Nanotechnologies offer improvements that can be used in active and implantable medical devices such as pacemakers and ICD’s (implantable cardioverter-defibrillator) to offer superior functionality whilst reducing the size of the device and improving biocompatibility. It is already known that the human body may respond differently to nanomaterials than to other materials, thus holding promise for future innovations, improving products, however also introducing potential new risks at the same time. The long term goal is to create implants that merge so well with the human body that rejection is severely reduced, and the implants are as efficient and natural as organs themselves.

With the aging population, the need for optimal performance and safety of medical devices increases. Several challenges will need to be overcome to achieve this.

The Challenge
Rejection of foreign material is an important issue for implants. Any foreign material will be recognized by the immune system and may lead to inflammation or other undesired responses.

The direct interface between the implants and the tissue must be optimized, not only to improve biocompatibility, but also to improve efficacy, especially related to transfer and interpretation of electronic signals. Nanotechnology may be able to assist in enabling both aims. The functionality of pacemakers and ICDs will not only depend on biocompatibility and electronic signalling, but also on the power supply, and durability of the materials directly interacting with the heart.

Background to nano development
Pacemakers and ICDs are examples of products where nanotechnological advances could lead to major improvements. The main research areas include MEMS technology, biocompatibility, interface and power supply. While pacemaker manufacturers may not overtly declare a use of nanotechnology, several publications and private communications illustrate that they are working on some nanotechnology features. Even when nanotechnology has only an incremental impact in the case of pacemakers – it has to be considered as an application. MEMS – including pacemakers – have many characteristics that make them appealing for medical or biological applications including the ability to control their physical and chemical characteristics on the micrometre and nanometre scale. However, medical devices sold in the EU must comply with the EU Active Implantable Medical Devices Directive 90/385/EEC. To fulfil these conditions is challenging. Some interesting solutions from the scientific community are frequently proposed which include, for example, biocompatible diamond-like carbon (DLC) coatings for pacemaker housings, fractal coatings for electrodes, vibration generators based on the piezoelectric effect and biothermal batteries (which convert the body’s own heat into electricity). These developments can be clearly related to nanotechnology advances. However, as such devices must comply with the directive to obtain a CE marking, many are still far from the market.

Impacts
The ageing population is a global issue. Particularly in Europe and Japan the demographic change poses grand challenges. Cardiovascular diseases are prominent and account for approximately 50% of deaths in Europe (according to the World Health Organization more than 4.35 million people die each year in Europe, and over 1.9 million of these are in the European Union). Disorders such as bradycardia, sick sinus syndrome (SSS), atrioventricular blocks (AV Block), and atrial fibrillation are treated with pacemakers. Bradycardia mainly arises from SSS and AV block. Every year 600,000 patients are treated for bradycardia. In the US alone approximately one in 1000 patients suffer from first degree AV Block and three out of 10,000 people from SSS. The incidence of both disorders has risen in recent years. Sudden cardiac death is the cause of 300,000 deaths each year.

The average age for receiving a first pacemaker is 75 years. The use of pacemakers is one of the contributing factors in increased life-expectancy. The adaptation of frequency by Biotronik (termed closed loop stimulation) allows for the heart rate to be adjusted based on the physical and physiological constitution. Young patients and professional athletes in particular benefit from this function.
In addition, the increase in cardiovascular diseases, especially in young people, has led to a growth in the market for cardiovascular devices in which the pacemaker devices constitute an important sector.

**Economic/Industry**

According to BCC Research, the worldwide market for cardiovascular devices which includes pacemakers and defibrillators is predicted to grow from an estimated $84.6 billion in 2010 to about $97.3 billion by 2015, with a compound annual growth rate (CAGR) of 2.8%.

