Benefits of Nanotechnology in Cardiovascular Surgery—Review of Potential Applications

a report by

Dr Rahul C Shetty

Department of Cardiac Surgery at Quebec Heart Institute, University of Laval Hospital, Canada

Nanotechnology is a area of science that involves working with materials and devices on a nanoscale level. On scalable terms, a nanometer is approximately 1/80,000 of the diameter of a human hair, or 10 times the diameter of a hydrogen atom. Its functions are spread across all areas of sciences including physics, chemistry, and biology. Nanotechnology has grown in leaps and bounds over the last few years—applications of this technology in the field of medicine have been an important spin-off. Many biological structures are at nanometer scale. For example, a quantum dot is approximately the size of a small protein (less than 10nm) and drug-carrying nanostructures are the same size as some viruses (less than 100nm). Applications of nanotechnology for the treatment, diagnosis, monitoring, and control of biological systems has recently been referred to as 'Nanomedicine' by the National Institutes of Health (NIH.

Nanostructures display unique mechanical, electrical, chemical, and optical properties. Understanding and controlling such properties is challenging, but harnessing them will provide exciting new opportunities for research, diagnosis, and therapy of heart, lung, blood, and sleep (HLBS) disorders.[1]

Nanotechnology will offer the tools to explore the frontiers of medical science at a cellular level. It can provide novel techniques in the treatment of a multitude of diseases, including cardiovascular disorders. Richard Feynman, winner of the Nobel Prize in Physics, was a pioneer in area of nanotechnology. In his famous 1959 speech 'There is plenty of room at the bottom,' he emphasized the role of nanotechnology in cardiac sciences and envisioned the potential applications of nanotechnology in cardiovascular medicine.[2]

The tools offered by nanotechnology in medical and cardiac sciences are in the areas of diagnosis, imaging, and tissue engineering. Applying nanotechnology methods has offered insight into the potential benefits of nanotechnology in cardiovascular sciences. Although the benefits of nanotechnology transcend all specialties of medicine, one of the important applications of nanomedicine is in the area of cardiovascular sciences.

Design and Development of Miniature Surgical Instruments

The prevalence of coronary heart disease (CHD) in the US is over 13 million individuals.[3] Surgical treatment is one of the optimum modes of management of these diseases when medical and other interventional methods fail. Traditional surgical procedures involve opening of the chest through the sternum, connecting the patient to a cardiopulmonary bypass machine, and arresting the heart. Various surgical techniques are then performed on the arrested heart. However, these techniques can lead to additional morbidity in that they provoke central nervous system disturbances, as well as gastrointestinal complications in few patients.

These complications multiply in obese patients and also in elderly patients. Minimally invasive cardiac surgery offers hope for patients afflicted with cardiac disease in whom conventional open-heart procedures add considerable morbidity. Nanoscience provides technology to design and develop newer cardiac instruments, which are not only smaller in size but also more effective.

Robotic surgical systems are being developed to provide surgeons with unprecedented control over instruments to offer precision. This is particularly useful for minimally invasive cardiac surgery. Instead of manipulating surgical instruments, surgeons use their fingers to move joystick handles on a control console to maneuver robot arms containing miniature instruments that are inserted into ports in the patient. The surgeon's movements transform large motions on the remote controls into miniature movements on the robot arms, greatly improving mechanical precision and safety.

The other vital application of nanotechnology in relation to medical research and diagnostics are nanorobots. Nanorobots, operating in the human body, could monitor levels of different compounds and record the information in their internal memory. They could be rapidly used in the examination of a given tissue, surveying its biomechanical and histometrical features in greater detail. Just as biotechnology extends the

Rahul C Shetty, MD, works in the Department of Cardiac Surgery at Quebec Heart Institute, University of Laval Hospital, Canada. He also works as a Research Fellow in the Cardiac Surgery Research Department of Hospital Laval. His main research interests include tissue engineering of bioprosthetic heart valve substitutes and the study of bone regulatory proteins associated with the calcification of heart valves. His other research foci are nanotechnology and its napplications in cardiovascular surgery and utilizing virtual reality techniques for the education of future medical professionals. He has written numerous articles about the application of nanotechnology in cardiovascular surgery. He is also the founding member of American Academy of Nanomedicine (AANM) and also a member of the Heart Valve Society of America.

