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Technologies for global health

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Executive summary

Availability of health technology is inversely related to health need. Although health-care systems in high-income countries make extensive use of technology, people in the world's poorest countries often lack the most fundamental drugs and devices. A concerted global effort to encourage the development and use of health technologies that can benefit the poorest people in the world is needed.

Technologies for global health refers to a broad category of interventions that reduce malnutrition, improve sanitation, and increase safety on roads, and they are distinct from health technologies specifically designed to prevent, diagnose, or treat illness, from the highly specific (eg, a vaccine for a particular disease) to the more widely applicable (eg, a blood pressure monitor). The contribution of technologies for health should be acknowledged, and they are considered here, although this report mainly focuses on the narrower category of health technologies.

Technology is often associated with complex devices such as surgical robots, but this report takes a broader view, including less tangible technologies such as clinical guidelines and electronic applications. As an increasingly widespread technology, the potential for mobile telephones to support health (m-Health) are discussed in detail.

For the greatest global health challenges—those targeted in the Millennium Development Goals (MDGs) and the rising burden of non-communicable disease—technology is already making a contribution to meeting global health needs. However, it could have a greater effect on health outcomes in low-income and middle-income countries, where the greatest burden of disease lies. Insufficient resources have been dedicated to the development of so-called frugal technology to meet the needs of the world's poorest people. Even when the necessary technology does exist, it is frequently inaccessible, either because it is too expensive or because of constraints related to distribution, energy supply, or human resources. Efforts should also be made to ensure that technology is acceptable to, and will be adopted by, users.

Decisions to introduce health technologies into resource-poor settings should be evidence based, with careful consideration given to achievement of successful implementation and scale-up, requiring a focus not only on technology but also on associated process innovations that enable effective use. Introduction and use of technology in resource-poor settings raises several issues that need to be addressed. How can technology be ensured to improve rather than damage health? And how should technology be deployed in an equitable, but financially sustainable way? Additionally, greater focus on frugal technology offers truly global promise. Novel technologies are being created in low-income and middle-income countries that might help mitigate escalating health-care costs in high-income countries.

This report also sets out recommendations. Some of these recommendations are for specific organisations or health needs. Five are overarching. First, increased funding and support are needed to enable the development of more frugal technologies. Second, technology should be combined with other innovations to support effective adoption and implementation—technology should not be considered in isolation from the wider context or health system of a low-income or middle-income country.

Third, we need to think broadly and take a multidisciplinary approach to development and introduction

Key messages

- Technology can improve global health, and includes not only pharmaceuticals, vaccines, and devices, but also advances such as better sanitation and agriculture.
- At present, technology for health focuses on the needs of the wealthy.
- More frugal technology, specifically designed for the world's poorest people, is needed.
- Such technology also has the potential to be a disruptive technology for health care in high-income countries.
- Technology alone is not enough—it needs to be combined with innovations in processes to have the greatest effect.
- Capacity to successfully create and use technology should be part of the post-2015 assessment of global development.

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See Editorial page 447

See Online for a video interview with Peter Howitt

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of new technologies. Most health problems are best addressed by a combination of technologies, some of which are specific to health, such as drugs and medical devices, whereas others have health benefits that arise from use outside of health, such as the internet or irrigation. Fourth, when possible, technology that is already available in resource-poor settings (such as mobile telephones) should be used as a platform for health interventions. Fifth, development needs to be assessed after 2015; the capacity to create and use technology should be a key development measure and a focus for global action.

Introduction

Health care in high-income countries is hugely dependent on technology; for example, in 2007, nearly 27·5 million MRI scans were done in the USA.[1] Health technology affects all aspects of health care, from computerised records in primary care to robotic surgery in a tertiary hospital. Dependence on technology is set to grow—in England nearly 30 000 radiotherapy fractions per 1 000 000 people were delivered in 2005, but this number could almost double, to 54 000 fractions per 1 000 000 people, by 2016.[2] Health technology has provided new treatment possibilities in high-income countries—for example, stroke care has been transformed through a combination of CT scanning and the use of thrombolytic drugs to treat acute ischaemic strokes, thereby reducing death and long-term disability in affected groups.[3]

However, many of these new treatments and technologies are not readily accessible to the world's poorest people. In 2008, 2·47 billion people lived on the equivalent of less than US$2 a day,[4] and these people live in low-income and middle-income countries with often little access to technology for health. For example, although antiretroviral therapy is available to all those in the UK who need it, only 14% of those in the Democratic Republic of Congo who need such drugs receive them.[5] The latest medical devices are scarce in low-income and middle-income countries—Japan has almost 90 times as many MRI scanners per head as has India[6]—and their use might be restricted to a wealthy elite who can afford to pay for health care.

This report explores how health technology can be of benefit worldwide rather than just to those who live in high-income countries. It puts into context what is meant by technology for global health and discusses the contribution of technology to the greatest global health challenges. The Commission explores some of the obstacles to use of technology to improve the health of poor people worldwide, and outlines key actions that can help with scale-up of access to technologies for health. The report concludes with some practical proposals, including specific recommendations for groups such as ministries of health of low-income and middle-income countries, the health-care industry, and academia.

What is meant by technology for health?

Technology for health is broader than health technology. For example, technologies for health could increase agricultural output in low-income countries—such as the foot-operated treadle pump—which improves health by reducing hunger and malnutrition. Likewise, technologies that improve road safety—such as motorcycle crash helmets—contribute to public health, but are not classified as health technologies. Such technologies improve health, but they are not usually the main concern of a health system.

By contrast, health technologies are directly focused on health needs. WHO defines health technology as "devices, drugs, medical, and surgical procedures—and the knowledge associated with these—used in the prevention, diagnosis and treatment of disease as well as in rehabilitation, and the organizational and supportive systems within which care is provided".[7] The first two categories of health technology included in the definition—devices and drugs—are material artifacts and the common view of technology is of a physical product.[8] However, this definition of health technologies unnecessarily narrows the notion. Technology also includes important but less tangible elements ("the knowledge associated with these") that are crucial for the operation of health systems. Some of these technologies have a very simple physical form, such as a paper checklist or a clinical guideline on a computer screen. Often interaction between an object and knowledge is necessary—for example, WHO *Guidelines on Hand Hygiene in Health Care*[9] is a source of knowledge that enables effective use of alcohol-based handgels.

One way to view these different types of health technologies is to classify them into six categories: drugs, biological products (including vaccines and cellular therapies), medical devices, medical and surgical procedures, support systems (eg, drug formularies and clinical laboratories), and organisational systems (eg, clinical pathways; figure 1).[10]

At the boundary between technologies for health and health technology is information and communication technology. This category includes television and radio, which are used by more than 75% of people in low-income and middle-income countries and can be the best medium for transmission of health messages. The social enterprise Development Media International believes that such approaches can be very cost effective and are assessing use of radio health campaigns in a randomised controlled trial in Burkina Faso.[11] However, the internet and telephone, which are more interactive, are the focus of the Millennium Development Goal (MDG) 8 subtarget F. The target refers to the need to "make available the benefits of new technologies, especially information and communications" and the indicators focus on measurement of telephone lines, internet users, and mobile telephone subscribers per 100 people. Progress for these indicators has been striking. 90% of the world's population are covered by a mobile

telephone signal, there are 5·3 billion subscribers,[12] and growth rates of use are higher in Africa than in any other continent. Mobile telephones are used for a wide range of functions, such as banking—M-Pesa in Kenya allows users to transfer money via text message.[13] Although internet use is overshadowed by the explosion in mobile telephone ownership, more people in developing countries use the internet than in developed countries.[14]

The internet and the mobile telephone have become key platforms for delivery of health care and are able to run a wide range of programmes and applications that are specific to health. Low-income and middle-income countries could even overtake high-income countries—which have been slow to move away from existing systems and processes—for use of information and communication technology. Information technology for health is used by fewer than 20% of doctors' surgeries in USA, but nearly 60% of Indian hospitals have electronic systems.[15] m-Health—the use of mobile telephones for health—and the potential of individual and population-based health information are discussed in the appendix.

Most health technology is produced by companies from high-income countries for high-income markets, as shown by the market for medical devices; the top 30 companies, which account for 89% of sales revenues, all have their headquarters in high-income countries, 19 of which are in the USA.[16] Their sales overwhelmingly take place in high-income countries—87% of which are in the EU (plus Norway), Japan, and USA.[17] Health technology is therefore mostly designed for an environment with high spending on health, a reliable energy supply, and large numbers of trained health-care professionals.

By contrast, low-income and middle-income countries have little money, underdeveloped infrastructure, and few health-care workers. However, technologies from high-income countries are often deployed in these settings without enough thought of the consequences, and such technologies might rapidly become useless; according to hospital inventories, an estimated 40% of health-care equipment in developing countries is out of service, compared with less than 1% in high-income countries.[18]

Donation of second-hand or surplus devices from hospitals in high-income countries contributes to this excess of unusable technologies. Some low-income countries receive as much as 80% of their medical devices as donations.[16] Although well-intentioned, donations can place a burden on recipients; oxygen concentrators donated to a Gambian tertiary hospital required a voltage incompatible with the electricity supply in that country. Time-consuming attempts were made to find a solution without success.[19] Technology should therefore only be donated when the donor and recipient work together to identify beneficial technology and put in place a process to enable effective deployment of the technology (eg, by including a service contract), adhering to WHO's guidelines to support successful donations.[20]

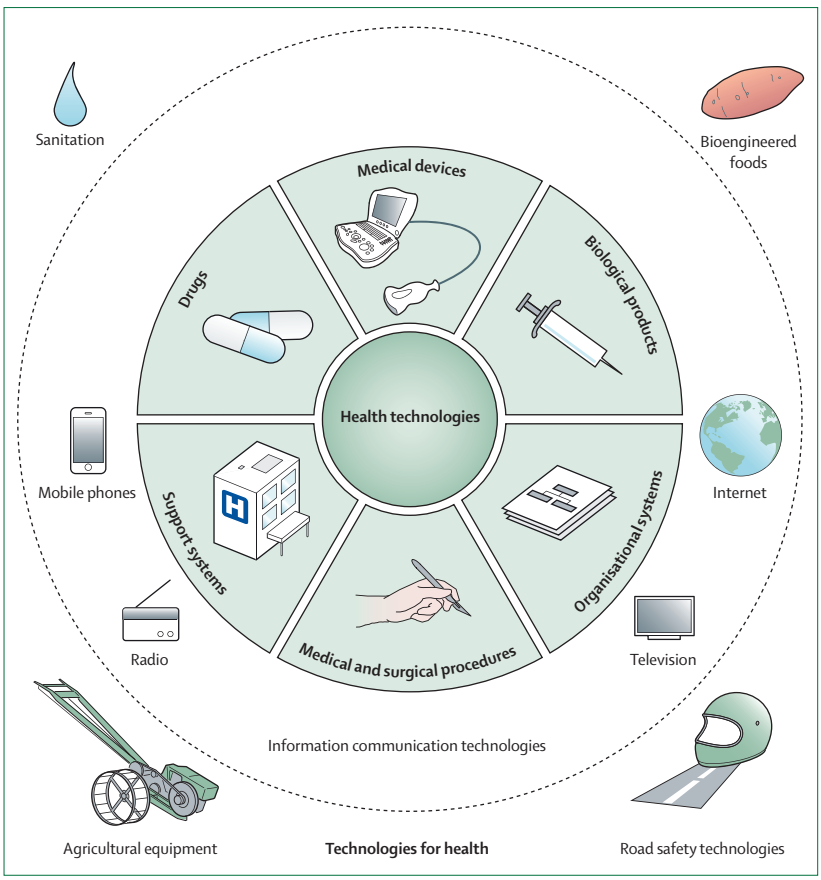


Figure 1: **Overview of technology for global health**

Although carefully considered donations can be beneficial, a better approach for low-income and middle-income countries is to develop more **frugal technologies** that are specifically designed to meet the needs of low-income countries. One of the most famous frugal technologies is the Jaipur foot (panel 1). A list of attributes of such technology has been developed.[23] One of the most important attributes is the involvement of users as co-designers.[24] User involvement can be difficult to achieve in resource-poor settings; for example, a study in Kenya showed that designs often imitated foreign designs or were based on perceived needs, since this approach was cheaper than extensive market and field testing—frugal technology does not necessarily originate from the poorest countries. Indeed, 75% of devices listed in WHO's compendium of technologies that are likely to be suitable for use in low-resource settings originated in high-income countries.[25] One study suggests that the greatest drivers of development of frugal technology will be multinational corporations with operations in emerging markets such as India and China.[26]

Although this report focuses on technology, technology on its own is rarely sufficient to improve health outcomes. Technology needs to be accompanied by innovation to have an effect, which is why frugal innovation is referred

See Online for appendix

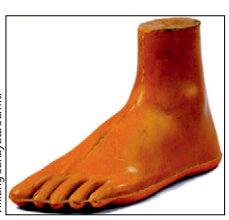
Frugal technologies
Frugal technology is technology that is specifically developed to meet the needs of the world's poorest people.

