanotechnology is still in its early stages. The applications discussed in this report have already been developed and are already helping patients all over the world. As further research continues in this field, more treatments will be discovered. Many diseases that do not have cures today may be cured by nanotechnology in the future. Nanotechnology is the ability to work at the atomic, molecular and supramolecular levels (on a scale of _1–100 nm) in order to understand, create and use materialstructures, devices and systems with fundamentally new properties and functions resulting from their small structure. Nanotechnology is putting the goal of building a "lab-on-a-chip" within reach. By using very small channels, only nanogram quantities of analytes and reagents are required. Throughput can increase while cost decreases. Such devices could dramatically change the care model by making sophisticated tests widely and immediately available at lower cost in office settings, at home, or at a patient's bedside. Some of the concerns were also discussed but with proper care these problems can be avoided. Scientists who are against the use of nanotechnology also agree that advancement in nanotechnology should continue because this field promises great benefits, but testing should be carried out to ensure the safety of the people. If everything runs smoothly, nanotechnology will one day become part of our everyday life and will help save many lives.

Reference

1. Santhi K, Dhanaraj SA, Joseph V, Ponnusankar S, Suresh B. A study on the preparation and anti-tumor efficacy of bovine serum albumin nanospheres containing 5-fluorouracil. Drug Dev Ind Pharm 2002; 28:1171-1179.[CrossRef][Medline]
2. Mu L, Feng SS. A novel controlled release formulation for the anticancer drug paclitaxel (Taxol): PLGA nanoparticles containing vitamin E TPGS. J Control Release 2003; 86:33-48.[CrossRef][Medline]
3. Chawla JS, Amiji MM. Biodegradable poly (epsilon-caprolactone) nanoparticles for tumor-targeted delivery of tamoxifen. Int J Pharm 2002; 249:127-138.[CrossRef][Medline]
4. Xu L, Frederik P, Pirollo KF. Self-assembly of a virus-mimicking nanostructure system for efficient tumor-targeted gene delivery. Hum Gene Ther 2002; 13:469-481.[CrossRef][Medline]
5. Liu G, Li D, Pasumarthy MK, et al. Nanoparticles of compacted DNA transfect postmitotic cells. J Biol Chem 2003; 278:32578-32586.[Abstract/Free Full Text]
6. Lewin M, Carlesso N, Tung CH, et al. Tat peptide-derivatized magnetic nanoparticles allow in vivo tracking and recovery of progenitor cells. Nat Biotechnol 2000; 18:410-413.[CrossRef][Medline]

7. Adhikari, Raju. “Nanobiotechnology: Will It Deliver?” Healthcare Purchasing News. Jan. 2005: 1-3. <http://findarticles.com/p/articles/mi_m0BPC/is_1_29/ai_n8708476> (12 Nov. 2006).
8. 2. Amazing Nanobots. <http://www.amazings.com/ciencia/images/261101b.jpg> (25 Dec. 2006).
9. Balbus, John, et al. “Getting Nanotechnology Right the First Time.” Issues in Science and Technology 2005: 1-4.
10. < http://www.findarticles.com/p/articles/mi_qa3622/is_200507/ai_n14716314 > (7 Nov. 2006).
11. Blender Battles. <http://battles.mudpuddle.co.nz/albums/userpics/10002/n_nanobots.jpg> (3 Nov. 2005).
12. Donaldson, Ken, and Vicki Stone. “Nanoscience Fact Versus Fiction.” Association for Computing Machinery (Nov. 2004): 113. Full Text (ABI/INFORM. ProQuest).
13. Earth Buried In Nanobots. < http://flickr.com/photos/sunsetswirl/129859434/> (20. Nov. 2006).