Nanotechnology and Nanomedicine

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Management in the Health System
1. Executive summary

Nanotechnology is a new science that deals with manipulating matter at atomic or molecular level. This opens up huge possibilities in areas like manufacturing, construction, computing, science of materials and medicine.

In particular, in medicine, it is expected to help humans to heal diseases and expand the functionality of the human body. Clear examples of this are: manipulating DNA helixes, killing cancer cells, removing obstructions in the circulatory system and developing artificial cells and organs.

The main obstacle for its adoption will be the resistance by doctors and pharmaceutical companies, since the balance of power in the health system will shift towards high-tech companies.

Nanotechnology will also bring big risks and ethical considerations. Hence, the need for strong regulation by Governments and International Institutions.

Nanotechnology is clearly seen today as one of the most promising research areas. Though, this technology is still in the birth stage with mostly theoretical research and no actual working nanorobot yet built.

2. Introduction to nanotechnology

Three big revolutions have happened in the 20th century, and are continuously changing our everyday life: information technologies, biotechnology, and the science of materials. As a consequence of them, a series of technologies have emerged as ways to improve human well-being and heal diseases. Among those we can find:

- Genetics
- Innovative diagnostics techniques
- Telemedicine
- Innovative surgery procedures
- Nanotechnology

In this report we will focus on nanotechnology and its application to the medical world (nanomedicine).
Nanotechnology can be defined as the science that deals with the design and construction of machines that are able to manipulate at levels in the order of magnitude of the nanometer, or said in a simpler way, at atomic and molecular level (see graph below).

Nanorobot is the name of a programmable device that operates at nanometric level. Some of them will be designed with the capacity to self-replicate, which is the ability to create an exact copy of itself that will in turn replicate itself, and so on.

Nanotechnology opens up a wide range of possibilities to science; let’s explore some of them:

- **Manufacturing and construction:** By designing and building programmable self-replicating manufacturing systems, we should be able to achieve very low manufacturing and building costs, though the design and development of such systems will be a major task and will likely require many years or decades.

- **Creating new materials:** Manipulating materia at an atomic level will enable us to build new materials with advanced properties. For example, carbon nanotubes (see image) are six times more elastic than steel and are ten times more resistant than the most resistant fibers like Kevlar and spider web.

- **Army:** As programmable devices they are, nanorobots will execute whatever instructions are contained in its code. As a consequence, armamentistic use is one potential yet frightening use of nanotechnology.
(for example, building including nanometric mass-destruction mechanisms that demolish cities while replicating themselves).

- **Computers/IT:** Processing power and storage capacity will virtually explode as size of chips and memory decrease to nanometric level.

- **Environmental cleaning:** Nanorobots will be able to degrade or eliminate contaminants from the air, water, and even restore the ozone hole.

- **Adhesives:** Adding certain particles of nanometric scale to adhesives significantly increases the adhesive efficiency of some materials.

- **Medicine:** Also called nanomedicine, it will provide the means to heal diseases and improve capabilities of the human body. This topic will be explored in detail on the next point.

### 3. Nanotechnology in the medical world (Nanomedicine)

#### 3.1 Introduction

Disease and ill health are caused largely by damage at the molecular and cellular level. Today’s surgical tools are, at this scale, large and crude. From the viewpoint of a cell, even a fine scalpel is a blunt instrument more suited to tear and injure than heal and cure. Modern surgery works only because cells have a remarkable ability to regroup, bury their dead and heal over the injury.

Nanotechnology will let medicine, for the first time, intervene in a sophisticated and controlled way at the cellular and molecular level.

#### 3.2 Description and applications

The typical medical nanodevice will probably be a micron-scale robot assembled from nanoscale parts (three microns is about the maximum size for bloodborne medical nanorobots due to the capillary passage requirement). Carbon will likely be the principal element, probably in the form of diamond because of the tremendous strength and chemical inertness of diamond (it will provoke less response from the immune system).
The typical nanomedical treatment (e.g. to combat a bacterial or viral infection) will consist of an injection of perhaps a few cubic centimeters of micron-sized nanorobots suspended in fluid administered by the doctor. The typical therapeutic dose may include up to 10 trillion individual nanorobots. Nanorobots will be removed from the body once they have finished their job, either through human excretory channels or by excision by medical personnel.

The nanorobots will do exactly what they are programmed to, and nothing more (side effects and symptoms such as fever and itching have specific biochemical causes which can also be managed, reduced, and eliminated using the appropriate injected nanorobots).

Let’s explore some of the particular applications that nanotechnology can provide to medicine:

- **Developing artificial biological matter**: cells, tissues, organs, and blood substitutes

- **Tissue repairing and strengthening**: Repairing will be applicable to damaged tissue arising from diseases, accidents and cryogeny. On the other hand, strengthening can make human bones or muscles more resistant.

- **Drug delivery systems**: Implementing inside the human body devices that will monitor the state and deliver drugs when needed directly on the appropriate organ (see image beside), will relieve some patients from the dependency of self-administering drugs, for example, diabetics with insulin.