Panel 1: The Jaipur foot

The Jaipur foot[21,22] is a rubber prosthetic for people who have lost their leg and foot below the knee. It was designed in India in 1968, and was adopted in low-income countries because it has a flexible design that enables walking on uneven surfaces and—unlike prosthetics from high-income countries—can be worn without a shoe.

The Jaipur foot is used in 22 countries (including countries in Asia, Africa, and South America), as well as 19 sites in India. Scale-up has been possible for several reasons. The rubber is locally available and the foot can be mass-produced with commercially available ovens, taking just 1 h to assemble. Additionally, the device is not patented, decreasing the cost of production since no licence fees or royalties need to be paid.

The result is a product with a very low price that is easy to make. The Jaipur foot costs roughly US$40 (2009 prices), compared with $8000–12 000 for the equivalent bespoke prostheses used in high-income countries. However, even $40 is too much for most amputees in India, so the Jaipur foot is distributed for free by the non-profit organisation Bhagwan Mahaveer Viklang Sahayata Samiti, which relies on donations and funding from public and private bodies. This approach is working; Bhagwan Mahaveer Viklang Sahayata Samiti fitted more than 20 181 artificial limbs in 2007–08, making it the world's largest provider of prosthetic limbs.



M K Mathur/Bhagwan Mahaveer Viklang Sahayata Samiti

Jaipur foot

to more commonly than is frugal technology. Health-care innovations are any initiative that takes novel ideas, inventions, or processes and applies them to achieve improved health and greater health equity.[27] Innovation has often been split into two categories—product innovation, relating to new objects, and process innovation, whereby new approaches allow a product to be more effectively implemented and used.[28]

Examples of process innovations include methods to improve business, such as the balanced scorecard and Six Sigma, which are useful for health care, even in developing countries.[29,30] The Narayana Hrudayalaya Hospital in India is famous for its process innovations, which have helped reduce its costs by effective exploitation of technological assets, such as its cardiac catheterisation laboratories, which are used 15–20 times a day, more than five-times the rate in US hospitals.[31]

Process innovation is needed to complement technology for health. For example, new vaccines are only fully effective if a critical mass of the population is vaccinated to achieve herd immunity. Asm Amjad Hossain—a district immunisation medical officer from Bangladesh and the first recipient of the Gates Vaccine Innovation Award—raised immunisation rates in the two districts for which he was responsible from 67% to 85% and 60% to 79% in 1 year. His innovation was to register pregnant women with their expected date of delivery, location, and phone number, so that vaccinators knew when children were born, where they were, and an easy way to contact their mothers. He also made vaccinators easier to contact and publicised vaccination schedules to make them more accountable to the community.[32] Process innovations, which are often simple, are therefore needed to support implementation of frugal technologies.

Global health needs and contribution of technology

Assessment of the contribution of technology to meeting global health needs is not easy. Evidence shows the benefits of health technology in high-income countries,[33] but worldwide and in low-income and middle-income countries the benefits are not well studied. The 1999 World Health Report[34] (taking a very broad view of technology; every advance not related to income or education) suggested that worldwide "half the gains in health between 1952 and 1992 result from access to better technology". Such a broad definition avoids difficult issues such as how to disentangle the importance of a new drug from the necessity of having sufficient health-care workers to ensure that it is effectively used. By looking at the major global health needs this Commission aims to provide an in-depth assessment of where technology does, and does not, play a substantial part in improvement of health.

The MDGs

The MDGs[35] (eight targets that all UN member states agreed to achieve by 2015) include the dominant health problems that have challenged low-income countries in the past few decades. Three of the goals (MDG 4, MDG 5, and MDG 6) are explicitly related to health, whereas the others (especially MDG 1 and MDG 7) have health components. The goals overlap susbtantially, as recognised in a previous Commission,[36] and figure 2 shows the connections between them.

MDG 4 is to reduce the mortality rate of children aged younger than 5 years by two thirds, between 1990 and 2015. Worldwide, between 1990 and 2010, infant mortality fell from 88 to 57 deaths per 1000 infants. This rate means that to achieve this MDG, almost as much improvement is needed in the final 5 years as has been achieved in the previous 20 years. The greatest challenge is in sub-Saharan Africa, where infant mortality has only decreased from 174 to 121 deaths per 1000 infants.[37]

Technology has played a part in reduction of infant mortality. The measles vaccine is a good example. In 2009, almost 80% of children received at least one dose of the vaccine compared with 69% in 2000, and this improved coverage has reduced the number of children dying from measles by 74% from 750 000 deaths in 2000 to 139 300 in 2010. Use of the vaccine has been driven by the 2001 establishment of the Measles Initiative[38]—a partnership led by the American Red Cross, US Centers for Disease Control and Prevention, UN Foundation, UNICEF, and WHO—to coordinate delivery of immunisation in low-income countries. More than a billion children have been vaccinated against measles in the past decade for less than $1 per child (the low cost is principally because the vaccine, first licensed in 1963, is off patent). Measles is now the cause of just 1% of deaths of children younger than 5 years.

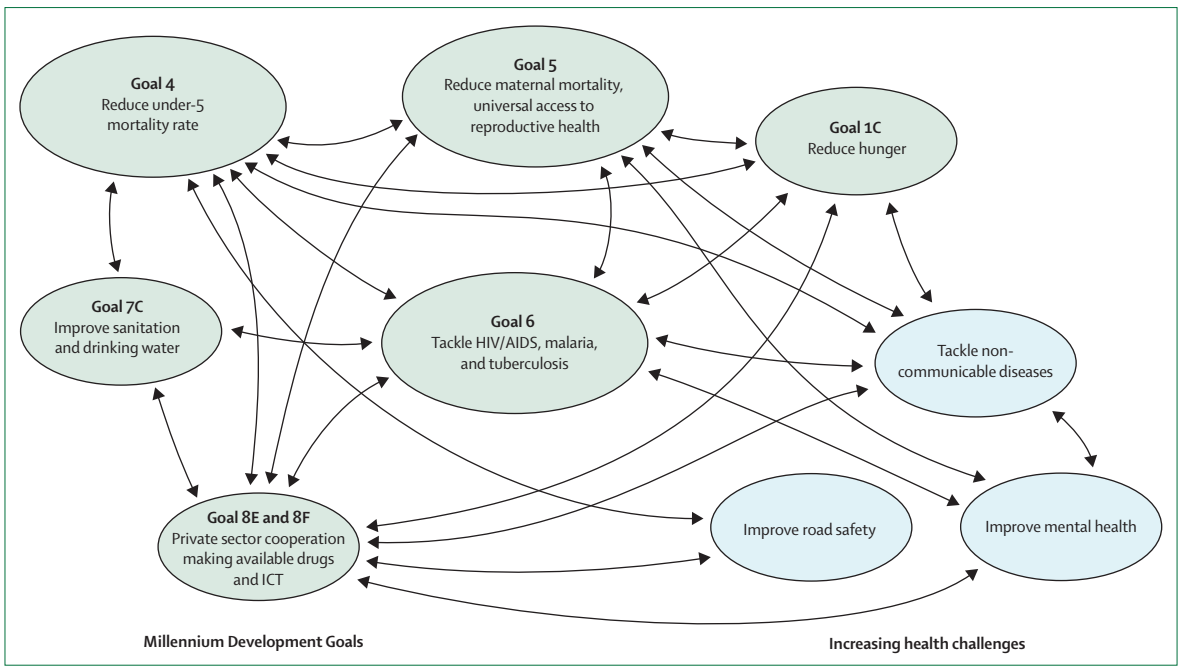


Figure 2: **Connections between Millennium Development Goals and increasing health challenges**
ICT=information and communication technology.

By contrast, malaria, pneumonia, and diarrhoea combined cause more than 40% of deaths of children younger than 5 years worldwide.[39] Tackling malaria will be discussed for MDG 6; here the contribution of technology to the treatment of diarrhoea and pneumonia are discussed. Prevention of some types of pneumonia is possible by vaccination for pneumococcal disease (pneumonia and meningitis caused by bacteria). Additionally, a non-technological solution—exclusive breastfeeding for the first 6 months of an infant's life—reduces the incidence of pneumonia by 15–23%.[40]

Children with very severe or severe pneumonia should usually be treated in hospital, but many low-income and middle-income countries do not have a sufficient number of hospital beds for this strategy. The main treatment for pneumonia is antibiotics, but these are also often unavailable. For example in India, which has the highest number of yearly child deaths from pneumonia, 69% of children with suspected pneumonia are taken to a health-care facility but only 13% receive antibiotics.[41] To tackle this shortfall, the Alliance for the Prudent Use of Antibiotics is working in Uganda and Zimbabwe to understand how antibiotic use could be improved in such countries.[42]

If pneumonia is combined with hypoxaemia, as happens in 13% of cases, children are five-times more likely to die than are those with only pneumonia.[43] Oxygen concentrations should therefore be monitored and oxygen therapy should be made available, but this approach is not always possible. Low-income and middle-income countries need an estimated 1000000 pulse oximeters (because monitoring blood oxygen concentration is important for other areas of health care, such as the use of anaesthetics), and a WHO project has been established to tackle the shortfall.[44] Availability of oxygen concentrators to provide oxygen therapy is also patchy in developing countries because of cost and failure of the devices in challenging environments.

Treatment of diarrhoea in low-income countries has substantially improved because of the availability of oral rehydration therapy. Developed in India and Bangladesh in the 1960s and early 1970s, this therapy uses salts, glucose, and other simple ingredients to replace lost body fluid. WHO advocated the uptake of oral rehydration therapy in 1979, and by 1995 use had risen from close to 0% to 81%. Yearly deaths from diarrhoea fell by 67% from 4·6 million in 1979, to 1·5 million in 1999, and although the contribution of oral rehydration therapy is difficult to quantify, it is probably highly important.[45] Perhaps a result of resistance to transfer of knowledge from resource-poor to resource-rich settings, high-income countries took more than 30 years to adopt regular use of oral rehydration therapy, and persisted in using more expensive, less effective methods, such as intravenous therapy.[46] Although oral rehydration therapy is effective, it depends on the availability of salts and their correct use. An alternative approach is to prevent diarrhoea. One way is through improved sanitation. Another is by vaccination (panel 2).

MDG 5 is to reduce by three quarters the maternal mortality ratio and achieve universal access to reproductive health. Maternal mortality has decreased in developing countries, with deaths falling from 440 per 100000 women in 1990, to 290 per 100000 women in 2008. However, this

Panel 2: A vaccine for rotavirus

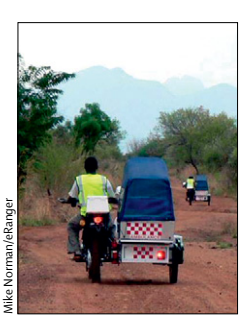
Rotavirus infection accounts for more than 500 000 diarrhoeal deaths per year, mostly (440 000) in children younger than 5 years.[47] Only 20–40 of those deaths take place in USA, yet the first vaccine against rotavirus—RotaShield—was used there in 1998. However, after just 9 months the vaccination programme was stopped after more cases of intussusception (in which part of the intestine folds into another part, causing a block) than expected occurred in vaccinated children. The US Centers for Disease Control and Prevention investigated and withdrew its recommendation that RotaShield be used in vaccination programmes.

The risk of side-effects meant that the vaccine was judged unsuitable for use in the USA and was subsequently not taken up by low-income and middle-income countries, even though the potential health gains (lives saved and hospital admissions avoided) were far higher than those in high-income countries. Frustratingly, subsequent examination of the evidence from the USA shows that intussesception occurred predominantly in children who were given the first vaccination at a late stage (after 3 months; the first dose is recommended to be administered at 2 months).[48]

RotaShield's commercial potential was destroyed by the US investigation. The rights to RotaShield were obtained by the non-profit International Medica Foundation, which has successfully completed a clinical trial in Ghana giving two doses of the vaccine, one soon after birth and the second before the child is aged 60 days. The Foundation has also developed a heat-stable variant of the vaccine, which will not need refrigeration at all times.[49]

Two more rotavirus vaccines, prequalified by WHO, exist—Rotarix and Rotateq—and are being introduced into national immunisation programmes in developing countries. However, since neither product was designed for use in resource-poor settings, limitations exist for both dosing schedule and stability.[50] The manufacturers of Rotarix (GlaxoSmithKline) and Rotateq (Merck) have announced access pricing agreements with the GAVI Alliance that mean that they will sell their vaccines for US$2·50 and $5·00 (falling to $3·50 after 30 million doses), respectively.[51] For Rotarix this price is roughly 5% of its price in high-income countries.[52] The International Medica Foundation hopes to make their RotaShield vaccine available for $1 per dose.

