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Nanorobots: The Emerging tools in Medicinal Applications – A Review

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Abstract: Nowadays medical science is more and more improving with the blessings of new scientific discoveries. Nanotechnology is such a field which is changing vision of medical science. New automated procedures are being discovered with new aspects of self-guided nanorobots. Nanorobot is an excellent tool for future medicine. We can envision a day when you could inject billions of these nanorobots that would float around in your body. Nanorobots could carry and deliver drugs into defected cells. These nanorobots will be able to repair tissues, clean blood vessels and airways, transform our physiological capabilities, and even potentially counter act the aging process. Many scientists working on this bright field of nanorobots especially on Alzheimer disease and cancer treatments. The engineering of molecular products needs to be carried out by robotic devices, which have been termed Nano robots. Nano robotics, sometimes referred to as molecular robotics, is an emerging research area as evidenced by recent topics in the literature. A multifunctional platform based on nanorobots, with various types of nanomachines will surely fight against major diseases like cancer, HIV etc. In this review, we will summarize briefly about nanorobots and its tools, mechanism, approaches and main futuristic applications of the same which mainly useful for medicinal and to develop new formulations related to nanotechnology to cure the major diseases.

Keywords: Virtual 3D Nanorobots, Biosensors, DNA joints, Brain Aneurysm

INTRODUCTION:

Nanorobotics is emerging as a demanding field dealing with miniscule things at molecular level, and it is mainly used for medical applications. Nanorobots are nano electromechanical systems designed to perform a specific task with precision at nano scale dimensions. Its advantage over conventional medicine lies on its size. The design of nanorobots is derived from biological models, specifically in the behaviour of bacteria. The various components in the nanorobots design may include on board sensors, motors, manipulators, power supplies, and molecular computers. The idea of introducing small submarines through the blood vessels has been captured in many films. But the blood at nanoscale becomes viscous and sticky fluid which does not let the submarine to drive along the vessels. Another phenomenon that would not let the submarine to travel is the Brownian movement of the molecules; the collisions between molecules are in controllable and unpredictable.[1-3]

In the last decade, progress in developing nano sized hybrid therapeutics and drug delivery systems has been remarkable. These nanoscale and often multicomponent constructs can be seen as the first nanomedicines, already bringing clinical benefits. A good flow of related technologies is also in development. But are these 'nanomedicines' really new? The educated answer is 'not really'. The concepts of antibody-conjugates, liposomes and polymer-conjugates stem from the 1970s. At first, they were seen as competing technologies; only one would emerge as a 'magic bullet' for all drug targeting applications. But each has advantages and disadvantages. Antibodies have exquisite potential for selective targeting but, even as humanized proteins, can be immunogenic. Liposomes have high drug-carrying capacity, but can either release drug too quickly or entrap it too strongly and are prone to capture by the reticuloendothelial system (RES), even when polymer coated. Similarly, it is hard to steer nanoparticles away from the RES after intravenous injection. The ideal delivery system often merges benefits of two or more technologies. As we mark the birth of nanomedicine, it is worth reflecting on the revolution it could bring to healthcare. It is essential that benefits of genomics and proteomics research and advances in drug delivery, are quickly harnessed to realize improvements in diagnosis and therapy. Nanotechnology is already making a key contribution, but this is just the start. There are opportunities to design nanosized, bioresponsive systems able to diagnose and then deliver drugs (theranostics) and systems able to promote tissue regeneration and repair (in disease, trauma and ageing), circumventing chemotherapy. These ideas may seem like science fiction, but to dismiss them would be foolish. Risks and benefits must be addressed carefully to yield useful and safe technologies.[4] an interdisciplinary approach will ensure that the exciting potential of nanomedicine's many facets will be a practical reality in the foreseeable future. The tightly-integrated interdisciplinary team of medical researchers, pharmaceutical scientists, physicists, chemists, and chemical engineers, has an extensive range of expertise to facilitate research on Nano medicine. The long term goal is the development of novel and revolutionary biomolecular machine components that can be assembled and form multi-degree-of-freedom nanodevices that will apply forces and manipulate objects in the nanoworld, transfer information from the nano to the macro world, and travel in the nanoenvironment. These machines are expected to be highly efficient, controllable, economical in mass production, and fully operational with minimal supervision.[5] these ultra-miniature robotic systems and nano-mechanical devices will be the biomolecular electro-mechanical hardware of future biomedical applications (IGERT).

