Chapter 1

ADVANCES AND TRENDS IN HEALTHCARE TECHNOLOGY

Stopping Diseases Before They Start

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Abstract: This introductory chapter describes the drivers for recent and future changes in healthcare: (1) socio-economic developments in society (in particular the aging society and the growth of chronic disease), (2) the healthcare politics that these developments induce, and (3) advances in healthcare technology. Three major trends in healthcare technology are singled out: The impact of Moore's Law on medical imaging, molecular medicine, E-health and personal healthcare.

Keywords: Socio-economic developments, the aging society, chronic disease, healthcare politics, medical technology, advances in medical imaging, molecular medicine, E-health, personal healthcare

1. INTRODUCTION

Society today is in overdrive with no sign of braking or even slowing down. Time and speed are the key parameters guiding our path. From the era of the microsecond, we moved into the world of the nanosecond where everything goes so fast that its representation is frozen, it cannot be captured by the human eye. The Czech novelist, Milan Kundera, wrote: "Speed is the new ecstasy that technology has bestowed on man". By ecstasy, he meant a simultaneous state of both imprisonment and freedom. Man is caught in a fragment of time, totally disconnected from his past and his future. Nowadays there is often reference made to 'real time'. Does it mean that time was 'non-real'? The concept of real time first appeared in the mid 1950s, when mention was made of computers. But computers never dealt with real time, they dealt with simulated time in simulated realities. Only

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recently with the fast increase of compute power, can we think of real time compute applications.

In this fast moving world, also healthcare is changing at rapid speed, influenced both by demographics and by advances in technology, mainly in electronics and in molecular biology.

In this introductory chapter we will consider the main socio-economic, political and technological factors influencing healthcare. After this, we will describe three fields of technology that we see as the major ones in healthcare.

2. DRIVERS IMPACTING THE GROWTH OF MEDICAL TECHNOLOGIES

2.1 Socio-economics

The number of people of 65 or over is expected to grow in the USA from 35 million in 2000 to 70 million in 2030 (Figure 1-1). By that time one out of five Americans will be 65 or older[1]. The gap between the average age reached by male and by female is closing. Once 65, the remaining life expectancy for male in the USA in 2000 was 16.3 years, whilst that for female was 19.2 years.

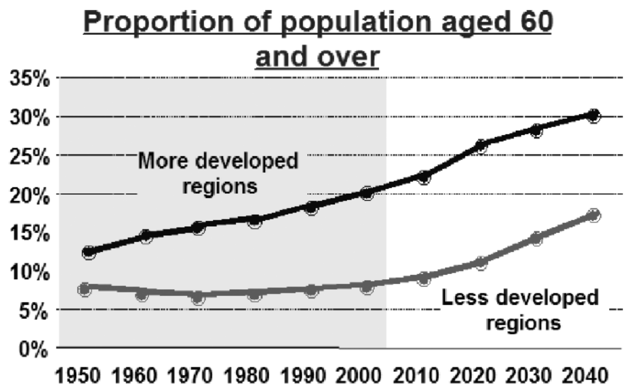

Figure 1-1. Proportion of population aged 60 and over in more and in less developed regions (Source: WHO).

This trend to longer life is mainly due to declines in heart disease and stroke mortality. These have to do with improved medical technology as well as with a healthier life style. Chronic diseases, such a diabetes and high blood pressure, however, are becoming more prevalent among older adults. Also, a considerable proportion of older Americans (about 20%) experience mental disorders. For all developed countries similar trends can be observed[2,3].

The increasing ratio of elderly, often retired, people versus younger people, usually having a job – caused by a combination of longer life and a lower childbirth in the population – puts a great pressure on society. According to a recent study, 60% of healthcare costs are incurred by people of 65 years or older[3]. These developments put pressure on income taxation and other social costs, they put pressure on the level and onset of retirement schemes and – relevant for the present chapter – it puts pressure on the healthcare costs in society.

Healthcare costs show a general increasing trend (in the USA now more than 1.7 trillion dollar/year or more than 15% of GDP, Figure 1-2). Since the mid-1990s healthcare costs in the USA have grown on average by 9%/year[4], the drivers being the above-mentioned aging society with the related phenomenon of long-living individuals with non-lethal chronic diseases, as well as the continuing advances in diagnosis and treatment methods. According to projections by David Cutler[3], healthcare costs will further increase by another 6% of GDP in the coming 30 years, about equally caused by the effects of the aging society and by the introduction of new medical technology.