These developments are all positive, but if the original vaccine had been tested first in a resource-poor setting where the problems of diarrhoea are greatest, a 10-year delay in the introduction of a vaccine to where it was most needed might have been avoided, with millions of lives saved.



Mike Norman/eRanger

eRanger ambulance

34% reduction is well short of the 75% set by the MDG, which seems unachievable by 2015.[37] More than a third of all maternal deaths are caused by obstetric haemorrhage during or just after delivery, and a further 8% are caused by sepsis.[39] The best way to combat these causes is to have medical supervision during birth so that conditions such as heavy bleeding can be managed. However, in 2009, in the two regions with the highest proportions of maternal deaths—sub-Saharan Africa and south Asia—only 46% and 50% of all births were attended by skilled health-care professionals.[37] Compared with health-care personnel, the role of technology in helping meet this MDG might seem of little importance, and it is when compared with other MDGs, especially MDG 6. However, effective transport for women in labour can be key for getting such women to a health-care facility (panel 3). Additionally, two drugs can be used to reduce the risk of post-partum haemorrhage. The most effective drug is oxytocin, which is injected into the uterus.[55] However, oxytocin needs to be refrigerated and might not be effective if stored at temperatures higher than 25°C, which is a common ambient temperature in many low-income and middle-income countries. The Oxytocin Consortium is a public–private partnership that was established to address this problem by developing heat-stable oxytocin.[56] Until this aim is achieved, the oral medication misoprostol is a less effective alternative if oxytocin is unavailable and was added to WHO's list of essential medicines in 2011.

A technology being developed that might help reduce maternal mortality is WHO's Safe Childbirth Checklist. Checklists provide a clear and useful way of checking that essential steps in a patient's care are completed and were first used for surgery. Complications after surgery in the eight hospitals included in the pilot study[57] fell from 411 of 3733 patients before to 277 of 3955 patients after and deaths after surgery decreased from 56 of 3733 patients before to 32 of 3955 patients after. Improvements were greatest in hospitals in low-income countries (Tanzania and India). Building on this success, a 29-item Safe Childbirth Checklist has been developed,[58] field tested in ten countries, and piloted in southern India, with highly encouraging results.[59] A large randomised controlled trial is underway in northern India to measure the effect of the programme on maternal, fetal, and newborn survival and results will be reported in 2015.

As for maternal mortality, the goal of universal access to reproductive health services by 2015 seems distant. For example, 25% of women aged 15–49 years in sub-Saharan Africa have an unmet need for family planning (a desire to delay or avoid pregnancy but no form of contraception). This percentage has lessened by just 1% since 1990.[37] Worldwide, progress has been made, with a drop from 14% to 11% in developing regions between 1990 and 2008. One technology that has contributed is longacting, injectable, hormonal contraception.[60] However, re-use of syringes and needles needs to be prevented because of the accompanying risks of transmission of hepatitis C virus, HIV, or other infections. To meet this challenge, the non-profit organisation PATH (Seattle, WA, USA) developed the Uniject injection system.[61] This disposable device consists of a sealed plastic pouch pre-filled with the correct quantity of solution or suspension for a single injection and fitted with a needle with a valve to prevent refilling. The device is simple for lay health workers to use, and eliminates overdosing and transmission of infections between patients. Uniject devices loaded with once a month hormonal contraceptives have been developed by PATH and the Concept Foundation (Thailand).[62,63]

MDG 6 is to have halted by 2015 and begun to reverse the spread of HIV/AIDS and achieve, by 2010, universal access to treatment for HIV/AIDS for all those who need it and have halted by 2015 and begun to reverse the incidence of malaria and other major diseases. In 2009, around 2·6 million people were newly infected with HIV, a 21% reduction in incidence from the peak in 1997. As

with the other MDGs, the greatest HIV burden is in sub-Saharan Africa, which has 69% of the world's new HIV cases and 72% of total deaths caused by HIV/AIDS.[37] Technology's role in reduction of the spread of HIV/AIDS has been small. Increased use of condoms is important, but the problem has not been the supply of condoms but encouraging people to use them. Some developments are promising, such as the Just Milk project[64] to adapt nipple shields to carry medication to help prevent mother-to-child transmission of HIV. A vaccine for HIV/AIDS, the global health holy grail, is still some way off, although 30 candidates are in phase 1 or 2 trials. Because the cost of lifelong treatment with antiretroviral drugs is high (estimated at $7400) even a vaccine with little efficacy and a high cost per dose could still be beneficial.[65]

However, a breakthrough study in 2011 showed that antiretrovirals might be the best solution for prevention, as well as treatment. The study,[66] of 1763 HIV-serodiscordant couples, was stopped before its planned closing date of 2015, because the risk of transmission of HIV from the infected to the non-infected partner fell by 96% if antiretroviral treatment began immediately after diagnosis. Sexual transmission accounts for 80% of HIV infections, so reduction of infection by this route is important. This finding puts an even greater premium on expansion of access to antiretroviral drugs.

With few resources, antiretroviral use has been focused on treatment of the sickest patients. This strategy means that the 2010 universal access MDG was not for all 33·3 million people with HIV/AIDS, but the 14·6 million who WHO defined as benefiting from antiretroviral therapy.[37] For this subpopulation, coverage was 47% at the end of 2010. Access to drugs is growing: almost 6·65 million people in low-income and middle-income countries received antiretroviral therapy in 2010, which is nearly 1·4 million more than in 2009 and the largest ever yearly increase.[5] The increasing availability of treatment has been driven by improved financing and the availability of fixed-dose combinations of antiretroviral drugs (panel 4). Nevertheless, if universal access is to include all people with HIV/AIDS, much more needs to be done, since more than 80% of patients are not receiving treatment.

As with HIV, overall frequency of malaria has decreased, from 233 million cases in 2000, to 216 million cases in 2010. Over the same period deaths from malaria have fallen by more than a third—from nearly 985 000 to 655 000—according to WHO.[73] A more recent estimate suggests more deaths and even greater rate of reduction (from 1·8 million deaths in 2004, to 1·1 million deaths in 2010) with technology playing a key part in this progress, most notably artemisinin-based combination therapies and insecticide-treated bednets.[74] Bednets can reduce deaths from malaria because mosquitoes carrying the *Plasmodium falciparum* parasite are most likely to bite at night, and results of a study[75] show that mortality attributable to malaria decreased by 55% in children younger than 5 years who used a bednet.

Panel 3: The eRanger, a durable rural ambulance

The eRanger ambulance was designed to help meet the need for medical transport in rural Africa. Because of poor roads and few resources, the sophisticated ambulances used in high-income countries are not appropriate. However, transport is desperately needed, particularly to reduce maternal deaths by transporting women with complications during labour to a hospital.

The eRanger ambulance uses a motorbike and stretcher sidecar. The motorbike is a type commonly used in Africa (which means that spare parts are more widely available), modified to work effectively with a stretcher sidecar that can carry one or two people (the patient and, if necessary, a health-care worker).

Use of the eRanger in three rural health centres in Malawi reduced median delays in referral to the district hospital by 2·0–4·5 h (35–76%).[53] The initial cost of the eRanger was 19-times less than that of a four-wheel drive ambulance based at the district hospital. Running costs for the eRanger were also substantially lower than for the car ambulance. The eRanger's fuel consumption is 25–30 km/L versus 5–8 km/L for the average four-wheel drive vehicle. Adjusting for distance travelled, the running costs of the eRanger per km is a quarter of those of the car ambulance. Most importantly, the eRanger has improved health outcomes; a WHO study shows that the eRanger has contributed to a reduction in maternal mortality in Malawi.[54]

Panel 4: Simplification and development of low-cost antiretroviral therapy[67]

Effective treatment of HIV became possible in 1996, with the development of highly active antiretroviral therapy, which delays the onset of AIDS. Within 4 years, deaths from HIV/AIDS had fallen by 84% in high-income countries. However, at a cost of $10 000–15 000 per person per year, such treatment was not affordable for low-income countries and by 2001 only 2% of people with HIV in these countries were able to access antiretroviral drugs.[68] In 2001, generic drug producers developed a triple-dose treatment of stavudine, lamivudine, and nevirapine that cost less than $300 per person per year. Since then costs have continued to fall and are now less than $100 per person per year.

Identification of one fixed-dose combination as a first-line treatment was essential for scale-up of access to antiretroviral therapy by enabling manufacturers to focus production on one regimen. Nurses and health-care assistants have been able to treat patients at rural clinics with this one regimen. The pill is taken twice a day, which is easy to comply with, is suitable for pregnant women, and does not need to be refrigerated.

However, use of the fixed-dose combination has not been without controversy: stavudine has toxic, potentially fatal, side-effects that have almost completely stopped its use in well-resourced programmes. As a result, the widespread use of stavudine, coupled with late initiation of treatment in low-income countries, has led a commentator[69] to compare HIV care in resource-poor settings with the notorious Tuskegee studies in which institutionalised black patients with neurosyphilis were left untreated to enable the natural history of the disease to be described. This claim perhaps over-states the case, and whether scale-up of antiretroviral therapy could have been done without the use of stavudine is contentious. Nonetheless, in 2009, WHO called for stavudine to be replaced with the recommended alternatives zidovudine and tenofovir.[70] This switch is now being implemented, aided by the availability of a new fixed-dose combination of zidovudine, lamivudine, and nevirapine. However, because the two alternative drugs are more expensive than stavudine (in 2010 the lowest priced WHO-approved first-line regimen was $116),[71] this change reduces the resources available for other aspects of HIV treatment and the replacement of stavudine could be regarded[72] as less important than ensuring access to CD4 cell count monitoring and initiation of antiretroviral therapy for people with CD4 cell counts of less than 350 cells per mL.

AFP/Getty Images

Xpert MTB/RIF diagnostic test

Insecticide-treated bednets are estimated to have saved the lives of almost 250 000 infants in sub-Saharan Africa between 2002 and 2008.[76] Distribution of bednets has intensified in recent years, with 290 million nets supplied to sub-Saharan Africa during 2008–10, enough to protect 76% of the population at risk from malaria. Bednets have also become more effective in the past decade since nets are now treated with longlasting insecticide (effective for their 3 year estimated lifespan), whereas those available in 2000 had to be re-sprayed every 6–12 months.[77]

Standard white bednets to prevent malaria are unpopular in some parts of Africa because of their similarity to funeral shrouds used to swathe deceased people,[78] so to encourage their use organisations distributing nets have changed the colour (green is often the default, and investigators in Kenya have noted[79] that green was the preferred colour). The number of people protected by bednets is increasing—for example, in 2009, 64% of children younger than 5 years in Tanzania slept under a bednet, compared with just 2% in 2000.[14]

Artemisinin-based combination therapies use artemisinin or its derivatives in combination with other antimalarial drugs. They are the main treatment for people infected with *P falciparum*. Artemisinin comes from the sweet wormwood plant (*Artemisia annua*), the tea of which has been used as an anti-malarial treatment in China for 2000 years.[80] If used for uncomplicated malaria, artemisinin-based combination therapies are 90% effective with few side-effects.[73] The challenge is to develop cheap methods to manufacture such therapies and ensure that they are used effectively, although innovative financing (with global subsidies) and delivery models (using the private sector) are helping to increase the availability of artemisinin-based combination therapies in low-income and middle-income countries.[81]

Although progress has been made in tackling the health burden of malaria, an effective vaccine would still be an important development, especially since recent progress might be hampered by increased insecticide resistance of mosquitoes and parasite resistance to existing drugs. Results of a phase 3 trial[82] of the RTS,S vaccine (which boosts children's immune systems) in Africa show a roughly 50% reduction in malaria cases in children aged 5–17 months in the year after vaccination. Although encouraging, this decrease is short of the 80% reduction hoped for by the Malaria Vaccine Initiative. The vaccine has not yet been shown to reduce mortality and the trial will not finish until 2014, but WHO have suggested that, if results are positive, the vaccine could be approved for use in 2015.