THEORY OF NANOROBOTS:

Since nanorobots would be microscopic in size, it would probably be necessary for very large numbers of them to work together to perform microscopic and macroscopic tasks. These nanorobot swarms, both those which are incapable of replication (as in utility fog) and those which are capable of unconstrained replication in the natural environment (as in grey goo and its less common variants), are found in many science fiction stories, such as the Borg nanoprobes in Star Trek. The word "nanobot" (also "nanite", "nanogene", or "nanoant") is often used to indicate this fictional context and is an informal or even pejorative term to refer to the engineering concept of nanorobots. The word nanorobot is the correct technical term in the nonfictional context of serious engineering studies.

Some proponents of nanorobotics, in reaction to the grey goo scare scenarios that they earlier helped to propagate, hold the view that nanorobots capable of replication outside of a restricted factory environment do not form a necessary part of a purported productive nanotechnology, and that the process of self-replication, if it were ever to be developed, could be made inherently safe. They further assert that free-foraging replicators are in fact absent from their current plans for developing and using molecular manufacturing.[6-7]

ELEMENTS OF NANOROBOTS

Carbon Nano tube, motor, bio sensors, DNA Joints

APPROACHES:

1. Biochip:

The joint use of nanoelectronics, photolithography, and new biomaterials, can be considered as a possible way to enable the required manufacturing technology towards nanorobots for common medical applications, such as for surgical instrumentation, diagnosis and drug delivery. Indeed, this feasible approach towards manufacturing on nanotechnology is a practice currently in use from the electronics industry. So, practical nanorobots should be integrated as nanoelectronics devices, which will allow tele-operation and advanced capabilities for medical instrumentation.[8, 11]

2. Nubots:

Nubot is an abbreviation for "nucleic acid robots." Nubots are synthetic robotics devices at the nanoscale. Representative Nubots include the several DNA walkers reported by Ned Seeman's group at NYU, Niles Pierce's group at Caltech, John Reif's group at Duke University, Chengde Mao's group at Purdue, and Andrew Turberfield's group at the University of Oxford.[8, 9]

3. Positional nanoassembly:

Nanofactory Collaboration founded by Robert Freitas and Ralph Merkle in 2000, is a focused ongoing effort involving 23 researchers from 10 organizations and 4 countries that is developing a practical research agendaspecifically aimed at developing positionally-controlled diamond mechanosynthesis and diamondoid nanofactory that would be capable of building diamondoid medical nanorobots.

4. Bacteria based

This approach proposes the use biological microorganisms, like *Escherichia coli* bacteria. Hence, the model uses a flagellum for propulsion purposes. The use of electromagnetic fields are normally applied to control the motion of this kind of biological integrated device, although his limited applications.[8-9]

ADVANTAGES OF NANOTECHNOLOGY:

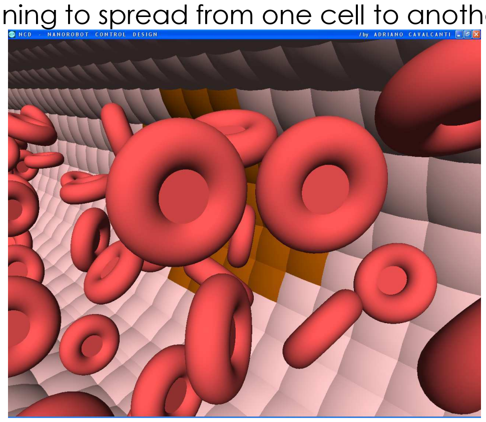
1. To cure HIV, Cancer, and other harmful diseases and research also under progress.
2. The nano robots will treat and find disease, and restore lost tissue at the cellular level.
3. Useful for monitoring, diagnosing and fighting sickness.
4. It will be able to monitor neuro-electric signals and stimulate bodily systems.

MECHANISM OF NANOROBOTS:

The research and development of nanorobots with embedded nanobiosensors and actuators is considered a new possibility to provide new medical devices for doctors.[9,19-21] As integrated control mechanisms at microscopic environments differ from conventional control techniques, approaches using event-based feed forward control are sought to effectively advance new medical technologies.[22,23] In the same way the development of microelectronics in the 1980s has led to new tools for biomedical instrumentation, the manufacturing of nanoelectronics.[24,25] It will similarly permit further miniaturization towards integrated medical systems, providing efficient methodologies for pathological prognosis.[26-28]