Cardiovascular devices can be divided in three segments: the interventional cardiovascular devices which demonstrate the largest segment, expected to grow from nearly $60 billion in 2008 to $74 billion in 2015 at a 5 year compound annual growth rate (CAGR) of 2.4%. A similar CAGR of 2.6% is predicted for the second segment – diagnostic cardiovascular devices – estimating an increase from $13 billion in 2008 to $16 billion in 2015. The global market for pacemakers will increase to $6.1 billion in 2015, an annual growth rate of 5.4%. The increase in cardiovascular diseases pushes the market not only in Europe and the USA but also in Asia. Figure 1 illustrates the most active institutions in terms of patent applications for pacemakers.

Medtronic is the worldwide leader producing about 50% of the total implanted pacemakers around the world. Other important players are St. Jude Medical, Boston Scientific and Biotronik. Medtronic owns more than 250 manufacturing facilities, sales organizations, research and education centres and administration facilities in 120 countries.

![International Applications](image)

*Figure 1: Leading institutions in terms of patent applications for pacemakers according to WIPO – World Intellectual Property Organization, November 2010*
**Technology readiness levels**

![Technology readiness levels diagram](image)

**Figure 2: TRLs for Nanotechnology related features for pacemakers and ICDs.**

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**Societal Impact on European Citizens**

Implantable medical devices can considerably improve the quality of life. Whether this is cochlear implants to restore some level of hearing, retinal implants for some level of vision. Each can restore some independence to individuals.

With pacemakers and defibrillators, patients can even resume strenuous physical activities (such as sport) as the devices can adapt the heart rate in response to varied respiratory volumes and vibration sensors. Furthermore, there are no longer general complications with other electronic devices and e.g. MRT exploration.

**Challenges**

Implantable medical devices in general, and thus also pacemakers and ICDs must meet the following challenges:

- **Reducing costs**
  Pacemakers and ICDs are already quite popular. However, the prices for these devices are still high. The challenge is to reduce costs while finding a wider acceptance of electronic active implantable medical devices in the wider public.

- **Quality of life**
  Patients who have medical implantable devices are commonly reliant on these devices. This means that there are huge requirements for these devices to protect the quality of life. These devices must be reliable and not interfere ostensibly with everyday life.

- **Battery**
  Further problems are batteries. They must have a long life and minimal size (the battery takes up most of the room in pacemakers and defibrillators). The defibrillators have a second consideration - needing a high voltage in a very short time, which could be further optimised.

**Ethical Concerns**

The European Group on Ethics has analysed ethical questions related to ICT implants in the human body. The main concerns include respect for human dignity and human rights; privacy and surveillance aspects, especially of ICT implants that communicate with the outside world through the internet or other signals; informed consent of patients; fair access to implants; and precaution. There does not appear to be major opposition to pacemakers.

**EHS Aspects**

Health related issues concerning pacemakers and ICDs include the biocompatibility of the used materials and non-invasive methods for device power supply management. Nano-features like coatings could improve biocompatibility. On the other hand, the risk of release of free nanomaterials from the coating should be assessed, as this could lead to undesired side effects. Batteries are embedded inside the device, so the body will normally not be exposed to nanomaterial components of the batteries. Exposure of the environment may occur at the disposal stage. Potential effects should be evaluated and managed.

**EU Competitive Position**

In the first period after the invention of the pacemaker the number of international patent applications rose very slowly. Since the nineties, however the number of patents has increased considerably, particularly in 1996 when the two-chamber pacemakers entered the market (Figure 3). The impact of home-monitoring can also be seen in the more recent patents. The country distribution (Figure 4) illustrates the clear dominance of the USA in terms of patents.
The United States and Europe captured 75% of the business volume in 2008 and dominate the global market for cardiac pacemakers. Europe represents the second largest market for these devices after the United States. A huge growth potential is estimated for the market of Asia-Pacific and Latin America.³

Summary

- The demand for pacemakers and ICDs continues to increase due to an ageing society
- Cost reduction is an important issue to disburden the health care system
- Peacemakers and defibrillators save many lives every year
- 72% of patients with a pacemaker are aged between 70 and 90 years old

Contact information

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