range and efficacy of treatment options available from nanomaterials, the advent of molecular nanotechnology will again enormously expand the effectiveness, comfort, and speed of future medical treatments, while at the same time significantly reducing their risk, cost, and invasiveness.[4]

Nanotechnology in Education for Future Cardiac Surgery Professionals

The considerable rise in cardiovascular diseases such as coronary artery disease and valvular heart disease in developing countries all over the world has also led to an increase in complications such as atrial fibrillation. Minimally invasive surgery offers a better treatment option to these patients when other methods of treatment fail. However, currently there are some limitations to the widespread use of these techniques, including the need for safe and effective training systems. Computer-assisted techniologies such as augmented training can offer a viable option. The benefits of using this system of training is that it offers real-life-like training in a simulated environment with the ability to simulate potential complications.

The development of medical training simulation software has been very slow, but it is steadily emerging. Artificial intelligence-based healthcare information management systems, hospital database management systems, and medical decision support systems, etc., have already been developed, which in various ways assist medical professionals in patient management; however, they lack immersion, haptic feedback, and so on.[5] Despite their increasing popularity, the technology-driven training devices available today are incapable of immersing the trainee in the dynamic, environmental stressors of modern medicine and its demand for the relentless maintenance of intellectual and practical skills. This is where an interactive, 3D game-like simulation would be very effective. The major limitation is the size of the instruments.

Medical training simulation games have the potential to resolve many of the problems that come with traditional training methods. Training with a virtual clinical environment and experimenting with different treatment methods on virtual patients is not only non-life threatening, but also gives the trainee his or her results immediately, as well as giving feedback. This in turn will leads to higher quality healthcare through more experienced staff. Utilising nanotechnology, which helps in the minaturisation of surgical equipment, can have applications in future surgical procedures.[7] These surgeons could be trained by applying nanotechnology-based tools in a virtual environment, similar to those offering flight simulator-based training to airline pilots in aviation industries but at nanolevel, wherein nanosurgery could be performed at a cellular level on myocardium.

The Future of Nanomedicine

Developed nations spend billions of dollars of their healthcare budgets on nanotechnology. The US plans to spend around $3.7 billion on the development of nanoscience and nanotechnology by 2008; Japan plans to spend around $3 billion in the same period; and the EU is planning to spend around $1.7 billion on this emerging technology. Clearly, these countries are taking the gamble on the immense potential benefits.

What about countries such as India and China? China invests about 1.1% of its annual gross domestic product (GDP) on science and technology, India around 1–1.2%, and Brazil around 1.1%. However, for these countries the precise figure for investment in the areas of nanoscience and nanotechnology are not known. Investment in new and emerging technologies by developing countries is negligible, and in the area of nanoscience and nanomedicine it hardly exists.

This gives rise to the paradigm shift wherein developing countries cannot catch up with the pace of development in nanoscience, causing a divide—nanodivide. There is a need to establish centers of research and development in these areas at the earliest stage, before it is too late for them to be part of this journey. Developed countries need to take the initiative in creating centers of excellence, not only in developed countries but also in developing countries around the Asian and African regions. The continued advances in the field of biomedical nanotechnology require the collaboration of research groups in complementary fields. Such collaboration has to be maintained internationally. The successful development and implementation of international collaborations fosters a global perspective on research and creates benefits for mankind in general.

However, nanotechnology in medicine faces enormous technical hurdles in that long delay and numerous failures are inevitable. Caution needs to be taken the interface between nanotechnology and medicine in order to produce immense health benefits to all mankind. Ethical implications in the use of this technology and its impact on medicine should be considered, as it is in only a nascent stage today Current promises offered by the use of this technology will touch all spheres of our life. In future, we need to have a balanced view about the prospects of this technology so that it does not offer us unsubstantiated hope.

Nanoscale science and know-how is growing throughout the world and international interaction is key for bringing alive the benefits of nanotechnology to medicine more quickly.[8] ■

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