The use of micro devices in surgery and medical treatments is a reality which has brought many improvements in clinical procedures in recent years.[29] For example, among other biomedical instrumentation, catheterization has been successfully used as an important methodology for heart and intracranial surgery.[30-32] Now the advent of biomolecular science and new manufacturing techniques is helping to advance the miniaturization of devices from micro to nanoelectronics. Sensors for biomedical applications are advancing through teleoperated surgery and pervasive medicine and this same technology provides the basis for manufacturing biomolecular actuators.[33-35] A first series of nanotechnology prototypes for molecular machines are being investigated in different ways [18 36-38], and some interesting devices for propulsion and sensing have been presented.[18,36-39,41] More complex molecular machines, or nanorobots, having embedded nanoscopic features represent new tools for medical procedures.[42-44]

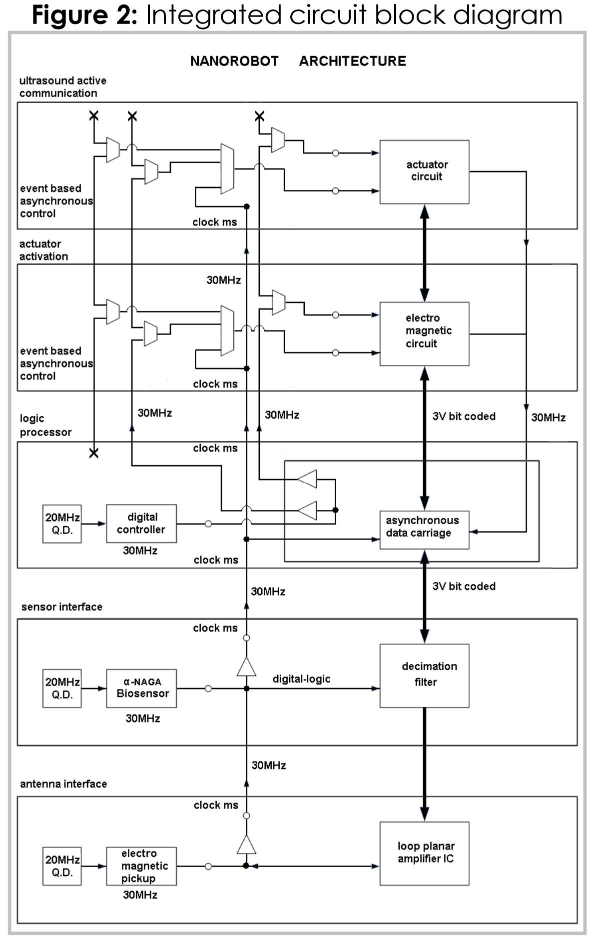
Figure 1: The bloodstream flows through the vessel in the 3D model. The vessel endothelial cells denote in brown color the influenza virus beginning to spread from one cell to another. [3, 6]



Nanorobot Architecture:

The medical nanorobot for biohazard defense should comprise a set of integrated circuit block as an ASIC (application-specific integrated circuit). The architecture has to address functionality for common medical applications [18], providing asynchronous interface for antenna, sensor, and a logic nanoprocessor, which is able to deliberate actuator and ultrasound communication activation when appropriate (Fig. 2). The main parameters used for the nanorobot architecture and its control activation, as well as the required technology background that can advance manufacturing hardware for molecular machines, are described next. As a practical rule, the number of nanodevices to integrate a nanorobot should keep the hardware sizes in regard to inside body operation applicability.[3-6, 35, and 47]

Figure 2: Integrated circuit block diagram

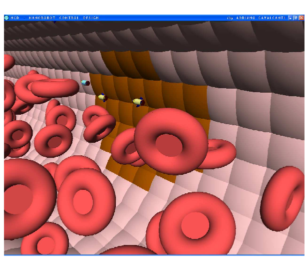


System Implementation:

The nanorobot model prototyping uses a task based approach with detection of protein alpha-NAGA higher concentrations. The simulation and analysis consist of adopting a multi-scale view of the scenario with bloodstream simulation. It incorporates the physical morphology of the biological environment along with physiological fluid flow patterns, and this is allied with the nanorobot systems for orientation, drive mechanisms, sensing and control. The real time 3D simulation is used to achieve high-fidelity on control modelling and equipment prototyping. Hence, the NCD (Nanorobot Control Design) software was implemented and is used for nanorobot sensing and actuation. The computational model is applied as a practical tool for control and manufacturing design analyses. Real time 3D design and simulation are important for the fast development of nanotechnology, helping also in the research and development of medical nanorobots.[37,37] Such tools have significantly supported the semiconductor industry to achieve faster VLSI implementation.[36] It has similarly direct impact on nanomanufacturing and also nanoelectronics progress.[24] Simulation can anticipate performance, help in new device prototyping and manufacturing, nanomechatronics control design and hardware implementation.[1,38]