2.2 Healthcare politics

Although increasing healthcare spending can also be seen as an opportunity for economic growth (more employment in the healthcare system and new opportunities for companies in healthcare technology and services[5]), governments often see it as a threat. This leads to measures to stimulate the efficiency and effectiveness of the healthcare system, whilst (in most countries) trying to preserve the entrance to the healthcare system for all members of the population. It also leads in the healthcare system itself to growing attention for efficiency and effectiveness, leading to concepts like managed care in order to control costs. Also, the tendency to form larger conglomerates of healthcare providers as well as the trend to focus on the core function of the care center (diagnosis and treatment) and to outsource other functions (like the restaurant and hotel function), stem from the drive to more efficiency. This leads to fewer hospital beds, fewer hospitals, conglomerates of hospitals, and transfer of hospitals to for-profit organisations[6].

Another, sometimes opposing trend is that of the self-confident and often well-informed patient. Patients belonging to the more affluent part of the society (including many elderly), when placed in a situation where the government wants to limit access to certain diagnosis or treatment methods, are prepared to use their private resources. In countries like China, this is in many cases anyhow needed to get access to advanced healthcare.

It reminds of the story of the robber directing a pistol at his victim's chest and asking: "your money or your life?" Usually, the choice is easily made. It explains phenomena like 'health tourism' and 'the CT in the shopping mall'. It stimulates the tendency towards privatizations in the healthcare market.

Information on health and disease is abundantly available, in particular through the Internet. Patients thus have the opportunity to better inform themselves, and many do. They may come to their doctor with own ideas and demands on the diagnosis and treatment of their problems.

Governments as well as individuals take prevention more seriously and try to stimulate a healthier life, developing more physical activity for greater fitness and suppressing unhealthy habits like smoking and obesity.

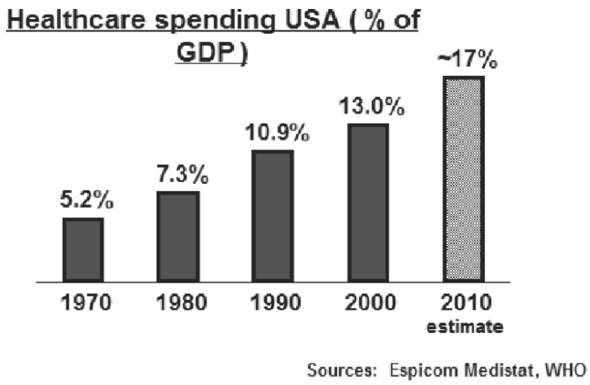

Figure 1-2. Healthcare spending in the USA as a percentage of GDP.

Advances in medicine and medical technology play a dual role in increasing or reducing healthcare costs: They permit better diagnosis and treatment, thus leading to a longer life expectancy and allowing an acceptable quality of life, even for people having one or more chronic diseases. An example is diabetes, where self-analysis and treatment make a long life possible for patients who in earlier times in history or in less developed countries would have died at an early age.

These advances, as we will see later, also help early detection or even prevention of diseases and thus help avoid costs for expensive treatment.

They may also allow more efficient procedures, such as minimal invasive treatment (also reducing the length of hospital stay), faster and more reliable diagnosis by computer-aided detection, and may also enable patients to be monitored at home instead of in the clinic (as in the example of diabetes patients; in the future this will also apply to cardiac patients being able to be monitored at home or underway, whilst nevertheless being in contact with their physician).

Also, modern IT and communication technology has enhanced and will further enhance the efficiency of the healthcare system. It enables much more efficient administrative procedures in the hospital and in the healthcare system at large, it allows much faster access to and interpretation of medical data, and it helps to avoid medical errors. In Germany, in the coming years, a smart card will be introduced for all patients to be used in hospitals, with general practitioners and with pharmacies all over the country, leading to a better integration of and workflow in the healthcare system.