Tuberculosis has, like malaria, falling incidence and mortality rates. The number of new cases peaked at 142 per 100 000 people in 2004, and has since fallen to 137 per 100 000 people in 2009. China and India account for 35% of all new cases. From 1990 to 2009, worldwide mortality fell by a third, although deaths in sub-Saharan Africa rose from 32 per 100 000 people to 53 per 100 000 people.[37]

Effective treatment of tuberculosis has been driven through increased finance and the widespread adoption of short course directly observed therapy.[83] Technology has a crucial role in this programme through diagnosis by sputum smear microscopy and administration of a short course of antibiotic drugs.[80] However, several challenges remain that need new solutions. Diagnostic tests have been inadequate and although Xpert MTB/RIF (panel 5) has improved the situation, a point-of-care test is still needed. Support of patients to help them comply with antibiotics is important; failure to do so has contributed to the emergence of multidrug-resistant tuberculosis, which is resistant to first-line regimens. New drugs (existing tuberculosis drugs are more than 40 years old) offering shorter treatment durations are needed to tackle multidrug-resistant tuberculosis in eastern Europe, India, and China, and for people with HIV and tuberculosis—80% of whom live in sub-Saharan Africa—if MDG and international targets for tuberculosis and HIV are to be achieved.[88]

Goal 1C is to halve, between 1990 and 2015, the proportion of people who suffer from hunger. Although not strictly a health MDG, malnutrition is clearly an important factor that affects health. For example, malnourished infants are more susceptible to illnesses (such as diarrhoea and pneumonia) and consequently have higher mortality rates than do properly nourished children—malnutrition is estimated to be a contributory factor in more than a third of deaths of children younger than 5 years.[37] This MDG is not expected to be achieved by 2015 because the proportion of people in developing regions who are undernourished has plateaued at 16% in 2005–07, down from 20% in 1990–92.[37]

Technology has provided some solutions to tackling of malnutrition. The green revolution of the 1960s and 1970s combined effective use of agricultural techniques (including pesticides, fertilisers, and irrigation) with use of improved crop varieties, and concentration of production in fertile areas greatly increased food production in Asia and South America. However, sub-Saharan Africa, with small-scale farming and poor land and water resources, did not benefit. As a result, all sub-Saharan countries except Ghana will miss MDG target 1C. Ghana will achieve the target because of the focus of its Government on improvements in agriculture, with almost 10% of the national budget devoted to this aim. This approach has helped to increase output of staple crops such as cassava, production of which trebled from 1989 to 2009.[89]

Aside from such funding commitment, agricultural technology is needed that will provide benefit in the harshest, least productive environments. A good example of such technology is new rices for Africa, which are rice strains that combine disease resistance and drought tolerance of African rice (*Oryza glaberrima*) with the high yields and fast growth of Asian rice (*Oryza sativa*).[80] First introduced in 1996, more than 300 000 hectares of this rice are now grown in west, east, and central Africa.

Dietary deficiencies in low-income countries are not only about too few calories, but also not enough key micronutrients such as vitamin A, iron, and zinc. Such deficiencies can exacerbate health risks. For example, pregnant women with iron and vitamin A deficiencies have high rates of mortality.[80] Biofortification—the development of staple crops that are rich in micronutrients—can provide a solution. A combination of selective breeding and bioengineering enables the creation of crops such as an orange-fleshed sweet potato, rich in β-carotene, which when fed to primary school children increases vitamin A. HarvestPlus (Washington, DC, USA), a joint venture between the International Centre for Tropical Agriculture (Colombia) and the International Food Policy Research Institute (Washington DC, USA), calculate that this sweet potato could be used in Uganda for less than $5 per disability-adjusted life-year saved.[90]

An alternative to crop modification is use of vitamin supplements. Vitamin A supplements distributed by female community health workers have helped to reduce child mortality in Nepal.[91] Some African countries have more than 80% coverage of vitamin A supplementation, although less than 50% of people take supplements in South Africa, Mozambique, and Namibia.[80]

Goal 7C is to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation. As with malnutrition, unsafe drinking water and inadequate sanitation are key determinants of poor health. The target for increasing access to safe drinking water has already been met; as of 2010, 89% of the world's population had access, which is up from 77% in 1990.[92] This proportion is expected to rise to 92% by 2015, although access is still a challenge for poor people living in rural areas. By contrast, improvements in basic sanitation have been disappointing. At current rates of progress the target of 77% of the world's population having access to flushing toilets or other forms of improved sanitation will not be met until 2049.

Technological solutions are needed in several areas. One application is to improve emptying of pit latrines, which restricts their sustainability and safety in low-income and middle-income countries, especially in densely populated areas where space to dig new latrines is scarce.[93] A project led by the London School of Hygiene and Tropical Medicine (UK) is investigating one innovative solution, by using worms (*Eisenia fetida*) to degrade faecal matter and keep latrines functioning for longer.[94] Another challenge is to develop portable sanitation that can be rapidly deployed in disaster zones such as post-earthquake Haiti, where existing sanitation systems have been destroyed and large populations were made homeless for weeks or months. Another need is the development of improved sanitation for areas that have high water tables and are subject to flooding, which could wash stored faecal matter into drinking water sources.

Sanitation has an effect across MDGs—for example, it can help to reduce deaths from diarrhoea in children. When combined with better hygiene practices and improved drinking water it can reduce deaths from diarrhoea by 65%.[95] Sanitation is also needed to complement mass drug administration for control of some neglected tropical diseases (panel 6).

Non-communicable diseases

The MDGs represent the prevailing health problems of the time. In 2004, HIV/AIDS, perinatal conditions, and

Panel 5: Diagnostic tests for tuberculosis

The most common diagnostic test for tuberculosis was sputum microscopy, yet it misses half of all cases and cannot detect drug resistance or diagnose whether a patient has both HIV and tuberculosis. Therefore, an improved simple diagnostic test for tuberculosis is needed, with a 2006 study[84] estimating that a test for active infection could save about 400 000 lives in a year.

In 2010, the Xpert MTB/RIF diagnostic test was launched with endorsement by WHO. This fully automated nucleic acid amplification test provides results in less than 2 h with good sensitivity and specificity, including identification of whether the bacteria are resistant to rifampicin, a first-line drug for tuberculosis, in nearly 98% of cases.[85] However, Xpert MTB/RIF needs a power supply, has operating temperature and humidity restrictions, and uses consumable cartridges. These limitations make the test costly—even with price reductions for low-income countries the instrument price (with associated computer) is US$17 000 and each cartridge costs $14 in 2012.[86] These constraints mean that, as the WHO recognises, although Xpert MTB/RIF "may bring diagnosis closer to patients, it is not a point-of-care assay".[87] A cheaper, truly point-of-care test, which does not require infrastructure, is still needed.

Panel 6: Sanitation and drug delivery interventions to prevent neglected tropical diseases

Neglected tropical diseases are a group of chronic, debilitating conditions that are an obstacle to socioeconomic development and productivity of vulnerable and disadvantaged communities.[96] They have been estimated to cause 534 000 deaths yearly, mainly affecting rural areas in low-income countries.[97]

The transmission of many neglected tropical diseases, such as schistosomiasis, soil-transmitted helminths, and trachoma, is directly associated with poor sanitation and water quality. Much has been done to develop technically effective sanitation for low-income communities, as well as effective ways of ensuring acceptance of these technologies within the community and long-term sustainability. However, the performance of different sanitation technologies for reduction of neglected tropical diseases has not been quantitatively assessed at the community scale. Likewise, operational research and resources have been devoted to development and implementation of drug delivery programmes for such diseases, which have substantially reduced morbidity. However, to completely eliminate neglected tropical diseases in afflicted communities, a combined effort is needed involving drug administration and environmental improvements, such as improved sanitation and hygiene.

Multidisciplinary work at Imperial College London (UK) aims to address these gaps in knowledge through quantitative assessment of neglected tropical diseases and case studies monitoring existing programmes. Epidemiology, sanitation engineering, and broader management of environmental quality are all being considered. The result will be the development of recommendations for policy makers, programme managers, and community leaders to achieve the most cost-effective, sustainable, multidisciplinary control strategies for these diseases. Such multidisciplinary research should be encouraged.

diarrhoeal diseases were all in the top ten causes of disability-adjusted life-years. By 2030 the effect of these conditions will have fallen substantially (figure 3), suggesting that although most of the MDGs will not be achieved in time, substantial progress will have been made.[99] However, other causes of illness will have increased in importance, especially heart disease, chronic obstructive pulmonary disease, and diabetes mellitus.

The greatest health challenge in the future will be the effect of these non-communicable diseases. In 2008, 36 million people died from such diseases, which is 63% of total deaths. Deaths from non-communicable diseases are projected to rise to 52 million by 2030, an increase of more than 40%.[100] Most deaths are of poor people—in 2005, 80% of deaths caused by chronic disease (a category that largely overlaps with non-communicable diseases, although the term is being used less frequently as better health care makes some communicable diseases, such as HIV/AIDS, longlasting) were in low-income and middle-income countries.[101] Poor people are thus set to face a double disease burden of non-communicable diseases alongside communicable diseases.

The challenge of non-communicable diseases is such that the UN General Assembly held a high level meeting in September, 2011, which was only the second such meeting on a health topic in its history (the previous meeting was for HIV/AIDS). The resolution[102] adopted by the General Assembly called for recognition that "the rising prevalence, morbidity and mortality of non-communicable diseases worldwide can be largely prevented and controlled through collective and multisectoral action by all member states and other relevant stakeholders at local, national, regional, and global levels, and by raising the priority accorded to non-communicable diseases in development cooperation by enhancing such cooperation in this regard".

Does technology have a large role in prevention and control of non-communicable diseases? At first, one might think not—technological developments have led to more sedentary lifestyles and (notwithstanding the challenge of MDG 1C) more widespread availability of processed foods high in saturated fat and sugar, which are two of the primary causes of the burden of these diseases. Furthermore, as the resolution makes clear, many measures are designed to change behaviours, such as exercising more and giving up smoking; technology seems to have little to contribute.

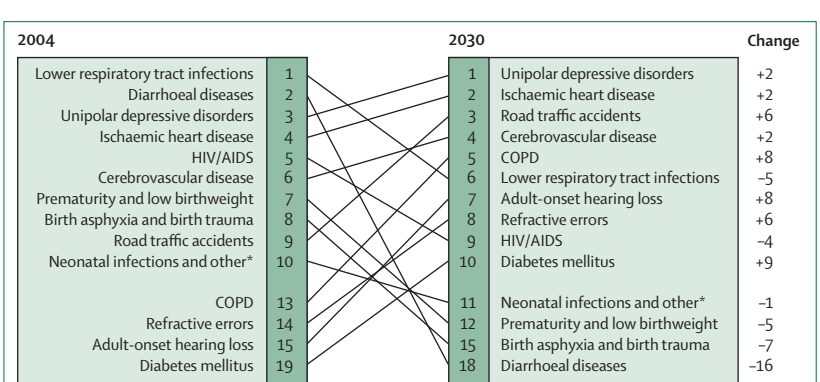


Figure 3: **Projected changes in rankings of leading causes of disability-adjusted life-years 2004–30**
Data taken from WHO.[98] COPD=chronic obstructive pulmonary disorder. *Includes other non-infectious causes arising in the perinatal period, apart from prematurity, low birthweight, birth trauma, and asphyxia.

However, technology can help to support behaviour change. For example, results of a UK study[103] show that cessation of smoking is twice as successful if people receive supportive and encouraging text messages (311 of 2911 people in the intervention group had biochemically verified continuous abstinence from smoking at 6 months *vs* 141 of 2881 people in the control group). By 2030, more than 80% of worldwide deaths from tobacco will occur in low-income and middle-income countries,[104] so aids for smoking cessation are desperately needed. With some adaptation and, if required, translation, text message interventions could easily be trialled in a developing country to test whether this approach is as effective in that setting.

Even in addition to behaviour change, technology does have a role. The UN resolution recognises the need for member states to "contribute to efforts to improve access and affordability for medicines and technologies in the prevention and control of non-communicable diseases". One medicine that could help to reduce the burden of non-communicable diseases is the cardiac polypill (containing aspirin, a β blocker, a statin, and an angiotensin-converting enzyme inhibitor). This polypill has potential to reduce ischaemic heart disease, set to be the second highest cause of disability-adjusted life-years by 2030. As with fixed-dose HIV drugs, combination of multiple active agents in one pill helps to increase compliance. A trial has shown that treatment with this polypill reduces systolic blood pressure and concentration of LDL cholesterol, and could reduce cardiovascular risk by more than 50%, offering substantial benefits to a population at high-risk of cardiovascular disease.[105] The polypill could be the technological element—alongside reduced tobacco consumption, more exercise, and healthy diet—of a four-pronged strategy to reduce the global burden of cardiovascular disease.[106]

As well as the general statement about medicines and technology, the UN resolution also specifically mentions the benefits of technology for vaccinations to control cancer (eg, human papillomavirus vaccine for prevention of cervical cancer and hepatitis C virus vaccine for prevention of liver cancer) and, through comprehensive screening programmes, for detection of cancer at an early stage. In high-income countries, cervical and breast cancer mortality have been reduced by early detection.[107] Cervical cytology screening has not been feasible in low-income and middle-income countries because it needs pathology laboratory infrastructure and multiple follow-up visits.[108] However, a study[109] in rural India shows that human papillomavirus DNA testing reduced mortality

and was more effective than was cytological testing or visual inspection with acetic acid. At the time, such testing was expensive ($20–30) and results were not rapid, but the availability of the cheaper careHPV test—which gives results in less than 3 h—enables scale-up of testing, followed by cryotherapy with CO_2, in a screen-and-treat approach in resource-poor settings.[110,111]

For breast cancer, mammography screening is too expensive and requires skilled staff who are not available in the poorest settings.[112,113] Instead, clinical breast examinations can reduce mortality if basic histology, imaging, and surgery services are made available.[114] To support this approach, capacity for diagnostic ultrasound needs to be improved, as does preparation of histology specimens (either manually or automated) for haematoxylin and eosin staining and immunohistochemistry.[115] Mastectomies will be the most common operations in low-income and middle-income countries, since radiotherapy will usually be unavailable as an adjuvant for breast-conserving surgery.[116]

Road traffic accidents and mental health are gaining prominence. Road traffic accidents are projected to be the third highest cause of disability-adjusted life-years by 2030, with almost twice the disease burden of HIV/AIDS.[98] Yet, road traffic accidents have received little attention from health professionals, and have consequently been described as a neglected epidemic.[117] This disregard has partly changed with the announcement that 2011–20 is the UN decade of action for road safety and the establishment of a worldwide road safety fund.