The nanorobot exterior shape being comprised of carbon-metal Nano composites, to which should be attached an artificial glycocalyx surface, is used to minimize fibrinogen and other blood proteins adsorption or bioactivity, ensuring sufficient biocompatibility to avoid immune system attack.[52,53,58,63] Different molecule types are distinguished by a series of chemotactic sensors whose binding sites have a different affinity for each kind of molecule.[42,47] These sensors can also detect obstacles which might require new trajectory planning.[47] The nanorobot sensory capabilities are simulated, allowing it to detect and identify the nearby possible obstacles in its environment, as well as a-NAGA protein overexpression for continuous real time in vivo prognosis purpose. For chemical detection a variety of sensors is possible, enabling identification of various types of cells.[42, 61-63] A set of different views from the 3D environment can be observed (Figs. 3 and 4). A multiplicity of nanorobots allows precise detection of alpha-NAGA in initial stages of influenza infection.

Figures 3-8: Screenshots with nanorobots and red blood cells inside the vessel. The real time 3D simulation optionally provides visualization either with or without the red blood cells. The influenza infection with cell hostage begins to spread from infected to nearby uninfected cells. The nanorobots flow with the bloodstream sensing for protein over expression.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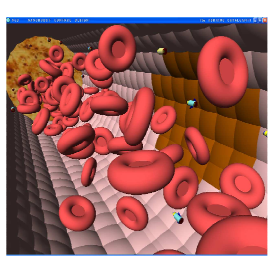
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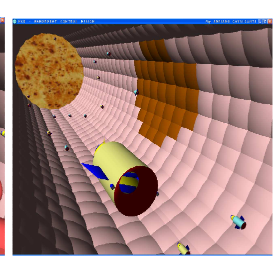
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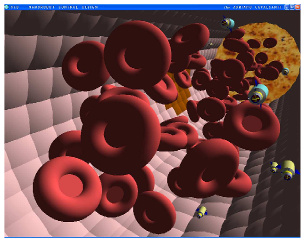

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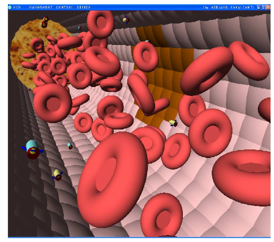

Figure 7

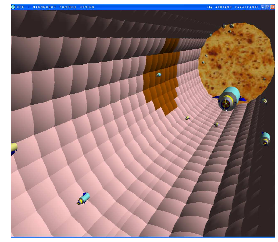

Figure 8

MEDICAL APPLICATIONS OF NANOROBOTS:

Nanorobots are expected to enable new treatments for patients suffering from different diseases, and will result in a remarkable advance in the history of medicine. Recent developments in the field of biomolecular computing have demonstrated the feasibility of processing logic tasks by bio-computers. This is a promising first step to enable future nanoprocessors with increased complexity. Studies targeted at building biosensors and nano-kinetic devices required to enable medical nanorobotics operation and locomotion, have also been progressing.[38]

In recent years, the potential of nanotechnology has indeed motivated many governments to devote significant resources to this new field. The U.S. National Science Foundation has launched a program in "Scientific Visualization" in part to harness supercomputers in picturing the nanoworld. A 1 trillion US$ market consisting of devices and systems with some embedded nanotechnology is projected by 2015. The research firm Display search predicts rapid market growth of organic light emitting diodes, from 84 million US$ in 2002 to 1.6 billion US$ in 2007. A first series of commercial nano products is foreseeable by 2007.[3,53] In order to build electronics at nanoscales, firms are collaborating to produce new nano products. Such companies include IBM, PARC, Hewlett Packard, Bell Laboratories, and Intel Corp., to name a few.