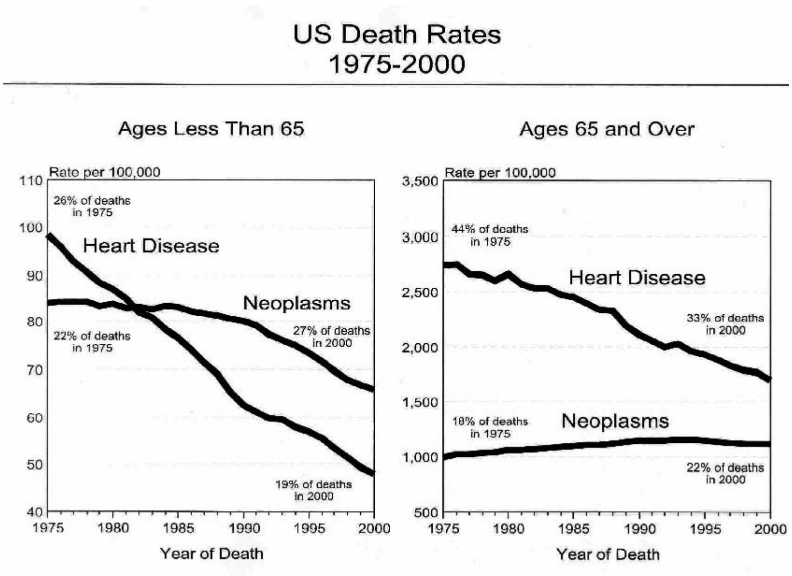

Figure 1-3. Development of death rates in the US over the period 1975-2000 (Source: NCHS public data).

There is a lack of quantitative studies on the net effect of new medical technology on healthcare costs. The fact that the initial effect is spending more money, may lead to sub-optimizations, e.g., by governments limiting investments in advanced diagnostic equipment, thus causing other costs and inconvenience, connected with waiting times for patients, lost economic activity and costs by medical complications due to non-optimal or late diagnosis. It is estimated that in German hospitals alone, there is an ‘investment queue’ for imaging equipment of 15 million Euros. If factors like gaining working hours by longer life and the value of increased life expectancy are taken into account, the effect of the introduction of new medical technology is clearly positive, as Cutler and McClellan[7] have calculated for a number of disease categories like cardiac disease: “around 70% of the survival improvement in heart attack mortality is a result of changes in technology”. History has demonstrated that advances that really help to improve the health of people can never be stopped, only delayed.

2.3 Healthcare technology

In the following sections we will summarize some of the main trends in healthcare technology. There are two key technological drivers for these trends: Ubiquitous electronics and Genomics/Proteomics.

Ubiquitous electronics: mainly enabled by the development in semiconductor technology as described by Moore’s Law, we have seen rapid progress over many years in the miniaturization and digitization of electronics, in low-power electronics, in faster computing with ever smaller computers, in data storage (hard-disk drives, optical storage and semi-conductor memories), in larger and flatter displays, in wireless technologies like mobile telephony and wireless LAN, in sensor technology and in rechargeable batteries. This progress is continuing at unchanged speed. These developments in electronics have enabled progress in medical technologies over a wide field, including real-time 3D imaging with ever higher resolution, image processing and computer-aided detection of clinically relevant data, implantable devices, sensor systems in and on the body, and many more.

Genomics and proteomics: the last decade has seen an explosion of the knowledge on the structure and the functioning of the human body at the cellular and molecular level. A major achievement was the unraveling of the human genome. Our knowledge about the relationship how DNA structures translate into proteins and the action of these proteins in the body is growing daily. How this translation process is related to development and treatment of diseases is extremely complex, and most of understanding this still lies ahead of us. Nevertheless, first successes in using targeted contrast media to image diseases at an early stage, have been achieved (‘molecular medicine’, promise to individualize the detection and treatment of disease.

They may permit measuring predisposition for certain diseases, detection of disease at a very early stage and individual therapy much more effectively than in the generalized approach used today. And even more, molecular medicine may help to develop new pharmaceuticals in a much more efficient way.

2.4 Healthcare in the future

How will medical care look like in a few decades from now? The physician and the hospital concentrate much more on prevention and aftercare, instead of having their focus on the acute phase of medical care ('disease management').

