Conclusion

Authors have several resources, including open access journals, open access archives, educational materials, and legal tools, which make open access relatively easy and fully legal to achieve. Although open access has made considerable progress, and more scholarly work is publicly available than ever before, most peer reviewed articles remain closed to both human study and indexing by software. Authors, institutions, funders of research, and scholarly publishers should continue the movement towards open access so that no scholar is disadvantaged by his or her economic status and so that the full value of technological progress can be applied to the scholarly literature.

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Sources and selection criteria: JW formerly worked on the semantic web team at the World Wide Web Consortium and founded and led to acquisition a bioinformatics company with a focus on semantics and data integration for the life sciences. He serves on the advisory board of the US National Library of Medicine's PubMed Central and is a signatory to the Berlin and Budapest declarations on open access.

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Startling technologies promise to transform medicine

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Many writers have dared to look into the future and, far more boldly, commit their vision to print. Readers, especially those graced with hindsight, can then assess the forecast and observe the inevitable inaccuracies. I have been asked to join those ranks and cheerfully accept the challenge of forecasting some startling new technologies that will change the practice of medicine. I will focus on existing technologies that are in various stages of development and on extensions of those technologies. The five areas of technological innovation that I think will change medicine in startling ways are molecular medicine and biometrics, nanotechnology, wave technology, fabricators, and robotics and simulation (box 1). These technologies already have had individual and collective effects on some aspects of medicine and their influence is increasing.[1] Alvin Toffler was correct when he said, "Technology feeds on itself. Technology makes more technology possible."[2] Four brief scenarios illustrate the types of changes I envisage.

Scenarios

John, who is 10 kg overweight, walks through a device that looks like an airport x ray scanner. When he emerges, about 2 kg of fat tissue has been "fried" by a laser.[3] Through the normal purging processes, the fat will be gone from his body in about three days. He repeats the process every two weeks until all the extra weight is gone. No side effects are seen apart from the resizing of his wardrobe.

Box 1 Categories of startling technologies
- Molecular medicine and biometrics
- Nanotechnology
- Wave technology
- Fabricators
- Robotics and simulation

Jane, who has hypertension and diabetes, has a barely visible radio frequency chip implanted just below the skin on her upper arm. This chip simultaneously monitors and transmits data on her heart rate, respiratory rate, blood pressure, and concentrations of blood sugar. The data are received in two places—a remote monitoring station in her general practitioner's office, and an implanted pump that is linked to her circulatory system and to an external reservoir of drugs that can be drawn down as clinically indicated.

Robert needs knee and hip replacements. Data from magnetic resonance imaging and computed tomography scans are fed into a CAD computer program that extrapolates a customised design for the

Box 2 Five startling new technologies

- Instant remote diagnosis and treatment
- Fat zapping
- Customised replacement of body parts
- Remotely activated drug dispensing
- Smart nappies

knee and hip replacements on the basis of his body's actual configuration.[4] The data are then fed into a stereolithographer to produce customised knee and hip parts, which are then implanted. Rather than learning how to manoeuvre with knee and hip parts manufactured for an "average" patient, Robert regains mobility with exact replicas of his original parts.

Judy has macular degeneration; however, her vision is almost normal thanks to miniature telescopes implanted in her eyes. The telescopes are powered by sunlight passing through the pupils to transparent, microscopic solar battery panels attached to her retinas. After several years, the telescopes and batteries are removed and replaced with a genetic patch that turns off the overproduction of blood vessels and restores her normal vision.

Startling technologies

What is a startling technology? Two technologies patented around the turn of the 20th century would surely qualify—aspirin (patented in 1899) and x ray machines (patented in 1900). Immunisations and antibiotics, which came into widespread use by the 1950s, would also qualify. Now, at the end of 2006, the four scenarios above illustrate potential clinical applications of technologies under development (box 2) in five key areas.

Molecular medicine and biometrics

Biometrics encompasses a broad range of approaches to measuring the anatomical and physiological characteristics of the human body. The wide variety of laboratory analyses used in medical practice and forensic medicine are familiar to professionals and increasingly so to the public, thanks to the recent number of television series based on them. A more accurate assessment of the physiological and anatomical status and functioning of individual patients will be possible with extension of traditional laboratory analysis into molecular medicine (for example, genomics and proteomics).[5] The combination of more accurate analytical processes with faster computation and communication suggests that real time medical intervention, both remotely and at the molecular level, will be possible soon. (See the Diane Sawyer clip in box 3 for a fascinating demonstration of the potential for robust, real time visualisation in cardiovascular medicine.)