The use of nanorobots may advance biomedical intervention with minimally invasive surgeries and help patients who need constant body functions monitoring, or ever improve treatments efficiency through early diagnosis of possible serious diseases. For example, the nanorobots may be utilized to attach on transmigrating inflammatory cells or white blood cells, thus reaching inflamed tissues faster to assist in their healing process. Nanorobots will be applied in chemotherapy to combat cancer through precise chemical dosage administration, and a similar approach could be taken to enable nanorobots to deliver anti-HIV drugs.[18-20,54,65] Nanorobots could be used to process specific chemical reactions in the human body as ancillary devices for injured organs. Monitoring diabetes and controlling glucose levels for patients will be a possible application of nanorobots. Nanorobots might be used to seek and break kidney stones. Another important possible feature of medical nanorobots will be the capability to locate atherosclerotic lesions in stenosed blood vessels, particularly in the coronary circulation, and treat them either mechanically, chemically or pharmacologically. Cardiovascular problems are generally correlated with the obesity, human sedentary lifestyle, or hereditary characteristics Heart problem is the world biggest killer.[31, 43, 61]

1. **Simulation Discussion**

The use of micro devices in surgery and medical treatments is a reality which brought many improvements for clinical procedures in the last years. For example, the catheterization has been used as an important methodology for many cardiology procedures in the same way as the development of microtechnology[63] has lead on the 80's to new tools for surgery, now nanotechnology will equally permit further advances providing better diagnosis, and new devices for medicine through the manufacturing of nanoelectronics.[8-12] Nanorobots may be considered as the most suitable tool for specialists to solve several problems in medicine in the coming few year here including cardiology interventions and medical analyses. In our study, the nanorobot includes external sensors to inform it of collisions and to identify when it has encountered a chemical signal or abrupt changes of temperature for targeted areas. As a practical approach for medicine, thermal and chemical parameters from the patient's body are used for the nanorobot activation. It is well known that there is significant temperature heterogeneity over inflamed plaque surfaces. They are typically hotter. The temperature difference at the site of the lesion from the core temperature can reach up to ~2°C Hence, in order to simulate various levels of inflammation, it was used different wall temperatures in the atherosclerotic plaque region, and calculated the temperature distribution in the stenosed coronary artery Significant temperature gradients were found in the recirculation zone, following the stenosis (Fig. 9).[52-55]

The transcardiac concentration gradient of some soluble adhesion molecules has been recently found to be correlative with the progression of coronary atherosclerosis. Therefore, their concentration in the blood vessel is also monitored, using a uniform distribution release from the plaque. In a similar manner, the concentrations of some specific pro-inflammatory cytokines is monitored, whose elevated concentrations are known as an evidence of formation of atherosclerotic lesions.

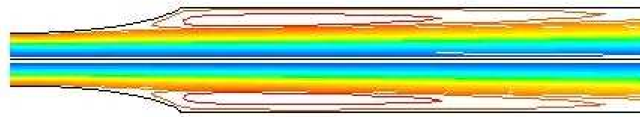

Figure 9: Flow streamlines, showing the recirculation zone after the stenosis

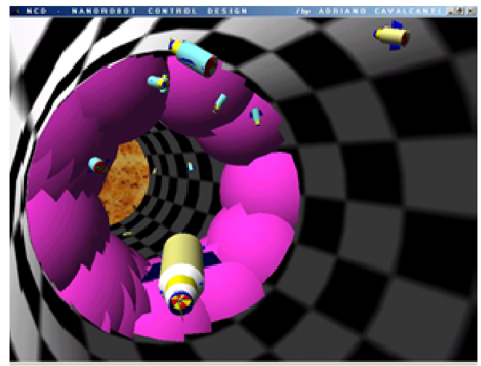

Figure 10: Vein inside view without the red blood cells.

The target plaque is represented by the pink spheres surrounding the vessel wall. The nanorobots swim in a near-wall region searching for the atherosclerotic lesion.

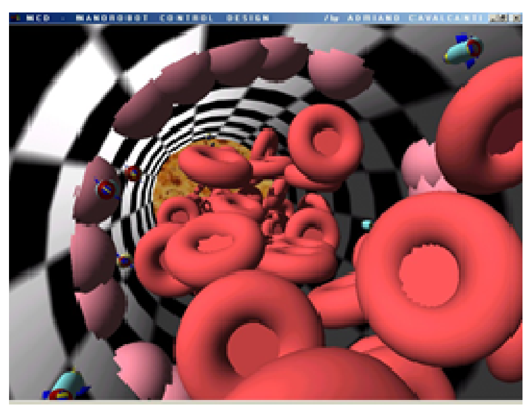

Figure 11: The atherosclerotic lesion was reduced due nanorobots activation. The temperatures in the region turn in expected levels.

