Nanomedicine: how it could reshape clinical practice

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'The development of procedures and devices in medicine generate great hopes for the improvement of the human condition...'

Among the many applications of nanotechnology, some of the most promising, and those likely to be first on the market, are within the biomedical sciences. These applications have the potential to impact directly the very existence of human beings by conquering disease [1] and/or restoring/enhancing their natural abilities. However, the emergence of nanomedicine (Box 1) has many 'disruptive dimensions' [2,3]. In this Editorial, I examine how nanomedicine could potentially transform clinical practice, with a close look at the patient–physician relationship. I argue that some of the traditional components of the patient–physician relationship are likely to be challenged by the increasing use of nanodevices, with regards to diagnosis, prognosis and the choice of treatments.

Before I examine the impact of nanomedicine on clinical practice, however, I provide an overview of the different domains of applications in nanomedicine. In so doing, I demarcate areas that do not challenge established standards of practice versus areas in medicine that are likely to be transformed by nanomedicine.

Applications of nanomedicine

This section aims to provide an overview of the potential uses of nanomedicine in various areas of medicine. These (some already in existence) include:

- New types of drugs, either based on the human genome or structural genomics (e.g., information related to functionality to be translated into protein structures) or biomimetics (e.g., the use of synthetic molecule/copy of the functional elements of a protein);
- Targeted drug delivery (i.e., bioavailability);
- Nanoscale biostructures, which include artificial bones, tissue engineering and cell therapy;
- Nanobots – nanomaterials;

- Various types of devices, for example, neuron–digital interfaces. These nanodevices should enable the interaction between computers and the nervous system.

Based on these applications, we can establish five categories (Box 2). Although only two (implantable devices and diagnostic tools) are really relevant to my analysis, a closer look at each category will help us see the enabling dimension of nanomedicine.

Biopharmaceutics

The first area of application is drug delivery, that is, the optimization of drug delivery. New technologies should influence the rate of absorption, distribution, metabolism and excretion of a drug in the human body [4]. Nanotechnology could offer new delivery solutions in two areas: drug encapsulation and functional drug carriers. The advantage of using encapsulation materials at the nanoscale is that they present better solutions for the delivery of certain drugs. Functional drug carriers are another type of drug delivery that uses nanomaterials to carry drugs to a particular location in the human body. For instance, certain nanostructures (fullerenes/buckyballs, dendrimers and nanoshells) can be used to target specific cells and subsequently release the payload as they enter the cells (cells can absorb materials that are <100 nm, hence the importance of developing nanoproducts).

Implantable materials

The possibility of repairing and replacing human tissues is another remarkable application of nanotechnology in the biomedical sciences. Scientists are developing a new generation of nanoscale biostructures that should solve some of the problems related to the repair and replacement of tissues in the body (the most common problems are immune rejection and invasive surgery). Nanotechnology offers new biocompatible nanomaterials and coatings that should increase the adhesion, durability and lifespan of implants [4].

Other areas of application of nanoscale biostructures include bone repair, bioresorbable materials and smart materials. In the case of bone repair, calcium phosphate apatite (CPA)

Box 1.

For the sake of clarity, I will define the term nanomedicine as ‘the science and technology of diagnosing, treating and preventing disease and traumatic injury, of relieving pain, and of preserving and improving human health, using molecular tools and molecular knowledge of the human body’ [11].

and hydroxyapatite (HAP), for instance, are two nanoceramic materials that can be used since they have the ability to conform to and bond with bone. Bioresorbable materials have the advantage of having the capacity to disintegrate without human intervention. For instance, these nanomaterials can be used in sutures and orthopedic fixation devices but, more importantly, they could be used as temporary implants, which would avoid subsequent surgery owing to their biodegradable nature [4]. Finally, smart materials are nanomaterials that have the ability to react to the environment (e.g., to temperature). These types of applications are usually considered as methods of restoring or enhancing human performance at the mental level (sensory) and physical level (increase strength or restore mobility).