These initiatives provide the perfect platform for the development of technologies to reduce the likelihood and mitigate the consequences of road traffic accidents in resource-poor settings. More than 90% of deaths from such accidents take place in low-income and middle-income countries despite these countries having only 48% of the world's vehicles.[118] The different profiles of road users in these countries (eg, motorbike use is more frequent and vehicles and pedestrians interact much more in low-income and middle-income countries than in high-income countries) means that approaches to road safety from high-income settings do not transfer easily.[119] Development of appropriate new technologies is needed to reduce both the likelihood and effect of road traffic accidents. One example is the low-technology child restraint car seat discussed in WHO's compendium of new and emerging health technologies.[25]

Although focus on road traffic accidents has increased, mental health still receives scant attention. WHO suggests that there is "no health without mental health".[120] However, 75–85% of people with a mental health disorder in low-income and middle-income countries do not receive treatment.[121] Yet, mental health needs in such settings are substantial; unipolar depressive disorders are projected to be the leading cause of disability-adjusted life-years worldwide by 2030. Suicide was the fourteenth most common cause of death in 2002.

WHO's mhGAP intervention guide for mental, neurological, and substance misuse disorders in non-specialised health settings[122] tries to address the current treatment shortfall by setting out interventions for resource-poor settings. Technology can play a part here—for example, anti-depression medication can be effective if made available. Studies[123] suggest that drug treatment for depression is much the same as antiretroviral treatment for HIV/AIDs or glycaemic control for diabetes as a cost-effective way to reduce disability-adjusted life-years. Treatments based on human interaction are the most challenging to provide in resource-poor settings, but technology could provide solutions through telemedicine counselling or computerised cognitive behavioural therapy. The present evidence for the effect of computerised cognitive behavioural therapy on depression is positive, but not rigourous,[124,125] and has only been done in high-income countries. Therefore, research is warranted into the effectiveness of computerised cognitive behavioural therapy in resource-poor settings.

Such research should consider the issue of different cultural responses to therapy. A study[126] of cognitive behavioural therapy for treatment of mental health problems in Pakistan has shown that this approach has practical drawbacks, such as little consultation time and the difficulties of translation of phrases such as "negative thoughts" into Urdu or other local languages. However, even if these problems can be overcome, major cultural barriers exist for acceptance of use of cognitive behavioural therapy, including poor engagement of the patient with therapy and the belief that mental health problems could be solved by spiritual healers. These cultural issues mean that mental health is an area that could particularly benefit from the development of frugal technology.

Antony Jones/UK Press/Press Association Images

A water pump

Overcoming barriers that prevent technology making a greater contribution to global health

Technology is not a panacea for the world's health problems and does not obviate the need for more health-care professionals, although it can sometimes be a substitute for local expertise (panel 7). Furthermore, technology cannot replace public health campaigns such as improved hygiene practices or encouragement of breastfeeding. However, it could do more. Three fundamental barriers exist to the greater use of technology (figure 4). First, the necessary technology is not available—no vaccine, drug, or medical device exists that is suitable for use in a resource-poor setting. Second, the technology exists, but is not accessible. This barrier is often caused by price, but it could also be because of other reasons, such as problems with distribution, energy supply, or inadequate human resources. Third, issues of acceptability and inertia; technology is not always used, even when accessible. Overcoming these barriers is crucial if the potential of technology for global health is to be realised.

Panel 7: Technology enabling health-care expertise to be shared

Technology can enable remote sharing of expertise from high-income countries. Two examples stand out—telemedicine and the use of virtual reality environments (eg, Second Life). Telemedicine is the use of information and communications technologies to deliver health care at a distance. Asynchronous telemedicine is the sharing of information at different times—for example, a radiograph shared with a specialist who then reviews and sends a response via email. Synchronous telemedicine takes place in real-time—for example, a videoconference between patient and doctor.[127]

Dermatology is making use of telemedicine in high-income countries. The African Teledermatology Project is extending this approach to sub-Saharan Africa; health-care workers take photographs of skin conditions and upload them for later review by an expert in Europe, Australia, or USA. In 2 years from February, 2007, 345 cases were reviewed in the project, which also has a focus on sharing educational material to improve dermatological care.[128]

Effective treatment of cancer requires specialist expertise. Tele-oncology can have a role here, enabling resource-poor settings to draw on expertise from cancer centres in high-income countries if internet access is available.[129] For example, outcomes for acute lymphoblastic leukaemia have improved with the Cure4Kids twinning programmes at St Jude Children's Research Hospital (Memphis, TN, USA), which uses teleconferencing.[130]

Low-cost online virtual reality environments offer the possibility to move beyond offering advice to the creation of interactive training environments. Studies in high-income countries show that virtual environments can provide highly effective, reproducible learning environments at a fraction of the cost of real-world simulations.[131] These principles are now being applied in a project by Imperial College London (UK) to assess the feasibility of training doctors from Malawi. Virtual environments offer the possibility of sustainably transferring skills and building capacity in resource-poor settings as an adjunct to existing training rather than merely offering a substitute from high-income countries.

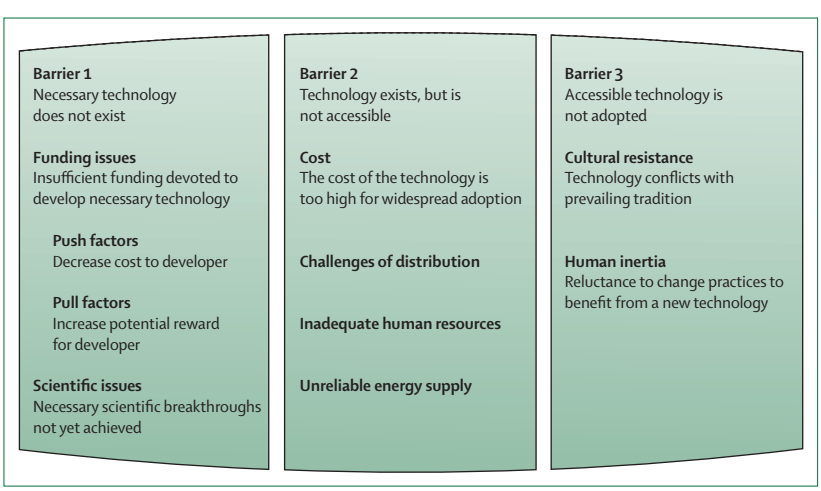


Figure 4: Barriers to greater use of technology for global health

Absence of necessary technology

Necessary technology can be absent because a scientific breakthrough has not yet been achieved. The clearest example of this barrier is a vaccine for HIV. Concerted attempts are being made to develop the necessary technology and no obvious barriers need to be addressed. However, cases of scientific limitation are rare. More common is a dearth of development of technology for low-income and middle-income countries because such countries do not have the resources to pay. Thus, for health problems that mainly affect poor people in developing countries, private sector companies might be reluctant to develop technologies because the return on their investment will be low. This effect is exemplified by the market for new drugs; from 1975 to 2004 only 1·4% of new drugs were designed to combat malaria, tuberculosis, or the most neglected tropical diseases such as Chagas disease or schistosomiasis.[132]

The development of the necessary health technologies should be encouraged. Approaches to do so can be divided into two broad categories: push factors, which reduce costs of research, development, and production to industry, and pull factors, which reduce costs through novel financing approaches and market signals (signs that a market exists for a technology), which create an incentive for the private sector to develop necessary technologies by guaranteeing, or increasing the likelihood, that they will recoup their investment.[133]

The most common push mechanism is the product development partnership, in which funders such as research councils share the costs of research and development with private sector companies. A good example of a product development partnership is the Malaria Vaccine Initiative, which uses funding from the Bill & Melinda Gates Foundation to support partnerships with universities, biotechnology businesses, the US military, and pharmaceutical companies,[134] including partnership with GlaxoSmithKline to share the costs of trials of the RTS,S vaccine. Another innovative university-led product development partnership is the CD4 Initiative (panel 8).

The Grand Challenges in Global Health initiative is another push funding mechanism.[138] The initiative sets a series of challenges, such as development of vaccines that do not need refrigeration or creation of strategies to reduce populations of disease-transmitting insects. Grants are given to researchers contributing to tackling one of these challenges. Other examples of push approaches include funding of research by donor organisations (such as the Drugs for Neglected Diseases Initiative) that is then available to all, or the greater use of patent pooling, making patented technologies available for further development, such as the creation of paediatric or fixed-dose formulations.[139]

Push funding is generally focused on early stage research and development, for which the risks for the private sector are greatest. However, in Africa, push funding could help commercialisation of frugal technologies. A study[140] has identified 25 promising technologies, such as a Ghanaian point-of-care diagnostic test for urinary schistosomiasis. These technologies have not yet been commercialised, principally because of a shortfall of funds to support proof-of-concept studies and development of prototypes. Capital for commercialisation of new technologies should be made available but private companies have been

understandably unwilling to invest in African countries, many of which have a history of poor government, war, and instability. In the absence of private investment, development non-governmental organisations have an opportunity to invest in health technology industries in low-income and middle-income countries.

One inexpensive pull mechanism is to establish and publicise the need for a particular medical technology. For example, a working group established by WHO and the World Federation of Societies of Anaesthesiologists wrote requirements, on the basis of international standards, for oxygen concentrators to be used in resource-poor settings. To meet the specifications, concentrators need to operate at temperatures of up to 43°C, a relative humidity of 90–95%, and altitudes of up to 4000 m above sea level as well as other requirements.[141] WHO also produced reports about the use of machines that meet these specifications, discussing why they were needed.[142] The immediate response was positive: three manufacturers produced devices to WHO specifications that were tested in many countries. However, the long-term effect has been less impressive; when the models were retired a few years later, newer models ignored WHO specifications, perhaps because of the extra cost, or because newer standards were issued by other standards organisations with an aim to target wealthier markets.[143]

Other attempts to specify requirements of a technology have had similarly little success. The World Health Imaging System for Radiography was an initiative of WHO to establish the key performance criteria of a basic radiology system that would be better than no radiology system. However, since the recommendations were released in 1993, fewer than 2000 units have been installed and fewer than 700 are estimated to still be working.[144] This number is less than 1% of the 80 000 radiology systems needed worldwide, according to the estimates of the World Health Imaging, Telemedicine and Informatics Alliance.[145]

In another example, a WHO committee established technical specifications for a blood pressure monitor for low-resource settings. Although such a monitor—the solar-powered Omron HEM-SOLAR—has been developed and should be beneficial, it did not meet WHO's specified performance for measurement of diastolic blood pressure and, most importantly, has a retail price of €25 although the specification was for a price of less than €20.[146]

These examples suggest that specification alone is insufficient; some funding is necessary to encourage development of sustainable, affordable technologies. Engineering World Health have sought to take this approach on a small scale with their Projects that Matter design competition in which successful designs, typically from bioengineering students, can receive $150 to build prototypes.[147] To motivate private sector companies and large research institutions much greater sums are needed, such as the $10 million prizes of the X Prize initiative.[148] The two current X Prizes in life sciences—for rapid genome sequencing and high-end m-Health applications—are not aimed at improvement of health care for people in resource-poor settings, although a prize for point-of-care diagnosis of tuberculosis has been proposed. Another pull mechanism with substantial financial draw is global financing instruments, such as the Global Fund to Fight AIDS, Tuberculosis, and Malaria, which provided large amounts of external financing for new technologies.[149]

An example of a pull mechanism that does not need large donor backing is the priority review voucher issued by the US Food and Drug Administration (FDA) if they approve a drug for a neglected disease, an approach introduced in 2008. Such vouchers, by enabling expedited FDA review, could be worth as much as $300 million if used to secure rapid licensing for a blockbuster drug applicable to high-income settings.[150] The only priority review voucher awarded so far was for a malaria drug that had been on the market outside the USA for several years, so it did not stimulate the drug's development.[134] However, in view of the length of time necessary to develop new drugs, it is too early to assess whether this scheme will stimulate the development of new drugs needed for poor countries.