- **Genetics**: Manipulating DNA chains opens new opportunities to combat hereditary diseases and improve the performance of the human.

- **Killing cancer cells**: We could design a small device able to identify and kill cancer cells. The device would have a small computer, several binding sites to determine the concentration of specific molecules, and a supply of some poison which could be selectively released and was able to kill a cell identified as cancerous. The device would circulate freely throughout the body, and would periodically sample its environment by determining whether the binding sites were or were not occupied.
• **Providing oxygen:** The nanorobot in this case is essentially a tiny pressure tank that can be pumped full of up to 9 billion oxygen and carbon dioxide molecules, stored onboard at pressures up to about 1,000 atmospheres. Later on, these gases can be released from the tiny tank in a controlled manner. When the nanorobot passes through the lung capillaries, oxygen partial pressure is high and carbon dioxide partial pressure is low, so the onboard computer tells the sorting rotors to load the tanks with oxygen and to dump the carbon dioxide. When the device later finds itself in the oxygen-starved peripheral tissues, the sensor readings are reversed. The nanorobot mimics the action of the natural hemoglobin-filled red blood cells, but it can deliver 236 times more oxygen per unit volume than a natural red cell. You could then hold your breath for nearly 4 hours if sitting quietly at the bottom of a swimming pool. Or if you were sprinting at top speed, you could run for at least 15 minutes before you had to take a breath.

• **Obstructions in the circulatory system:** A nanorobot enters the blood flow, locates the obstruction, and executes the appropriate mechanical action needed to restore the blood flow.

• **Monitoring of the human body:** Autonomous molecular machines, operating in the human body, could monitor levels of different compounds and store that information in internal memory. They could determine both their location and the time. Thus, information could be gathered about changing conditions inside the body. These molecular machines could then be filtered out of the blood supply and the stored information (and samples) could be analyzed.

### 3.3 Current state

No actual working nanorobot has yet been built. Many theoretical designs have been proposed that look good on paper, but these preliminary designs could change significantly after the necessary research, development and testing has been completed.

It is worth noting that if progress in computer hardware continues as the trend lines of the last 50 years suggest, we should have some form of molecular manufacturing in the 2010 to 2020 time frame. After this, the medical applications will require some additional time to develop.

How long it will take to develop these systems depends very much on what we do. If focused efforts to develop molecular manufacturing and its medical applications are pursued, we will have such systems well within our lifetimes.
Nanotechnology is clearly seen today as one of the most promising research areas. As a proof, former US president Bill Clinton announced in January 2000 that it would assign 100 billion dollars to his initiative on nanotechnology, while other European countries and Japan currently dedicate around 70 billion dollars to the same cause.

3.4 Impact on health systems

We can think of nanotechnology as a substitute for conventional medicine and surgery, hence its big impact on the current health system environment, especially because of the shift of power among the different stakeholders. Let’s try to understand the potential future structure health system in detail using the conventional framework.

Patients/ Clients/ Users/ Citizens

New ways to improve medicine in order to heal diseases and improve well-being will definitely be demanded by the final user, if they perceive nanotechnology as a safe and effective manner to heal diseases and improve well-being.

As part of the needed process of research and testing, patients who suffer from diseases and that find no better hope for healing will be key for exhaustive test and approval of nanodevices. Normal citizens will benefit from nanotechnology once it is approved and commercialized on the mass-market.
Science, Research, University

Nanotechnology opens up a big range of possibilities for science and medicine, so we can expect that the spirit of continuous challenge and desire of prestige will surely keep competition for new achievements high, and hence bring nanotechnology applications closer to the final user.

In order to achieve this, research institutions will need sufficient funding, that is expected to come both from public institutions and from private investors.

Supply industry: Pharma/ Biotech/ Tech

If nanotechnology rules out conventional medicine it will mean that instead of drugs, we will have nanorobots. Tech labs will gain terrain over traditional pharmaceutical companies, so we can expect the latter to either jump to this technology or try to block a technology that might drive them out of businesses.

In opposition, high-tech companies will have a new segment of business with promising future in which they will surely invest a big part of their efforts (in other words, they will try to “push” the product to the market”). An example is the company Zyvex, which is considered the first pure nanotechnology solutions provider.

Consulting firms

Consulting firms will find new lines of business: they will help nanotechnology suppliers to produce at lower cost, manage the image of the different companies involved, help on the definition of strategies and allocation of money, and act as a bridge between research institutions and hospitals.

NPOs, NGOs

NPOs and NGOs arise in order to cover lacks of the system and to support certain missions. It can be expected that new NPOs and NGOs arise in order to promote or spread nanotechnology to grounds where it is not as commercially viable or to enforce certain areas that might not be well-covered by the health system.
International institutions

The dramatic changes on medicine that nanotechnology provides will require strong regulation. As of today, two International Institutions seem to be crucial for the evolution of nanotechnology: the FDA and the Foresight Institute.