Implantable devices

When we turn to implantable devices, nanotechnology offers new technologies that enable the monitoring and collection of data in a more efficient way. Nanosized sensors could be used for the monitoring of blood sugar in diabetes. Other applications include the development of sensor microships by NASA to monitor body parameters, such as pulse, temperature and blood glucose.

Devices can also be implanted in the human body for specific medical applications. For instance, very small implantable fluid injection systems can be placed in the body to dispense drug on demand for the treatment of diseases such as cancer. The advantages are the ability to target the tumors to be treated and such devices enable a more optimum dosage of medication. Other applications include implantable heart sensors to monitor the heart's activity and the ability to be used as an implantable defibrillator.

Finally, some nanodevices are being developed to restore vision and correct hearing dysfunctions. These types of devices are built to collect and interpret information and transform

them into electrical signals transferred directly to the nervous system of an individual. Retinal implants use nanodevices to stimulate the functional neurons in the retina electrically. Hearing loss is usually caused by the absence or malfunction of sensory cells in the cochlea (spiral-shaped cavity of the inner ear that contains nerve endings essential for hearing). Cochlear implants function as a substitute for the action of the middle ear, cochlear mechanical motion and sensory cells.

Surgical aids

Another category of nanodevice that could change the practice of medicine is medical nanodevices that would enable greater precision, better monitoring of physiological and biomechanical parameters and safer and potentially less expensive (because they are less invasive) surgical procedures. For instance, a company is developing smart medical instruments (catheters able to measure the blood velocity along a vessel) that use sensors with micro-electromechanical systems (MEMS) technology. Robotic surgical systems are also under development to provide surgeons with unparalleled precision instruments. The great advantage of such technology is that it should provide less-invasive surgical procedures.

‘The miniaturization of diagnostic devices can also be used in the production of high-quality images of abnormal medical conditions, such as tumors, that escape the scrutiny of our current technology.’

Diagnostic tools

Finally, nanotechnology offers new applications in the area of genetic testing. In particular, these innovative solutions can increase speed and accuracy in the process of identifying genes and genetic materials either for treatment-oriented applications or the development of new drugs. Thus far, various new technologies have been developed. They include, for example, the use of gold nanoparticle probes that are coated with chemicals that enable them to stick to and so target genetic materials. Another promising application is the use of nanomaterials as instruments for analysis. This lab-on-the-chip approach could multiply the types of analysis performed because ‘micro and nanofluidic devices ... can

Box 2.

I am indebted to Gordon and Sagman for the summary of the various applications of nanotechnology in the biomedical sciences [4].

integrate mixing, moving, incubation, separation, detection and data processing in a small device' [4].

The miniaturization of diagnostic devices can also be used in the production of high-quality images of abnormal medical conditions, such as tumors, that escape the scrutiny of our current technology. Owing to the location of certain tumors in the human body, their detection is difficult and requires, if found, invasive surgical interventions. Also, research is being performed currently to develop nano-devices, such as miniature video systems contained in a pill that could produce pictures of the entire digestive system. Other applications use nanoprobes to detect cancerous tumors in the brain [4].

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Nanomedicine: transforming clinical practice

The five areas of application outlined in the previous section do not raise novel issues *per se*. Questions of availability, toxicity, regulatory issues and environmental and social impact are also present in other areas of scientific research [5,6]. That being said, there are two issues specific to the use of nanotechnology in the biomedical sciences that require a careful analysis owing to the 'disruptive' dimension of emerging technologies (Box 3). The first concerns the ethical issues raised by enhancement technologies that could transform our understanding of what it means to be human (the human-machine interface) and raise the issue of how to regulate the use of new powerful technologies [7,8]. The second issue is related to how these new technologies could potentially change clinical practice owing to the increased use of technology, such as smart devices. In what follows, I will focus on the latter.

Box 3.