The most high profile pull mechanism is advanced market commitments. The first such commitment was established in 2006 for a pneumococcal vaccine (pneumococcal disease kills 800 000 children per year), with $1·5 billion funding from Italy, Norway, UK, Canada, Russia, and the Bill & Melinda Gates Foundation. The

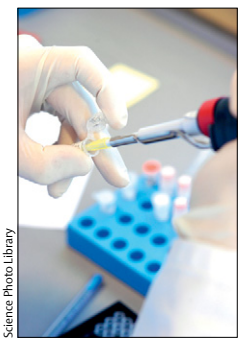
Panel 8: The CD4 Initiative

The best way to decide when to start antiretroviral therapy for HIV/AIDS is by CD4 cell count.[135] When this count falls below a threshold, therapy is started. This approach is current practice in high-income countries where access to diagnostic services is widespread. In low-income and middle-income countries, HIV/AIDS care is largely decentralised to rural health-care clinics, which often have little infrastructure for support and services. Consequently, many diagnostic services, if available at all, are at larger district or general hospitals. Patients must either attend these clinics in person or blood samples are sent to a larger clinic, resulting in a delay of up to 4 weeks. In countries with little or no public transport and a population with no money to access transport, sending blood samples is more common. However, up to half of patients do not return to receive their test results and many other results are lost or delayed. As a result, many patients default from care and often only return when they are very sick and when antiretroviral therapy therapy is least effective. A simple point-of-care CD4 test would provide physicians with instant results for treatment decisions and prevent loss to follow-up.[136]

The CD4 Initiative is developing new point-of-care tests for CD4 cell count that are simple to use, need no electronic instrumentation, are cheap, and deliver results in less than 2 h.[137] The Initiative does not try to modify technology used in high-income settings (eg, by making technology smaller and more portable) but rather to develop a new frugal technology. Test specifications were set after consultation with health-care workers in resource-poor countries and an open call for proposals was established. From an initial group of six academic and private sector partners, one company, Zyomyx (Fremont, CA, USA), has developed a simple CD4 cell count test that provides results in less than 10 min using a fingerprick of blood and without electronic instrumentation. The test is starting field trials in Malawi and Uganda. The CD4 Initiative model could be replicated for other global health priorities that need innovative and sustainable solutions.

Giacomo Pirozzi/Panos

Blood test for HIV



Science Photo Library

Testing for sickle-cell disease

commitment established a set price for any vaccine that met the specified requirements, guaranteeing a future market for vaccine producers and removing much of the risk of product development. Vaccines meeting these requirements have been developed by GlaxoSmithKline (Synflorix) and Pfizer (Prevenar-13), and a vaccination programme has been rolled out worldwide. The Central African Republic, Benin, and Cameroon have benefited most recently.[151]

This first advanced market commitment has sparked debate about the effectiveness of the approach.[152] The choice of pneumonia from the six proposed diseases (the others were cervical cancer, rotavirus, HIV/AIDS, tuberculosis, and malaria) meant that the pilot was for a vaccine that was already well developed.[153] An advanced market commitment for an early-stage vaccine, such as tuberculosis, needs to be tried before a judgment can be made about the potential of these devices for stimulation of research and development for health needs specific to low-income and middle-income countries. The approach could also be tried for a non-vaccine issue. One area for consideration is a rapid and inexpensive test for sickle-cell disease (panel 9).

Inability to access technology

The pneumonia advanced market commitment seems to have been beneficial for overcoming the second barrier to greater use of technology: making technology affordable and accessible to low-income and middle-income countries. Nicaragua—the first country in which the vaccine was rolled out, in December, 2010—had access to the Prevenar-13 vaccine just 10 months after it was approved for use in USA. Generally, 10 years or more are needed before a vaccine approved for use in high-income countries is deployed in resource-poor settings. The advanced market commitment is also very popular in low-income countries, who pay $0·15 per dose, with the GAVI Alliance paying the rest (the price of the vaccine is set at $3·50 per dose, with the advanced market commitment funding a doubling of the price received by the supplier to $7 per dose), and as a result additional funding has been made available by the GAVI Alliance to support rollout.

Panel 9: A test for sickle-cell disease for resource-poor settings

Sickle-cell disease is the most common genetic disorder in Africa. Patients are vulnerable to other diseases and 50–80% of the 400 000 children born in Africa each year with sickle-cell disease die before their fifth birthday.[154] However, if cases are diagnosed and treated, as has happened in Benin, then survival rates improve significantly.[155] Work is ongoing to improve treatment; a study in Tanzania is investigating the use of the chemotherapy drug hydroxycarbamide to reduce anaemia in people with sickle-cell disease.[156]

One of the key challenges is the scarcity of laboratory infrastructure to test for sickle-cell disease in many low-income and middle-income countries. A cheap and rapid diagnostic test is needed that can identify sickle-cell disease in resource-poor settings. The best way to fund research and development of such a test should be considered; a product development partnership might be beneficial, or an advanced market commitment could be tried.

Concerns still exist that advanced market commitments have not provided value for money and that vaccines could have been procured more cheaply by conventional UNICEF tender procedures.[134] Furthermore, how non-GAVI eligible countries (those with an income per head of more than $1500, which includes many middle-income countries) can afford to buy the vaccines is unclear. Nonetheless, by increasing access to the vaccine the advanced market commitment seems to have been successful.

The pneumococcal vaccine project shows that the key to making technology accessible is to make the final price as low as possible. In 2009, total spending on pharmaceuticals in the USA was $956 per person.[1] By contrast, in 2006, expenditure of the 49 lowest income countries on all health care was only $25 per person,[157] necessitating a concerted effort to produce affordable health technologies for low-income and middle-income countries and to address factors that might hinder the design and production of such technologies.

Most patent applications for health technology are from from companies, institutions, and individuals in high-income countries (figure 5). The role of patents in the development and availability of health-care technologies has been much debated, with polarised views in relation to its effect on access to and pricing of innovative treatments. Detailed discussion of intellectual property and patent systems, and their potential benefits and disadvantages, is beyond the scope of this report. Briefly, detractors claim that patents cause beneficial health-care technologies to be too expensive for people in resource-poor countries, thereby reducing access, whereas proponents assert that patents are essential for health technology companies, who will not invest in lengthy research and development programmes without assurance that they will have a period of protection of their intellectual property to recoup their investment. The debate on intellectual property and patents became highly polarised in the 1980s and 1990s, fuelled by the requirements of the World Trade Organization agreed in 1994, that its members (including most low-income and middle-income countries) must abide by agreements for trade-related aspects of intellectual property rights, which require that patents for new inventions be for 20 years from when the patent is filed and cover both processes and products. Before this agreement, many countries excluded sectors such as the pharmaceutical industry from patent protection, provided short-term patents (eg, in India patents lasted 5–7 years), or only had process patents, allowing reverse engineering to create the same product by a different means.[158] The subsequent Doha Declaration in 2001, responded to concerns that trade-related aspects of intellectual property rights could adversely affect public health by clarifying flexibilities, such as the use of compulsory licences by countries, enabling a third party to legally produce patented products to address a national health emergency.

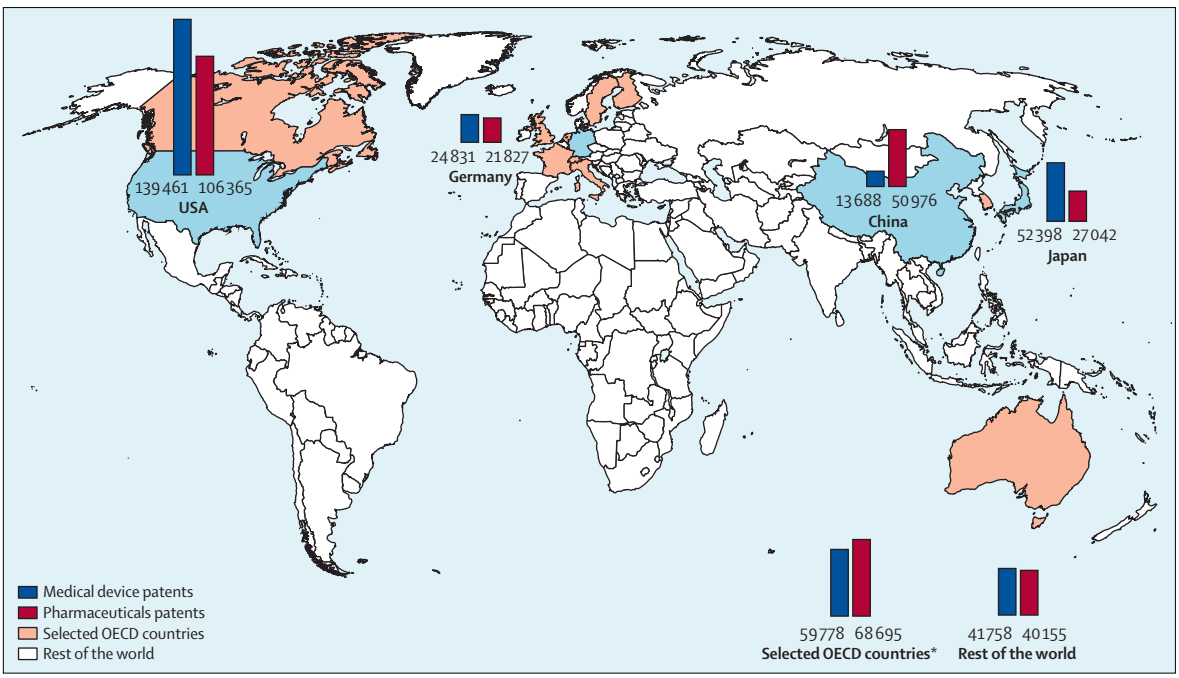


Figure 5: **Country of origin of patent applications**
OECD=Organisation for Economic Co-operation and Development. *Australia, Canada, Switzerland, Finland, France, UK, Italy, South Korea, Netherlands, and Sweden.

Evidence for the importance of patents is debated. One study[159] from 2003, showed that only 17 of the 319 medicines classified by WHO as essential for low-income and middle-income countries could be patented in developing countries, although it has been criticised for selection bias because the WHO essential medicines list contains mainly off-patent low-cost drugs.[160] Only 31% of possible cases had a patent, presumably because of the tradeoff between the complexity and cost of getting a patent compared with the potential market and the perceived protection afforded by such a patent.

MDG 8E advocates better cooperation between the public and private sectors to improve access to affordable drugs in developing countries.[161] Although this cooperation has successfully reduced costs of first-line HIV regimens, the costs of second-line regimens ($572–1545 per person per year in low-income and middle-income countries for key regimens)[162] and novel biotechnology products such as pegylated interferon remain high. In addition to the increased cooperation envisaged in MDG 8, innovative financing could improve access to novel technologies. Two strategies seem especially promising. First is the development of pricing mechanisms that enable research and development costs to be recouped separately, rather than passing them on to low-income country purchasers. Second is tiered pricing, which is currently used for many innovative products, whereby pharmaceutical companies price their new products on the basis of a countries' purchasing power parity, so that the drug is more affordable in resource-poor settings.

International issues of patents and lack of research into tropical diseases suggest that a solution is needed to improve research and development for technologies for health. Since 2003, a series of attempts have been made to reach a global consensus, including an independent Commission on Intellectual Property Rights, Innovation and Public Health.[163] These efforts have culminated in the publication of a report by WHO's Consultative Expert Working Group on Research and Development: Financing and Coordination, which calls for the establishment of a research and development convention that will address financing, coordination, and governance.[164] Although intellectual property and financing of research and development for neglected topics are still challenging issues in global health diplomacy,[165] an international convention has the potential to provide the needed comprehensive global approach, by establishment of binding obligations and commitments, such as the proposal that all countries spend 0·01% of GDP on government-funded research to meet the health needs of developing countries, which equates to $6 billion a year. The 2012 World Health Assembly has resolved to consult members on the feasibility of the report's conclusions.

Product standards are less high profile than are patents, but are also important. International standards for some health technologies are inappropriate for low-income countries. For example, international standards require defibrillator batteries to operate at –10°C (not a common temperature in tropical regions).[16] Such specifications increase production costs for products destined for markets in low-income and middle-income countries.

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Baby in an incubator

International standards organisations such as the International Electrotechnical Commission and International Organization for Standardization need to give greater consideration to the needs of low-income countries and engage more members from resource-poor environments when establishing standards.

How can the cost of technology be kept low? Although much modern medical technology is costly (eg, one multivault proton therapy unit for cancer treatment costs $150 million, exceeding the entire annual health budget of many resource-poor countries,[166] and even technology common in high-income countries, such as CT scanners, is prohibitively expensive at $1 million to $2·5 million), costs can be lowered. One alternative to purchasing the latest equipment, which is both cheap and environmentally friendly, is to recondition existing equipment, for example, neonatal incubators in Nigeria (panel 10).