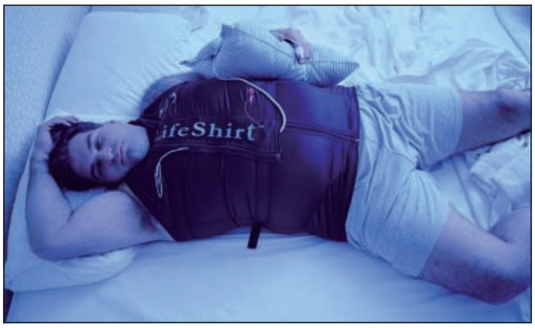
VIVOMETRICS TM

Fig 1 The LifeShirt system is a non-invasive, continuous ambulatory monitoring system that collects data on pulmonary, cardiac, and other physiological data and correlate them over time

Box 3 Web links for some startling technologies

- Diane Sawyer's heart. www.invisionguide.com/index.php?id1=&id2=5
- Stereolithography. www.stereolithography.com/movie
- Dextroscope. www.dextroscope.com/intro.html
- da Vinci. www.intuitivesurgical.com/products/da_vinci_video_overview.aspx
- LifeShirt. www.rnpalm.com/VivoMetrics.htm

Researchers have begun to monitor proteomic differences in human tissue during bacterial and viral pathogenesis.[6] A single drop of blood, urine, or faeces can be analysed to yield data about harmful pathogens, ranging from anthrax to influenza, during the presymptomatic stages of disease. The spread of infectious diseases would be dramatically reduced if people could be diagnosed, isolated, and treated before becoming symptomatic. For example, imagine the impact on the incidence of disease in a group of sailors if they were tested a day before their deployment on a ship. Sailors whose protein expression profile indicated they had a developing but asymptomatic infection would not be deployed until the emerging illnesses were treated and cured. This would dramatically improve their health and would be cost saving for the military health system. A more humorous and daily visible application might be a nappy that is programmed to change colour when common childhood pathogens are detected in the urine or faeces of an infant.

Devices that can sense and transmit heart rates and breathing rates already exist (for example, the LifeShirt; fig 1). Future applications will certainly include both wearable and implanted sensors. These sensors will be programmed to transmit data on variables such as blood sugar concentrations, risk factor substances linked to cardiovascular and cerebrovascular disease, and pathogen biomarkers.[7] A bit further into the future are links to implanted smart storage dispensers that, when signalled, can release clinically needed drugs to stabilise patients. This capability will be especially important to patients with complex combinations of chronic diseases who have a prescribed regimen of drugs.

Nanotechnology

I use nanotechnology here to indicate really small, but not necessarily one billionth of a metre small, technology. Tissue patches for blood vessels and specific organs are being developed (fig 2).[8] Artificial skin is an old example. More recent developments include liver and kidney patches along with artificial veins and wound closure patches.[9-12]

Implantable lenses are well known, but implantable telescopes and batteries are less so. Driven in large part by materials science and commerce, the movement towards extremely small applications is increasingly influencing technological developments in robotics and in the use of light, heat, and radio waves.

Wave technology

Wave technologies include those involving light, heat, and radio waves.[13] We have known for some time about the production of vitamin D and the beneficial effects of light on the relief of seasonal depression. Similarly, applications such as x rays, magnetic resonance imaging, computed tomography, and positron emission tomography scans are well known. What is new is that waves from different parts of the light spectrum are now known to affect different types of cells. Current investigations indicate that cancer cells may be disrupted by bioelectric pulses; that laser pulses of certain types of light wave destroy fat but do not harm other types of cells; and that radio transmitters embedded in implanted sensors can monitor patients with serious chronic disease and activate devices designed to deliver insulin, other drugs, and electric shocks as clinically indicated.[14] The doctor does not need to be in the vicinity or necessarily be aware of the situation for the treatment to begin.

Fabricators

The potential of fabricated tissue has already been mentioned. Other small scale fabrication technologies include manufactured biological bandages and drug delivery systems.[5 15] On a larger scale, stereolithography has the potential to manufacture many types of customised body parts (such as bones and organs) on the basis of data from individual patients and both asynchronous and real time CAD programming.[16]

Robotics and simulation

Nanorobots that can track and destroy pathogens, encircle threatened organs with defensive forces, or clean debris and tartar from teeth and gums are foreseeable. Robots that can carry out surgery more precisely are even more imminent.

We have every reason to believe that the 50 year old trend of miniaturisation will apply here as well. Future manufacturing of customised molecular and cellular structures and nanorobots, probably from biological material derived from individual patient cells, will greatly expand treatment regimens. This is especially applicable to attempts to repair damage and restore function after disease and injury.