Disruptive in the sense of potentially dislodging 'old technologies and replace them with new products or productions systems' [12]. Here, the concept of 'disruption' is applied to clinical practice and refers to the idea of dislodging traditional ways of practicing medicine (patient-physician relationship).

Reconceptualizing the role of the physician

The role of the physician must be reconceptualized in relation to the traditional components of medical practice but now, possibly, also in relation to 'smart' medical devices. The use of nanobots or sensors that are able to monitor and collect important data concerning bodily functions and possible diseases will transform the clinical encounter to a greater degree. Considering that patients should know how to collect the necessary information concerning their health and how to interpret the data, they will be able to assess their own medical condition and provide their own prediagnosis even more so. For instance, the use of sensors (monitoring and collection of data in conjuncture with new drug-delivery systems) could limit, to a certain extent, the role of the physician as a medical expert. The reason is that patients have become more knowledgeable as to their medical conditions.

Hence, a shift could occur regarding the specific role of the physician in the clinical encounter. Patients might be able to make decisions on their own because new innovative technologies could make it easier to implement certain low-risk treatments. For instance, blood tests and the injection of insulin for people with diabetes can be performed without the intervention of a medical professional. A few decades ago, this was not possible. However, new technology has made this a reality. We can imagine that, in the future, there will be other medical conditions for which patients will be able to treat themselves, assuming that they have the right training. In these instances, however, physicians might not only have the role of explaining and teaching how certain devices work; in addition, physicians might have the role of consultant, rather than a participatory role in the decision-making process of health issues. As such, the traditional model of the patient-physician relationship could be reconfigured.

Rethinking the traditional model of the patient-physician relationship

The second reason for a potential transformation of the practice of medicine is that the ability to monitor one's health could reshape how the clinical encounter takes place.

The traditional model of the patient-physician relationship is based on the assumption that there is an imbalance of expertise and power between the sick and the medical professional. Edmund D Pellegrino and David C Thomasma

formulate five imperatives that characterize the relationship between the physician and the patient [9]:

- The inequality of the medical relationship: the effect of illness on the mental state of the patient creates fear, anxiety and dependence on others (primarily the physician);
- The fiduciary nature of the relationship: trust and confidence as foundational to the patient–physician relationship;
- The moral nature of medical decisions: most medical decisions (diagnosis, prognosis and choice of therapy) are the combination of technical and moral components;
- The nature of medical knowledge: the characteristics of medical knowledge impose certain moral obligations (the care of the sick) on those who possess it and use it;
- The ineradicable moral complicity of the physician: the clinical encounter requires the collaboration of both the patient and the physician.

Here, I argue that these five imperatives preserve, to a certain extent, their relevance even by the introduction of innovative technologies in medical practice. However, I also contend that personalized medicine (i.e., the use of smart devices) will undermine certain aspects of the clinical encounter as conceived by Pellegrino and Thomasma, for at least three specific reasons.

First, the notion that patients are in ‘total dependence’ and are vulnerable because of the inequality of power in the relationship between the physician and the patient must be reassessed in light of the potential use of new technologies and new sources of medical knowledge. The reason is that the power of the physicians and/or medical professionals is related to the type of knowledge they possess. However, presently, patients have access to medical information that reconfigures how patients collaborate with their

physicians (i.e., see MedicineNet.com [101]) (Box 4). It is not unusual to see patients asking for alternative treatments or simply asking for a second (or third) opinion before accepting a particular diagnosis and treatment. But it is certainly the case that not all patients have the willingness to contest the doctor’s diagnosis or simply the ability to understand medical data. However, it is not uncommon to hear patients with no medical education or expertise being able to talk about their medical condition in a well-articulated fashion.

Let me emphasize that the fact that patients have become ‘more knowledgeable’ is not a new phenomenon. However, the use of innovative devices, such as the ones presented here, is likely to even further reconfigure the role of physicians.