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The parameters generated from the CFD simulation, namely velocities, temperature, signaling values, pro-inflammatory cytokines and soluble adhesion molecules concentrations, are transferred to the NCD [3, 5-7, 36] simulator to be included into the nanorobots operating environment.[45-47] As the nanorobot should perform a pre-defined task in a specific target area, the trigger must be activated when the nanorobot is as close as possible to the target. The nanorobot motion control in the artery keeps it near-wall region. It takes the advantage of the blood flow velocity profile in such areas, which shows significantly lower velocities. Thus, the rapid activation could result in lower demand of energy (Fig. 10). Optimization of control algorithms and activating triggers is the key for rapid behaviour response in minimal energy cost. The optimal trigger values are defined running the nanorobots control programs. Therefore, the investigated stenosed artery models provide important information useful to nanorobot manufacturing design in terms of sensors and actuators. The nanorobots activation goal is to decrease the artery occlusion (Fig. 11).

2. NANOROBOTICS IN DENTISTRY

The growing interest in the future of dental applications of nanotechnology is leading to the emergence of a new field called Nanodentistry. Nanorobots induce oral analgesia, Desensitize tooth; manipulate the tissue to re-align and straighten irregular set of teeth and to improve durability of teeth. Further it is explained that how nanorobots are used to do preventive, restorative, curative procedures.[23-27]

Major tooth repair

Nanodental techniques involve many tissue engineering procedures for major tooth repair. Mainly nanorobotics manufacture and installation of a biologically autologous whole replacement tooth that includes both mineral and cellular components which leads to complete dentition replacement therapy.

Tooth Durability and Appearance

Nanodentistry has given material that is nanostructured composite material, sapphire which increases tooth durability and appearance. Upper enamel layers are replaced by covalently bonded artificial material such as sapphire. This material has 100 to 200 times the hardness and failure strength than ceramic. Like enamel, sapphire is a somewhat susceptible to acid corrosion. Sapphire has best standard whitening sealant, cosmetic alternative. New restorative nano material to increase tooth durability is Nanocomposites [32, 47, 64-66]. This is manufactured by nanoagglomerated discrete nanoparticles that are homogeneously distributed in resins or coatings to produce nanocomposites. The nanofiller include an aluminosilicate powder having a mean particle size of about 80 nm and a 1:4 ratio of alumina to silica. The nanofiller has a refractive index of 1.503, it has superior hardness, modulus of elasticity, translucency, esthetic appeal, excellent color density, high polish and 50% reduction in filling shrinkage. They are superior to conventional composites and blend with a natural tooth structure much better.

Nano Impression

Impression material is available with nanotechnology application. Nanofiller are integrated in the vinylpolysiloxanes, producing a unique addition siloxane impression material. The main advantage of material is it has better flow, improved hydrophilic properties hence fewer voids at margin and better model pouring, enhanced detail precision.

3. NANO ROBOTS FOR BRAIN ANEURYSM

For brain aneurysm prognosis, nano robots need to track the vessel endothelial injury before a subarachnoid haemorrhage occurs. These changes on chemical concentration are used to guide the nano robots to identify brain aneurysm in the early stages of development (Figure 12.).[27, 32, 56]