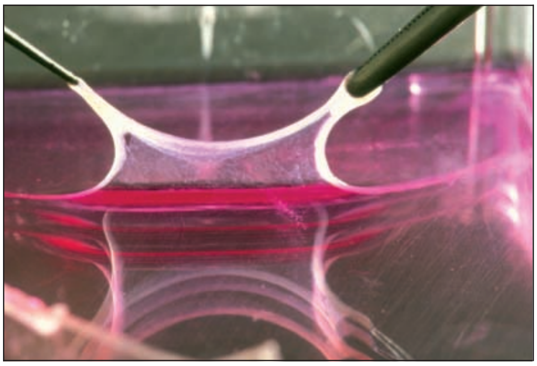
J C REVY/SPL

Fig 2 Skin culture. A layer of artificial human epidermis that has been cultured by seeding epidermal cells on to a small sample of human dermis


MIKE DERER/AP

Fig 3 The da Vinci surgical system, which allows the surgeon to do laparoscopic surgery using robotic arms while looking at a three dimensional image from cameras inserted into the patient

The da Vinci robot, which enables surgeons to carry out open surgery through very small incisions, is just one example of this emerging technology (fig 3). A few examples exist of efforts to extend robotic surgery over distance. In the short term, long distance surgery is likely to be used only by the military. In the long term, however, robotic surgery may prove helpful in providing services to remote populations.

Surgical planning, based on data from magnetic resonance imaging and computed tomography scans, coupled with simulations that project the flow and outcomes of individual surgical interventions, will improve efficency and reduce costs. The use of medical modelling and simulation technologies in medical training programmes will allow procedures to be practised virtually rather than on patients.[17 18] Immersive simulations provide a virtual and thus variable setting (for example, an operating room). The use of such simulations could make medical education as realistic and effective as flight training, during which pilots are thoroughly trained and tested before ever flying a real aircraft.[19] This type of training will be useful for practitioners who need to learn how to use new technologies and for students learning basic cognitive and procedural skills.

Conclusion

The author based his forecasts on 30 years in health care and academic medicine. They are drawn from the scientific literature, conference proceedings, and discussions with medical technologists. Readers who want to extend their exploration of emerging technologies might want to begin by visiting the websites listed in box 3.

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Back to the future: how good are doctors at gazing in the crystal ball?

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Twenty years ago, in a study commissioned by the Bristol-Myers company, 227 of the world's leading clinical scientists were asked to predict the state of medicine in the early 21st century.[1] The success of the 1986 predictions, or lack of it, may tell us the likely value of current attempts to foresee the speed and nature of medical advance: sometimes you have to look back to look forwards.

The scientists interviewed came from 10 countries (13 were from the United Kingdom), but most were based in the United States, so the US is usually the reality against which I test their predictions.

Curing cancer

Back in 1986, all the buzz was in biological response modifiers. We were going to dissect out elements of the immune response, amplify them, and set them to work on tumours with devastating effect. Of course, it came to very little: interleukins, interferons, and even tumour necrosis factor proved sadly ineffective against common solid tumours and were unexpectedly toxic when given in pharmacological doses. In the mid-1980s there was great, if misplaced, faith in these agents. Despite this, future rates of cure were predicted accurately.

The pollsters told the specialists they interviewed that "the average cure rate for cancer patients of all types" was about 50%. They then asked what it would be in the year 2000. Estimates ranged from no change to 90% , with a median of 65%. Currently, the Centers for Disease Control say that the overall five year survival rate for adults diagnosed with cancer in 1997-2002 is 65%.[2]

Of course, surviving five years from diagnosis does not actually equal "cure": screening or improved diagnostics may simply start the survival clock earlier in the course of a disease that will ultimately be fatal. But calculating five year survival rates is standard practice in oncology, so the specialists in 1986 were probably using the "five year equals cure" convention when making their estimates.


MEDIPIC/R STEPNEY

Harvesting bone marrow for transplantation after chemotherapy was one of oncology's "piecemeal" advances

Interviewees were also accurate in distinguishing between tumours for which survival would improve (haematological malignancies and breast, prostate, and ovarian cancers) and those for which it would not (cancers of the lung, liver, stomach, and pancreas, and malignant brain tumours).[3] The only big improvement they missed was in colorectal cancer.

Paradoxically, the specialists interviewed were wide of the mark when asked which treatments would be responsible for this improved outcome. Trastuzumab (Herceptin) and bevacizumab (Avastin) notwithstanding, neither in 2000 nor today is it monoclonal antibodies, "magic bullet" drug-antibody conjugates, or cytokines that are making the difference—nor is it