‘...the use of diagnostic tools might become an imperative in the mind of patients, which could reinforce the need for a (nano)technocratic medicine even for ‘benign’ medical conditions.’

The second reason why innovative technologies could transform the clinical encounter is related to the type of relationship between the patient and the physician. The fiduciary nature of the clinical encounter is likely to be transformed by the use of ‘smart devices’. Trust is built out of an established relationship between the patient and the physician. In contemporary healthcare, however, it is rare to have the same physician over a long period of time. Consequently, trust cannot be established in the same way as with family doctors owing to the inability to create the bonds necessary for trust to occur. The use of ‘smart devices’ creates yet another alternative for the source of medical information, which could undermine the trust of the patient in the physician’s ability to diagnose a specific medical condition. This is especially true if the diagnosis of the physician is different from the results of diagnostic nanodevices. For example, physicians are not always able to detect cancer in the early stage, despite lab tests, owing to the location of some cancerous tumors. The use of new diagnostic devices might create doubt in the minds of patients as to the ability of physicians to make the right diagnosis appropriately. Therefore, the use of diagnostic tools might become an imperative in the mind of patients, which could reinforce the need for a (nano)technocratic medicine even for ‘benign’ medical conditions. Needless to say, the push for more technology would increase the cost of healthcare even more.

Box 4.

On the website, MedicineNet.com presents itself as ‘an online, healthcare media publishing company. It provides easy-to-read, in-depth, authoritative medical information for consumers via its robust, user-friendly, interactive website. Since 1996, MedicineNet.com has had a highly accomplished, uniquely experienced team of qualified executives in the fields of medicine, healthcare, Internet technology, and business to bring you the most comprehensive, sought after healthcare information anywhere. Nationally recognized, 100% Doctor-Produces by a network of over 70 U.S. Board Certified Physicians, MedicineNet.com is the trusted source for online health and medical information.’

'The danger resides in removing (the good of) the patient as the focal point of medical practice on behalf of technomedical concerns.'

The third point gathers together the last three imperatives, that is, the nature of medical decisions as a combination of technical and moral components, the characteristics of medical knowledge and the moral complicity between the physician and the patient. The use of technology raises moral questions that demand a clear articulation of how to solve them. However, the resolution of technomoral issues is confronted to competing moralities that characterizes our culture. As scientists and engineers continue to develop innovative (and sometimes controversial) devices and technologies, the nature of medical decisions will not be defined necessarily in terms of the good of the patients. The prospective of the development of enhancement technologies will challenge the idea that physicians are stewards of medical knowledge and moral accomplices because the purpose of using these technologies goes beyond therapeutic purposes (i.e., enhancement [10]). In market-oriented medicine, such as in the USA, economic considerations have an important role as to what medical procedures doctors and healthcare professionals agree to perform. Hence, the decisional power lies partially outside the medical profession.

Conclusion

Undeniably, nanotechnology and its applications in the biomedical sciences could provide new opportunities that could change and

improve our way of life. The development of procedures and devices in medicine generate great hopes for the improvement of the human condition (e.g., the curing of diseases and the treatment of various neurological conditions). This Editorial has outlined areas of clinical practice that are likely to be affected by nanomedicine. In particular, I have focused on how the use of 'medical nanodevices' for the diagnosis and treatment of medical conditions has the potential to reconceptualize the role of the physician in the clinical encounter. These devices give patients access to medical data that could diminish patients' vulnerability and thus change how the clinical encounter takes place.

However, these changes in the patient-physician relationship require careful analysis of their impact on the care of patients. Ultimately, the danger is twofold. First, self-reliance (self-care) on the part of patients could result in more health-related harm owing to misdiagnosis, misinterpretation of data or misapplications. Second, the increased use of technology for preventive measures could shift the *telos* of medicine from therapeutic to health enhancement-related considerations – so as to prevent rather than cure or treat medical conditions. The danger resides in removing (the good of) the patient as the focal point of medical practice on behalf of technomedical concerns.

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