The risk profile of the patient for acute or chronic diseases is assessed on the basis of life style, family history and genetic predisposition; all these data are stored in the electronic patient record (which is accessible to the patient through the internet); the patient carries the essentials of this record with him/her in a smart card with a large memory.

The patient, depending on his/her risk profile, is regularly screened for the possible onset of acute disease or to follow the course of a chronic disease. The patient at home can do part of this screening, if relevant in wireless contact with the physician through a safe and privacy-protected data link.

If the onset of a disease has been detected by molecular diagnosis, the extent and the location of the disease is assessed by molecular imaging using a contrast agent specifically targeted to the disease.

If surgical intervention is needed, this is done using an image-guided minimal-invasive procedure.

Pharmaceutical treatment is individually adapted to the patient in terms of the pharmaceutical and dose chosen, taking into account his/her individual sensitivity to the drug. The dose in which the drug is delivered depends on a feedback system based on continuous measurement of the drug concentration at the targeted site in the body and the effect it has there. If relevant, the drug is only delivered at the site where it is needed ('local drug delivery'), e.g. by focused ultrasound.

If relevant, the patient gets a device implanted that takes over part or whole of the damaged body function. These devices are miniaturized and smart with – helped by their low power consumption – almost infinite battery life. Next to the presently existing smart cardiac pacemakers and defibrillators, there are implantable pumps supporting the heart function, as well as the first generation of complete artificial organs like pancreas, liver and even heart. Neurological diseases, like Alzheimer and Parkinson are kept under control using stable electrodes at the right position, provided with smart electronic signals.

Regenerative medicine and cell therapy have progressed so that parts of the heart that are damaged by heart infarction can be revived.

Personal healthcare systems allow elderly people with chronic disease to stay at home instead of regularly visiting or staying at a care center. Their physician can continuously monitor their health condition and help can be sent immediately when an emergency situation occurs. Similar systems can be employed to measure and improve the fitness of people, young and old, to help preserve their health.

Many examples of the new trends in healthcare technology will be described in subsequent chapters of this book. We would like, however, to set the stage with the three technologies that we consider to be the major ones supporting the drivers mentioned above.

3. IMPACT OF MOORE'S LAW ON MEDICAL IMAGING

"Doubling the compute power of microprocessors every 18 months" as Gordon Moore stated in the early 1970's has a profound impact on every electronic equipment development, and medical imaging systems are no exception. Besides more processing power in integrated circuits, there is availability of higher bandwidth in networks, ever increasing (almost unlimited) storage at lower cost, development of smarter algorithms leveraging the speed increase to provide better and easier understanding of clinical information. The goal of this new technology is to improve the quality of life of the individuals. We need to not only save lives, but at the same time reduce patient discomfort and minimize the number of avoidable medical errors. A study by the Institute of Medicine estimates the number of deaths in the USA due to avoidable medical errors at about 100,000 persons per year.

Improvement in prevention and early diagnosis will have a dramatic impact on cost reduction and number of lives saved. New technologies leveraging Moore's law with the availability of increased compute power will play an important role. Technologies like real time 3D imaging allow for easier and better understanding of anatomical details. As an example, in Figure 1-4, real time 3D ultrasound allows for early detection of heart anomalies, making this affordable technology available to a greater number of users.

Figure 1-4. Real-time 3D ultrasound image of the heart (Philips Medical Systems).

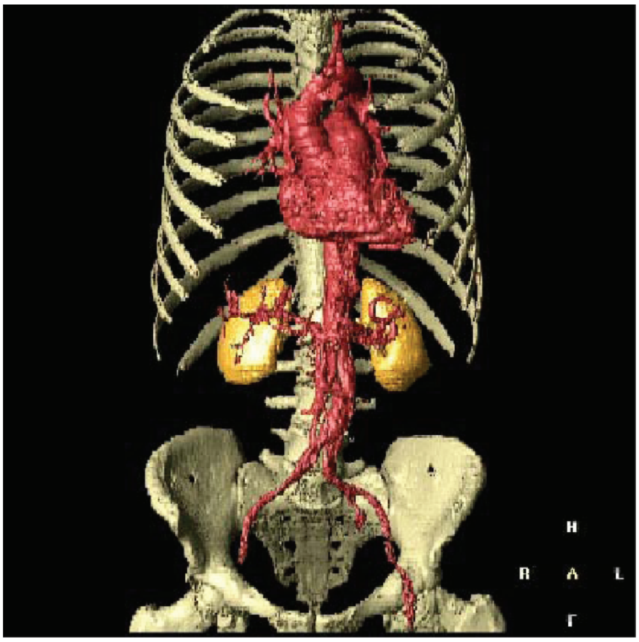

Figure 1-5. 3D CT image (Philips Medical Systems).