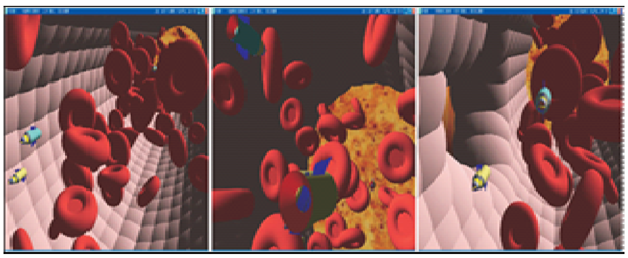

Figure 12: Working of Nanorobot on Brain aneurysm

4. Nanorobots in Arteriosclerosis:

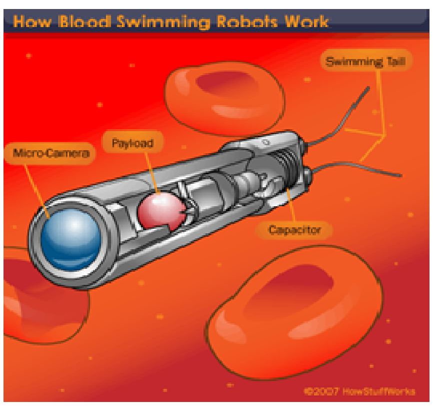

Figure 13: mechanism of arteriosclerosis

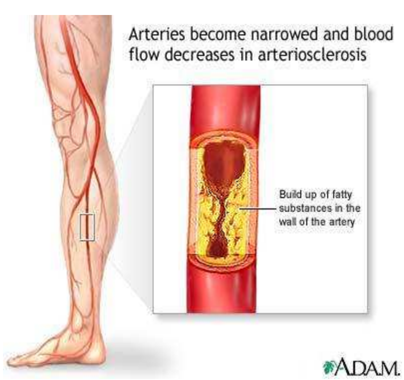

Figure 14: how blood swimming robots work

4. NANOROBOTS IN CANCER DETECTION AND TREATMENT

Cancer can be successfully treated with current stages of medical technologies and therapy tools. However, a decisive factor to determine the chances for a patient with cancer to survive is: how earlier it was diagnosed; what means, if possible, a cancer should be detected at least before the metastasis has begun. Another important aspect to achieve a successful treatment for patients, is the development of efficient targeted drug delivery to decrease the side effects from chemotherapy. [35, 38, 43-47] Considering the properties of nanorobots to navigate as blood borne devices, they can help on such extremely important aspects of cancer therapy. Nanorobots with embedded chemical biosensors can be used to perform detection of tumour cells in early stages of development inside the patient's body. Integrated Nanosensors can be utilized for such a task in order to find intensity of E-cadherin [62-64] signals. Therefore a hardware architecture based on nanobioelectronics is described for the application of nanorobots for cancer therapy. Analyses and conclusions for the proposed model are obtained through real time 3D simulation.[22-27]

5. NANOROBOTS IN GENE THERAPY[18-20, 64]

Medical nanorobots can readily treat genetic diseases by comparing the molecular structures of both DNA and proteins found in the cell to known or desired reference structures. Any irregularities can then be corrected, or desired modifications can be edited in place. In some cases, chromosomal replacement therapy is more efficient than in cytorepair. Floating inside the nucleus of a human cell, an assembler-built repair vessel performs some genetic

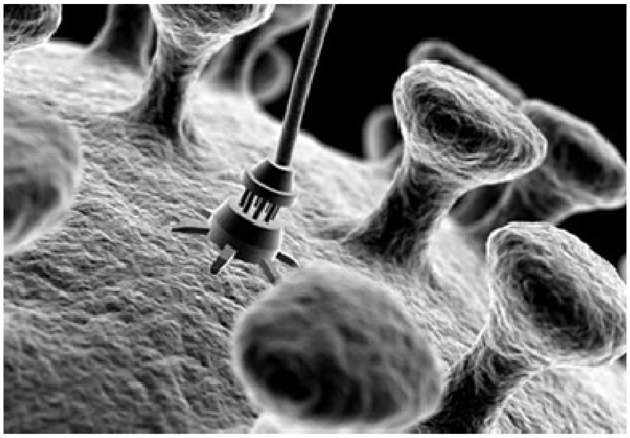

Figure 15: microscopic view of nano tools working on human cells

Maintenance. Stretching a supercoil of DNA between its lower pair of robot arms, the nano machine gently pulls the unwound strand through an opening in its prow for analysis. Upper arms, meanwhile, detach regulatory proteins from the chain and place them in an intake port. The molecular structures of both DNA and proteins are compared to information stored in the database of a larger nanocomputer positioned outside the nucleus and connected to the cell-repair ship by a communications link. Irregularities found in either structure are corrected and the proteins reattached to the DNA chain [56-58], which re-coils into its original form. With a diameter of only 50 nanometers, the repair vessel would be smaller than most bacteria and viruses, yet capable of therapies and cures well beyond the reach of present-day physicians. With trillions of these machines coursing through a patient's bloodstream, "internal medicine" would take on new significance. Disease would be attacked at the molecular level, and such maladies as cancer, viral infections and arteriosclerosis could be wiped out.