Another strategy is to develop frugal technology that cannot compete with high-end devices but meets most medical needs. Voltaire noted that "the perfect is the enemy of the good"[170] and it is sometimes necessary to be pragmatic and accept that although an approach might not be as good as that used by a specialist in a tertiary hospital in Europe, it still has potential to improve health and save lives. Economists use the notion of incremental or marginal cost-effectiveness, which assesses whether the benefits of upgrading to the next most expensive product or technology outweighs the costs.[171] This method fits with the stepwise approaches typically used by WHO to account for the resources of a health system. Such an approach can lead to the development of technologies specifically designed for the needs of the market—for example, Zhongxing Medical in China. Many hospitals in China cannot afford expensive imported radiography devices and so Zhongxing Medical produced their own. The device could only do routine chest radiographies, but cost 5% of imported machines, and as a result Zhongxing have captured 50% the Chinese radiography market.[172]

Brazil, Russia, India, and China could help to make health technologies more affordable. Production of health technology in these countries is substantially lower than in developed countries because of the lower costs of labour, less stringent regulation (although this aspect is changing; India has more FDA-approved production facilities than any country other than the USA), and lower construction costs for manufacturing facilities (vaccine production plants in developing countries typically cost less than $100 million, compared with a cost of $200 million to $400 million in developed countries).[134] As a result, multinational companies such as Johnson and Johnson and Bayer are manufacturing a wide range of medical devices in China, such as anaesthesia machinery, pacemakers, and imaging equipment.[173] Like China, Brazil has developed a thriving health equipment manufacturing sector and now 73% of the country's medical device needs are produced in Brazil.[174] The growth of a health technology sector has stimulated innovative new designs such as a portable haemoglobin monitor, a test for intestinal parasites, and a phototherapy unit for jaundiced babies that could benefit low-income countries. Only the UK and the USA provide more products in WHO's compendium of new and emerging health technologies than does Brazil.[25]

India—a low middle-income country with a huge health burden—has also been developing a thriving medical device and pharmaceutical industry. It has various medical device manufacturers with some that copy and modify the designs of existing products, whereas others, such as the Sree Chitra Tirunal Institute for Medical Sciences & Technology, Trivandrum, develop new devices, such as an artificial heart valve and a hydrocephalus shunt.[175] India has been described[176] as the "pharmacy of the developing world" and with good reason: its ten manufacturers of generic antiretroviral drugs account for nearly 90% of the donor-funded market share. In 2008, 96 of the 100 countries that reported purchasing antiretroviral drugs bought generic drugs from India.[177] The country has the potential to make other affordable generic drugs such as the cardiac polypill for less than $0·20 for a daily dose, making it accessible to other developing countries.[106] Finally, India is a world leader in low-cost vaccine production. When the Meningitis Vaccine Project was looking for a production partner, multinational companies could not provide a vaccine at a low enough price.[178] The Serum Institute of India was able to manufacture 20 million doses at a cost

Panel 10: Recycling neonatal incubators in Nigeria

Neonatal incubators are used to maintain the temperature of pre-term infants, who are at risk of hypothermia. The latest incubators are expensive, costing between £25 000 and £30 000.[167] A separate neonatal incubator is needed for each pre-term infant and in Nigeria, with its rapidly growing population, a typical tertiary hospital needs 20 or more incubators. However, a total cost of more than £500 000 is unaffordable.

In a study in that country, obsolete incubators were upgraded with generic components sourced from the internet.[168] Performance of the recycled incubators over 6 months was compared with modern incubators with neonatal clinical assistants assessing how well the incubators functioned on the basis of ten performance measures.

Overall scores for the modern and the recycled incubators were very similar for the ten indicators (65·8% *vs* 65·9%). Modern incubators had better heating transient response, were less noisy, had fewer problems with humidification, and looked better than did recycled incubators. By contrast, the recycled incubators were better for ease of maintenance, response to high ambient temperature, and coping with an erratic power supply.

The cost of recycled incubators was 20% of that of modern incubators and the costs of maintenance were 25%. Not having enough money was cited by clinicians and administrators as the principal reason (68% of survey respondents) for not having sufficient numbers of incubators in neonatal units in Nigeria, thus, the recycled machines have potential to increase the availability of incubators in the developing world.

Results of a 6 year follow-up study show that recycled incubators were viewed very positively by health-care staff, with 88% of those surveyed viewing them as the main reason for the fall in neonatal mortality in the period.[169] At the time of the follow-up study, 74% of functioning incubators in the main Nigerian hospitals were recycled.

of $0·40 per dose, enabling a major meningitis vaccination campaign in Africa.

How can value for money be achieved? Although manufacturing in bulk in China and India might be the best way to keep costs low, arguments also exist for encouragement of the production of health technology where it is used, such as sub-Saharan Africa. This suggestion is especially relevant for repeat-use medical devices, for which local production makes the availability of local product support and maintenance more likely, helping to keep the device functioning. Broader benefits of increased employment and wealth brought by local production also exist, as exemplified by A to Z Textile Mills in Tanzania. Through a joint venture with Japanese firm Sumitomo Chemical, A to Z Textile Mills produces 29 million longlasting insecticide-treated bednets in a year.[179] Their factory in Kisongo has created more than 7000 jobs and these employees support more than 35 000 people in the community. A survey of employees revealed that 71% used their wages to pay for their children's education. Furthermore, building the factory at Kisongo has led to the development of transport, water, and electrical infrastructure, which has benefited local residents. That A to Z Textile Mills cannot manufacture nets as cheaply as competitors in south-east Asia is outweighed by the developmental benefits of its production operation in Tanzania.

The wider value of local production is linked to the value for money of technologies for health and attempts to quantify their benefits. This effect should go beyond the strict health costs of a disease, such as the cost of treatment, to include wider societal costs, such as days of work missed. For example, efforts to control river blindness (onchocerciasis) in sub-Saharan Africa between 1974 and 2002 prevented 60 000 cases and are estimated to have generated $3·7 billion from improved worker and agricultural productivity.[91] One of the benefits of vaccination is improved educational attainment,[180] and analysis of the effect of antiretroviral treatment suggests that the costs are mostly offset, or even exceeded, by increases in labour productivity, averted orphan care, and deferred medical treatment for opportunistic infections.[181] More such analyses should be done. Recognition of the economic and humanitarian benefits of a health technology can increase access to available resources. For example, malaria is estimated to cause a $12 billion loss in productivity each year.[182] Acceptance of the effect of malaria and the effectiveness of a package of interventions, including insecticide-treated bednets and medicines, has resulted in a 15-times increase in donor funding for malaria, from $100 million in 2003, to $1·5 billion in 2010.[77]

Affordability is the biggest obstacle to access of health technology by poor people worldwide. However, it is not the only factor affecting accessibility and three others—challenges of distribution, inadequate human resources, and an absence of a reliable energy supply—deserve further consideration.

Even if a health technology is affordable and has government support in a low-income or middle-income country, ensuring that it reaches remote rural areas can be difficult. In their 2010 call for innovative technologies, WHO asked contributors what they perceived to be the major challenges to success. For those with products that can be made commercial, the greatest challenge given (by 43% of respondents) was problems with distribution.[183] The issue of distribution and supply is especially pressing for medicines, vaccines, and consumables for medical devices, for which stocks need to be resupplied. WHO reports that essential medicines are available at only 35% of public-health facilities in 30 developing countries.[184] One way to address distribution difficulties could be to use highly efficient distribution networks that exist for commercial products, such as the ColaLife project (panel 11). Likewise, the MEDIkit project uses commercially available toy parts (eg, Lego) as the building blocks for its customisable diagnostic methods.[187]

Another innovative approach to tackle distribution difficulties is franchising, in which a successful business model is replicated by licensing the approach for others to use. Child and Family Wellness Shops, which sell health-care consultations and drugs, are a franchise run by the HealthStore Foundation that was launched in Kenya in 2000.[188] Kenya had a shortage of pharmacies, with one per 50 000 people, almost ten-times as many people per pharmacy as in the UK.[189] Starting with 11 locations, Child and Family Wellness Shops have expanded to 65 outlets serving half a million people. Health-care workers and nurses can sign up as franchisees and receive business training. They also agree to abide by treatment protocols and drug prescription guidelines: such franchising can be an effective means to disseminate evidence-based medical practice. The franchise model enables economies of scale to reduce overhead costs and effective procurement of pharmaceuticals. It has helped to make viable the establishment of stores providing essential medicines in communities that were previously unserved.

Simon Berry/ColaLife

ColaLife project

Panel 11: **The ColaLife project**

In the 68 countries with the highest rates of infant mortality—accounting for more than 90% of infant deaths worldwide—median access to diarrhoeal medicines is just 42%.[185] Yet, a bottle of Coca Cola can be bought in some of the most remote places on Earth. ColaLife is a non-profit organisation that aims to exploit this paradox to improve distribution of rehydration salts for treatment of diarrhoea.

In Africa, Coca Cola bottles are initially transported from bottling plants in crates by lorries, but are then left at manual distribution centres or wholesalers. From there, they are conveyed by local entrepreneurs by whatever modes of transport are available, from bicycle to mule. ColaLife have designed a container for essential medicine (known as an AidPod) that can fit in the unused space between the necks of the bottles. They are launching a trial in Zambia (which has only 70 retail pharmacies)[186] to test the effectiveness of the scheme. One issue that they are testing is the incentive needed for entrepreneurs who distribute the drink and they are considering making small payments to distributors by mobile telephone money transfer.

Indian Immunologicals have also used a franchise model to tackle rabies, which is endemic in India.[190] Semiurban and rural health-care clinics agree to become Abhay Clinics. These clinics provide dog-bite treatment, including washing the wound and rabies vaccination, for a low price set by Indian Immunologicals. The clinics make a small profit on each treatment, but other incentives encourage health-care practitioners to join. First, patients being treated for rabies might purchase other services, second, Indian Immunologicals provide a refrigerator to store the vaccines (which can then be used for other products), and finally, franchise participants get their initial 30 doses of vaccine for free.[191] Indian Immunologicals deliver vaccines straight to the clinics and manage their own cold-chain storage so that the vaccine is kept at an optimum temperature. In 2007, 2000 Abhay Clinics covered 22 of India's 28 states.

For dissemination of knowledge about health care, the main challenge is to provide better access to the internet. Although paper copies of standard texts such as *Where There is No Doctor* have a role, only the internet has the potential to deliver universal access to up-to-date health-care information.[192] However, internet access is low in many low-income and middle-income countries. For example, only 11·4% of the population of Africa have access to the internet, and this proportion is inflated by high use in north African countries such as Egypt.[193] A concerted effort should be made to ensure that all health-care facilities have access to the internet.

If health-care professionals can access this resource then they can benefit from initiatives to share health knowledge. The Health Inter Network Access to Research Initiative offers free access to more than 8000 journals and information resources to health-care institutions in the poorest countries.[194] WHO has led another initiative to share technologies protected by intellectual property rights; the Map of Medicine provides evidence-based care pathways, and is freely available in Africa.[195] These schemes should be commended and expanded. More information can be shared and more can be done to make this information available in multiple languages.

Inadequate human resources are another challenge to access to technology. Low-income countries have shortages of trained health-care workers. This difficulty is greatest in sub-Saharan Africa, which has 11% of the world's population and 24% of the world's disease burden, but only 3% of the world's health-care workers.[196] Health-care workers are needed to enable effective use of health-care technologies such as the delivery of vaccines and compliance with medication. For more complex medical devices, trained operators are needed. For example, radiology technicians are needed to use imaging devices, but Liberia has just six such technicians for a population of 3·5 million.[197] If appropriately trained staff are not available, health-care technology is more likely to be used incorrectly—results of a 2006 study by Engineering World Health students in 33 hospitals in ten countries (including Tanzania, Nicaragua, and Sierra Leone) show that the second greatest cause of broken medical devices was user error.[198]

The issue of supply of health-care workers in low-income and middle-income countries is beyond the scope of this commission and is discussed in detail elsewhere.[199] However, a need exists for professionals with biomedical or clinical engineering skills to maintain and develop complex modern medical devices. Until recently, training in this discipline was non-existent, but this situation is changing; a qualification in clinical engineering has been introduced in India through a joint endeavour by Sree Chitra Tirunal Institute for Medical Sciences & Technology, Trivandrum, the Indian Institute of Technology (Madras), and Christian Medical College (Vellore; Niranjan Khambete. Personal communication).[200]

Another example is the biomedical engineering training programmes of Engineering World Health, which have been established in Cambodia, Honduras, Rwanda, and Ghana. In Rwanda, only 70% of adults are literate.[201] The programme in Rwanda began in late 2009 with the goal of providing enough trained technicians to serve every hospital in the country within 3 years. The programme is based at the Kigali Health Institute and 45 prospective technicians were enrolled in the first cohort.[202] In Ghana, the training programme focuses on continuing education for already trained biomedical engineers. This approach complements existing education of biomedical engineers in Ghana—a programme of training was started in 1998 by International Aid, and in 2009 the programme was taken over by the Ghanaian Valley View University. More than 80% of the technicians who have been through the established programme have continued to work in Ghanaian hospitals.