In the medical world, the FDA could be considered be the organization that will be in charge of deciding which nanodevices are safe, effective and efficient enough to reach the market.

The Foresight Institute is currently operating with the task to spread and coordinate all the knowledge about nanotechnology, and to prepare society for all the changes it will bring. In particular, its primary objective is that nanotechnology, once developed, be used to improve human conditions and not as means of destruction or for doubtful purposes.

Ministry

Ministers will be in charge of the regulation, control and funding of nanotechnological activities, hence their importance for the introduction and evolution of nanotechnology in each of the countries.

Financing institutions

Public institutions will have the difficult task of allocating money to new medical technologies, including nanotechnology. In the end, this means that they will have to derive funds from currently existing areas, which will provoke tensions all along the health system. An optimal allocation of funds will then foster some competition, while achieving the optimal health output (i.e. life expectancy increase).

On the private side, we find donors and the capital markets. Donors, just as the public institutions will have to decide whether to allocate their money on conventional or new technologies. Capital markets will see nanotechnology as a new opportunity to invest in high risk/high return opportunities (today it is clearly considered venture capital).
Health care providers

It is a natural question to wonder the role of doctors, and even if doctors will be necessary if nanotechnology becomes the standard. Nanorobots will be developed by high-tech companies in collaboration with doctors, but patients will treated directly by a mere administrator of nanorobots (and not a doctor as we perceive it today) hence completely changing or eliminating the current doctor-patient relationship.

It can be expected that doctors will completely oppose the adoption of nanotechnology, since they might initially perceive it as unsafe, it will make doctors less necessary, and it might undermine doctors’ prestige in favor or high-technology researchers.

In reference to hospitals, for the administration of nanotechnology there will be no need for plenty of means that hospitals provide (for example, operating rooms). As a consequence, there will be two different types of facilities where interventions take place: traditional hospitals and nanotechnological hospitals. If nanotechnology gains acceptance, it can be expected that the number of the former decrease in favor of the latter.

Summary

As we can see, the balance of power will gradually shift from doctors and pharmaceutical companies to high-tech companies and private ventures. The opposition of doctors and pharmaceutical companies to nanotechnology will delay or even disregard the adoption of this technology, and hence they can be considered the main obstacle for adoption.

Government and International Institutions will act as the referees for this battle, since the regulation and funding they will provide will key for the viability of nanotechnological ventures. Even if private investors allocate huge amounts of money, they will need an approval from Governments and Institutions to commercialize it to the mass-market, and make it worth the investment.

The rest of stakeholders will just adapt to the current state of acceptance of nanotechnology and the directives provided by the Government and other Institutions.
3.5 Risks derived from the use of nanotechnology

- Intentional use of nanotechnology to provoke illness or death. There must be strong regulation of the production of new nanodevices.

- Malfunctioning due to programming; malfunctioning might involve some unexpected interaction that is unlikely to have been exhaustively tested in full-up systems, in advance.

- With new methods to combat diseases, people will live longer, and this might also bring new diseases or side-effects (i.e. more depressions)

- What will humans do when nanorobots perform all tasks without the need of human intervention? What tasks will be left for human-beings? How will this affect society?

4. Conclusions

Nanotechnology opens up a huge range of possibilities for humans. In particular for the medical world, it will help to cure diseases and improve the functionality of the human body.

On the other hand, it will also bring huge risks; as of today, it is still unclear if the potential benefits will outweigh the risks.

Regulation will be key for the adoption of nanotechnology as a safe and effective technology.

There will be other obstacles for its adoption: for example, the resistance of key traditional medicine stakeholders (mainly doctors and pharmaceutical companies) and the initial resistance of customers if it is not perceived as a safe and effective technology.

Though nanotechnology is today at a very early stage, Governments and Institutions should start to think about the possible impact it will have in our everyday life and set some guidelines for the research and regulation of nanotechnology.
5. **Topics deserving further research**

- Advantages and disadvantages of nanotechnology against other innovative medical alternatives
- Real viability of nanotech as an error-free and safe medical technique
- The funding of nanotechnological research: who should do it? how much should be invested? with that amount of funding, when will nanotechnology become a real alternative for medicine?
- Necessary regulation for the adoption of nanotechnology as a safe technique
- Economic impact on the health system if nanotechnology is adopted
- Current perception of doctors about nanotechnology

6. **Links and Bibliography**

- [www.foresight.com](http://www.foresight.com) – Foresight Institute
- [www.nanomedicine.com](http://www.nanomedicine.com) – Source of resources about nanotechnology
- [www.zyvex.com](http://www.zyvex.com) – Zyvex company
- [www.ornl.gov/hgmis/](http://www.ornl.gov/hgmis/) - Human genome project
- [www.merkle.com](http://www.merkle.com) – Webpage of Ralph C. Merkle
- Nanomedicine – Robert A. Freitas
- Nanotechnology and medicine - Ralph C. Merkle
- Exploratory Design in Medical Nanotechnology – Robert A. Freitas