6. NANOROBOTS IN SURGERY

Surgical nanorobots could be introduced into the body through the vascular system or at the ends of catheters into various vessels and other cavities in the human body.[28-30] a surgical nanorobot, programmed or guided by a human surgeon, could act as a semi-autonomous on-site surgeon inside the human body. Such a device could perform various functions such as searching for pathology and then diagnosing and correcting lesions by nanomanipulation, coordinated by an on-board computer while maintaining contact with the supervising surgeon via coded ultrasound signals.[54-57]

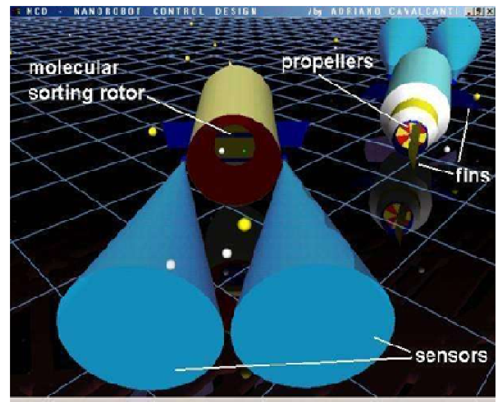

Figure 16: The depicted blue cones show the sensors "touching" areas that triggers the nanorobots' behaviours.

The earliest forms of cellular nanosurgery are already being explored today. For example, a rapidly vibrating (100 Hz) micropipette with a <1 micron tip diameter has been used to completely cut dendrites from single neurons without damaging cell viability. Axotomy of roundworm neurons was performed by femtosecond laser surgery, after which the axons functionally regenerated. A femtolaser acts like a pair of "nano-scissors" [63-67] by vaporizing tissue locally while leaving adjacent tissue unharmed.

7. NANOMEDICINE:

Potential applications for nanorobotics in medicine include early diagnosis and targeted drug delivery for cancer biomedical instrumentation, surgery, pharmacokinetics, monitoring of diabetes, and health care in such plans, future medical nanotechnology is expected to employ nanorobots injected into the patient to perform treatment on a cellular level. Such nanorobots intended for use in medicine should be non-replicating[65-67], as replication would needlessly increase device complexity, reduce reliability, and interfere with the medical mission. Instead, medical nanorobots are posited to be manufactured in hypothetical, carefully controlled nanofactories in which nanoscale machines would be solidly integrated into a supposed desktop-scale[61, 63] machine that would build macroscopic products.

Disadvantages:

1. The initial design cost is very high.
2. The design of the nanorobot is a very complicated one.
3. Hard to Interface, Customize and Design, Complex.
4. Privacy is the other potential risk involved with Nanorobots. As Nanorobots deals with the designing of compact and minute devices, there are chances for more eavesdropping [66-68] than that already exists.
5. Electrical systems can create stray fields which may activate bioelectric-based molecular recognition systems in biology. Electrical nanorobots are susceptible to electrical interference from external sources such as RF or electric fields, EMP pulses [68], and stray fields from other in vivo electrical devices[57-58].
6. Nanorobots can cause a brutal risk in the field of terrorism. The terrorism and anti-groups can make use of nanorobots as a new form of torturing the communities as nanotechnology also has the capability of destructing the human body at the molecular level.

Conclusion:

Nanotechnology as an emerging tool in medicinal applications especially for diabetes, arteriosclerosis, gene therapy, dentistry and cancer showed how actual developments in new manufacturing technologies are enabling innovative works which may help in constructing and employing nanorobots most effectively for biomedical problems. Nanorobots applied to medicine hold a wealth of promise from eradicating disease to reversing the aging process (wrinkles, loss of bone mass and age-related conditions are all treatable at the cellular level); nanorobots are also candidates for industrial applications. They will provide personalised treatments with improved efficacy and reduced side effects that are not available today. They will provide combined action drugs marketed with diagnostics, imaging agents acting as drugs, surgery with instant diagnostic feedback. The advent of molecular nanotechnology will again expand enormously the effectiveness, comfort and speed of future medical treatments while at the same time significantly reducing their risk, cost, and invasiveness. This science might sound like a fiction now, but Nanorobotics has strong potential to revolutionize healthcare, to treat disease in future. It opens up new ways for vast, abundant research work. Nanotechnology will change health care and human life more profoundly than other developments. Consequently they will change the shape of the industry, broadening the product development and marketing interactions between Pharma, Biotech, Diagnostic and Healthcare industries. Future healthcare will make use of sensitive new diagnostics for an improved personal risk assessment. Highest impact can be expected if those major diseases are addressed first, which impose the highest burden on the aging population: cardiovascular diseases, cancer, musculoskeletal conditions, neurodegenerative and psychiatric diseases, diabetes, and viral infections.

Figure 17: Nanorobot in arteriosclerosis

Nanomedicine holds the promise to lead to an earlier diagnosis, better therapy and improved follow up care, making the health care more effective and affordable. Nanomedicine will also allow a more personalised treatment for many diseases, exploiting the in-depth understanding of diseases on a molecular level.

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