Similarly, the on-going revolution in X-ray computed tomography (CT) with faster data acquisition and more detector rows (64 slices) will allow for fast diagnosis where the entire abdomen can be scanned in less that half a minute. One of the major consequences impacting the physician directly related to the acquisition and processing speed, is the overwhelming increase in the amount of data/information he/she has to deal with. Within less than 20 seconds, a complete lung exam takes place with a top of the line CT system. In that time frame more than 2000 images are acquired, images the physician has to analyze. This represents a factor of 10 increase in data volume compared to just a few years ago. The physician is therefore confronted with a new paradigm: the patient spends less and less time for data acquisition and the physician has to spend more and more time in front of an increased volume of data to provide an accurate diagnosis.

This again is where Moore's law finds its way. With increased compute power available, a new generation of support systems is provided to the physician through Computer Aided Detection (CAD) and/or Computer Decision Support Systems (CDSS). These new tools help the user navigate in the huge data set and provide automatic clues for the physician to focus on. Revolutionary 3D visualization techniques allow for virtual inspection of organs like in Figure 1-5.

New techniques like virtual endoscopy greatly improve patient comfort and reduce the threshold for colon cancer.

With faster compute capabilities, medical imaging systems can provide in real time improved spatial and contrast resolution by leveraging signal and image processing techniques. Automatic detection of key features in an image is now becoming a reality. Fusion of data coming from different sources of acquisition plays a role in improving the diagnostic efficacy of the physician.

Another consequence of Moore's law is related to the miniaturization of the equipment. Whilst keeping the level of performance constant, one can today 'shrink' the volume of electronic hardware significantly. There are today in the world about 2 billion cell phones each having the processing power of a mid 1990 personal computer with 100 times less power consumption. Similarly one sees today hand-carried ultrasound imaging systems that have the processing power of a mid 1990 high-end ultrasound system. This opens a new market for imaging systems, increasing the ubiquitous use of them in the clinical environment, creating new applications and opening new markets. This can be viewed as a disruptive technology as it enforces the following paradigm shifts:

- **Price-performance paradigm:** A high-end, high performance system is not necessarily best suited for all types of exams.

- **Application paradigm:** Ubiquitous usage of imaging systems in the clinical environment.
- **User's paradigm:** Less skilled professionals have access to this new tool.

4. MOLECULAR MEDICINE

The deciphering of the human genome and the arrival on the market of new generations of intelligent contrast agents and markers has been the trigger point for the new field of molecular medicine. This new field includes three linked sub-specialties:

- **Molecular imaging:** Leveraging the use of specific contrast agents designed to target expressed biomarkers to disclose the location and extent of the disease at its onset as well as its fate after and during therapy.
- **Molecular diagnostics:** In vitro test of biomarkers (e.g. proteins) that are expressed in body fluid or tissue to be used to diagnose disease even before clinical symptoms of the disease become evident.
- **Molecular therapy:** Gene-based therapies including targeted drug delivery and targeted cancer drugs.

Already today, cancer drugs (drugs that correct the specific genetic flaws that are the biological causes of cancer) have been approved for sale and are available on the market. The patient lobby being very strong, the cost and sometimes lack of efficacy of the treatment have not prevented the FDA from approving the drugs.

The NIH position statement when analyzing the impact of Molecular Medicine has been: Improving the Health of the Nation. This will be achieved in the following manner:

- **Early diagnosis and prevention:** Especially for cardiovascular diseases, cancer and stroke.
- **Better understanding of disease mechanisms:** For example islet beta cell mass in diabetes, detection of inhaled pulmonary pathogens, neuro-psychiatric disorders…
- **Impacting new therapies** like site targeted drug/gene therapy, stem cell imaging and therapy, organ/tissue transplantation.

The challenges to reach the target are multiple. The first one is to speed up the translation process between what has been achieved on animals to the human. This is a specific goal set up by the National Cancer Institute (NCI) in domains as varied as angiogenesis, anti-angiogenesis, apoptosis, atherosclerosis, and stem cell applications. The second challenge is to recognize that such an effort mandates partnership with partners in complementary arenas of expertise: contrast agents, pharmaceuticals, drug delivery, etc. Such partners can be academic medical centers and/or other industrial partners.

Molecular medicine moves us in the direction of predictive medicine. In the future one should be able to assess the genetic predisposition of individuals for a specific disease. Prediction will replace prevention. Furthermore, during treatment, molecular diagnostics should be able to assess very quickly the efficacy of the therapy. Today the availability of targeted contrast agents has been achieved. Such agents have been designed to target fibrin (for example) responsible for the creation of thrombus in vessels, enhancing the imaging contrast and facilitating the visualization of the location and extent of the thrombus.

Such targeted agents can be designed to be the carrier for a drug, delivering therefore the drug in situ. It thus becomes a targeted drug delivery system. Today experiments are conducted on animal models to validate the technique. The dream of the 'silver bullet' is not too far away.

5. E-HEALTH AND PERSONAL HEALTHCARE

Conventional interactions with patients in the healthcare domain require them to be present in the hospital or clinic. However, leveraging strength in semiconductor and consumer electronic domains, it is entirely conceivable to bring monitoring and treatment technologies to the home. As a matter of fact, the miniaturization of electronics we described earlier is key to this approach: the technology moves where the patient is located and not the patient where the technology is located.

Various initiatives have already started in this domain. A key one is the monitoring of CHF (congestive heart failure) patients at home. Simple and easy to use monitoring equipment is placed at the patient's home. The equipment is connected via an available network (a phone line) to a central server in the hospital. The server is monitored by medical professionals (specially trained nurses or paramedics) who react to the data received by either doing nothing, or calling the patient to modify his/her medication regimen, or having a doctor contact the patient or in the worst case sending an ambulance to bring the patient to the hospital. It has been demonstrated by analyzing reports from various implementations of such systems that, in doing so:

- The quality of care is not diminished.
- The patient feels more responsible for his/her own health.
- The cost compared to the traditional visit of the patient to his/her physician is significantly decreased.

In order for such a system to be successful, it requires complete cooperation across the whole healthcare value chain: insurers, hospitals, physicians, and emergency services.

An extension of this approach is to continuously monitor patients at risk through non-invasive sensing and, why not, implantable sensors. In the case of non-invasive sensing, a conceptual approach is to design intelligent clothing/underwear that carries sensors measuring body activity and embedding simple wireless electronic computing the outcome of the measurement and communicating it to the outside world. An example of such clothing is seen in Figure 1-6.

Figure 1-6. Underwear provided with sensors (Philips Research).

An obvious application for such a technology is the monitoring of patients at risk for sudden cardiac arrest. The miniaturized wireless electronics can also incorporate a GPS to help in locating the patient as well as an alarm system triggering the dispatching of an ambulance.

In the future, one can envision implanted sensors in the body, monitoring all kinds of events. Sensors could transmit the outcome of their measurement to each other as well as to some miniaturized central unit located outside the body. A real body LAN is then created.

Besides home blood pressure monitors, the first real therapeutic medical device reaching home in the USA is the Automated External Defibrillator (AED).

Approval for such devices that are crucial to resuscitate patients who have suffered a sudden cardiac arrest event has been granted in the USA in

2005. It is expected to see in the future more and more devices that once were solely used in the hospital environment move into the home.

6. CONCLUSIONS

We have just touched up on some important new trends in healthcare technology. More examples will be highlighted in the rest of the book like minimally invasive procedures, organ replacement, tissue engineering, regenerative medicine, therapy planning, etc. Each of these new technologies is developed to bring more comfort to the patient and improve the efficacy and cost of diagnostics and treatment. Imaging has made a big impact on healthcare over the last decades and will continue to do so. It is important to promote continuous technology development for better and faster diagnosis whilst lowering cost. The future is bright as true molecular medicine is coming in sight.

Reflecting on the introductory comments on time and speed, it is fair to say that for some time is money; however for us in the health domain, time means life.

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