Having skilled biomedical engineers is an important resource for low-income and middle-income countries. They can help to ensure that medical devices remain functional, effective, and safe. However, development of this expertise does not obviate the need for robust user-friendly design. Technology can be designed with built-in maintenance and troubleshooting aids. The eRanger has strategically placed stickers to encourage drivers to do routine maintenance checks. Additionally, health-care technology companies have a responsibility to support the sustainable use of their products in resource-poor settings, and one way to do so would be to ensure that all reusable medical devices are accompanied by operation and service manuals in local languages, which could be supplemented by electronic copies on the internet.

However, access to electricity is an important issue for much of the world. The International Energy Association estimates that in 2009, 1·4 billion people (20% of the world's population) did not have access to electricity.[203] The proportion of people with access to electricity is lowest in rural sub-Saharan Africa (14·3%), whereas the

greatest number of people without electricity live in south Asia, especially rural India. Electricity itself can be regarded as a technology for health; for example, access to electrical light removes the need for kerosene lamps, which emit fumes that can cause lung cancer and respiratory disorders.[204] Efforts to encourage access to electricity, such as the e.quinox project, which is building solar-powered charging stations in Rwanda,[205] should be encouraged by advocates of global health.

Much health-care technology relies on electricity. Although other infrastructure can be important (such as access to clean water), electricity is of primary importance. Most medical devices require electricity to function. However, a survey of 97 anaesthetists in Uganda reports that only 20% had a constant electricity supply for their machinery.[44] The need for electricity is greatest for therapeutic devices such as neonatal incubators, which need to be powered constantly. Diagnostic devices, by contrast, can be operated in a period when power is on. Drugs and vaccines might not need electricity for use, but they often need refrigeration for effective storage or electricity-powered diagnostics for correct use. Power supply seems to be a major factor for medical devices not functioning in low-income countries. The 2006 study by Engineering World Health students led to 644 pieces of equipment being repaired.[198] The largest single cause (29·9% of repaired items) of equipment failure was power supply problems such as faulty batteries, fuses, power cords, or surge protection, or frequency incompatibility.

Design can overcome the need for a reliable energy supply by avoiding the need for electricity. For example, the ShakerScope is a kinetically powered light source.[206] Shaking powers a light-emitting diode light, which lasts much longer and is easier to replace than are incandescent bulbs, which are usually used in traditional instruments. Shaking for 30 s provides 3 min of light. Three interchangeable heads turn the ShakerScope into a laryngoscope, an otoscope, or an ophthalmoscope. As a multipurpose electricity-free device, it has substantial potential for use in resource-poor settings. Prototype ShakerScopes have been used in military hospitals in Afghanistan and in the aftermath of the earthquake in Haiti.

An alternative to removing the need for an electrical power supply is to use an easily available source. Solar power has huge potential for low-income and middle-income countries, many of which have long periods of sunlight and an infrastructure of mobile telephone towers that can be fitted with solar panels to generate electricity that can be dispersed to the local community. More health-care technology could be solar powered, such as the Omron blood pressure monitor (Omron, Kyoto, Japan). A solar-powered autoclave designed in the USA (used to sterilise surgical and other medical instruments) uses 90% locally available materials and works as effectively as other table-top autoclave models, but does not need a supply of electricity.[183]

Frugal design could create more products for settings where electricity is restricted (eg, by removal of large colourful displays from fetal monitors). Such products that either use renewable energy or do not require electricity, might have a market in high-income countries as energy derived from fossil fuel becomes more expensive. Health care in high-income countries uses a lot of energy—it accounts for 8% of all US greenhouse gas emissions[207]—and technology that can reduce use and therefore emissions would reduce costs and help to prevent climate change.

Fiona McVeigh/Timesco

A kinetically powered ShakerScope

Reluctance to adopt accessible technology

Cost, wider economic effect, challenges of distribution, human resources, and energy supply are all factors that determine whether a technology can be deployed in a resource-poor setting. However, even when all these criteria are met and a technology is judged accessible, a final fundamental barrier to its implementation exists—persuading people to use the technology.

The most promising technology can struggle to gain acceptance. For example, male circumcision reduces transmission of HIV by up to 70%. Circumcision is less painful with new technologies, such as the Shang Ring, a pair of concentric plastic circles that are worn for a week to painlessly remove the foreskin.[208] The Shang Ring is cheap, simple to use, not dependent on electricity, and does not need stitching as do surgical techniques. However, only 5% of men in sub-Saharan Africa who could benefit have been circumcised.[32] The main barrier is not the technology, but cultural resistance to the procedure.

Technology theorists emphasise that technology needs to be attuned to a country's cultural climate.[209] In India, for example, sitting cross-legged is a regular part of daily life but standard prosthetic knees from Western countries (where such a posture is uncommon in adults) were too inflexible. An Indian orthopaedic surgeon designed the INDUS knee, which enables the recipient to sit cross-legged and is more culturally acceptable. However, alteration of a technology to fit a culture is not always possible. Cultural resistance can be overcome by carefully persuading users of a technology's benefits and engaging with their concerns. For example, alcohol-based handgels are the most effective way to ensure hand hygiene. However, alcohol consumption is prohibited by many religions, and in Islam alcohol is classified as forbidden.[210] Muslim health-care workers can therefore be reluctant to use alcohol-based handgels. However, the Quran does permit the use of alcohol for medicinal purposes and religious leaders such as the Muslim Scholars' Board have supported the use of alcohol to kill germs.[211] Experience shows that if clinicians are sensitively informed of the religious and scientific support for alcohol based handgels, such cultural barriers can be overcome. Saudi Arabia, for example, has deployed alcohol handgel dispensers in health-care facilities since 2005.

Persuasion and education of users follows a rational view of human nature, but people can also be subconsciously influenced to adopt health-care technology. Interest is growing in the use of behavioural economic insights to affect decisions about health in high-income countries.[212] Such approaches can also encourage scale-up of technology in low-income and middle-income countries. A well-established aspect of behavioural economics is the use of defaults. People are slow to change, even if the change is beneficial to them,[213] so the beneficial scenario is made the default and people are given the opportunity to opt out. This approach has been applied to prevention of mother-to-child transmission of HIV by making HIV tests a routine part of antenatal care. This opt-in approach caused HIV testing of expectant mothers rise to 99·9% during the first 6 months in Chitungwiza (Zimbabwe), compared with 65% tested during the last 6 months of opt-in testing.[214] More testing enables more HIV-positive women to receive drugs to reduce the chance of transmission; for example, 80% of pregnant HIV-positive women received prophylaxis in Botswana in 2005 after the introduction of opt-out testing in 2004 (less than 30% received prophylaxis in 2002).[215]

This example shows how inertia can be a positive factor. However, it is often a barrier, as in India, where the use of expensive imported medical devices with which doctors are familiar has hampered the uptake of cheaper, locally produced alternatives.[197] Adoption will be most successful if resource-poor countries are encouraged to appropriate the technology and make it their own,[209] such as with the WHO Surgical Checklist, for which core questions can be supplemented by locally agreed checks.

Implementation and innovation in technology for health

Even if the these barriers are overcome, implementation challenges remain, including scale-up of use, effective assessment and regulation, and issues of equity. Many studies address factors that affect scale-up of health-care innovations (panel 12).[218]

The lists share several similarities—they rightly emphasise the importance of the nature of the innovation itself. Frugal technologies fit these requirements well. However, both also consider the wider context—national health policies, the functioning of the health system, and political support for expanded use. These factors are crucial; for example, a new point-of-care diagnostic test for a sexually transmitted disease should integrate with existing efforts to provide health care to populations such as sex workers.

Thus, decisions about implementation of a technology in a low-income or middle-income country should combine a range of considerations, from cost per unit to how to encourage uptake. This process is known as a health technology assessment, which is defined as "the systematic evaluation of properties, effects, and/or impacts of health-care technology".[219] Health technology assessment considers whether a technology can work in a particular setting and the best way to achieve implementation. It should be used effectively in resource-poor settings. Establishment of an independent, autonomous health technology assessment process should be the responsibility of a national ministry of health or could be done at state level in large, highly populated countries such as India. Several countries have introduced such assessments, including Thailand and Colombia. Where this capability is not yet established, non-governmental organisations might need to do health technology assessments to ensure that aid is used effectively. Health technology assessment should not be bureaucratic and a list of 20 criteria, with further clarification of some terms to increase objectivity, could be the basis of a simple approach.[220]

Effective assessment should be a key part of implementation. As a new technology is trialled in a resource-poor setting an assessment should be done that strikes a balance between sufficient robustness and avoidance of delay of scale-up if the technology has clear potential to improve health. A cost-effective way to estimate the implications of scale-up is to use modelling and simulation.[221] For example, simulation techniques have been applied to the different types of malaria vaccine to test whether they are likely to be cost effective.[222] With such health-care modelling, organisations in high-income countries could try to support health-care systems in low-income and middle-income countries, either by direct modelling or, to achieve sustainability, through transfer of the necessary knowledge and skills.

Assessment is necessary to ensure that a technology is used effectively. Results of a study in Tanzania show that although point-of-care tests for malaria are more accurate than is diagnosis using microscopy, clinicians often ignore negative results from both. 54% of patients who tested negative for malaria after a point-of-care test and 51% of those who tested negative for malaria after microscopy were still being treated with antimalarial drugs.[223] Such over-treatment is expensive and risks reducing the effectiveness of malaria drugs. Artemisinin-based combination therapies are the standard treatment for malaria because over-use of the previous first-line drug chloroquine enabled *P falciparum* to develop resistance.[84] Distribution of the test and encouragement of its use is ineffective without a focus on how its implementation could alter medical practice.

m-Health is a good example of the need for assessment. The ubiquity of mobile telephones, even among some of the poorest people in the world, is such that m-Health seems to offer huge potential. We reviewed m-Health in low-income countries (appendix). m-Health has great potential such as for collection of health-care information, provision of mobile diagnostic tests, and encouragement of healthy behaviours. However, the review identified only nine randomised controlled trials for m-Health in low-income countries. A more robust assessment of

m-Health is needed, including the establishment of one organisation with overall responsibility for maintaining a registry of m-Health trials and assessments.

The need for regulation

Once implemented, technologies should be regulated to ensure that they are safe. Although regulation can increase costs of technology, it is necessary to protect patients. For example, counterfeit medicines (sales of which reached $75 billion in 2010)[224] can lack active ingredients (making them ineffective), contain active ingredients but not in the right proportions (reducing efficacy), or contain toxic ingredients. In Haiti in 1995, 89 people died after ingesting a cough syrup that contained diethylene glycol (a chemical commonly used as anti-freeze). Haiti is a good example, because people in low-income and middle-income countries are most at risk; counterfeit medicines are estimated to constitute more than 10% of the medicines market worldwide, ranging from roughly 1% in high-income countries, to 10–50% in low-income and middle-income countries.[225]

Often, capacity and infrastructure for regulation, quality control, and law enforcement of drugs lags behind counterfeiting. In 1984 WHO stated that "every country, regardless of its stage of development, should consider investment in an independent national drug quality control laboratory".[226] However, in 2012, of 191 WHO member states, only about a fifth have well-developed drug regulation and those that have some drug regulation often have inadequate resources, little training, inefficiency, and incompetence.[227] WHO's International Medical Products Anti-Counterfeiting Taskforce provides technical support to countries to build and strengthen national regulatory infrastructure, and raise awareness, exchange information, and develop standards.[228] Supplementing regulatory bodies, new technologies can provide part of the solution to substandard and counterfeit health technologies. Technologies such as barcodes and holograms can help to identify authentic products,[229] and mobile telephones can be used in surveillance against fake pharmaceuticals.[230]

Although counterfeit medicines have received increased attention in recent years, much less is known about problems with substandard and counterfeit products for other types of medical technologies. Several other product types might be counterfeited, including glucose test strips for use in conjunction with insulin, other medical test kits, contact lenses, combination products, and component parts, such as semiconductors used in imaging equipment.[231,232] Few low-income or middle-income countries regulate medical devices; only three do so in Africa (Egypt, Kenya, and South Africa).[16] Establishment of regulatory authorities for health-care technology should be a priority, not a luxury.

Equity and universal coverage of technology

Even low-cost health technology might not be affordable if people can use it only by making out-of-pocket payments. Such payments are estimated to exclude 1·3 billion poor people from access to health services and drive an additional 100 million people into poverty yearly. Out-of-pocket payments are mostly made in poor settings; in 2007, most of the 33 countries that relied on such payments for more than 50% of total health expenditure were classified as low income.[233] Health technology should be used as part of the drive towards universal health-care coverage.

One approach is to use aid budgets to distribute health technology for free, as with insecticide-treated bednets. Evidence for the uptake of bednets suggests that initial modest co-payment of $2–3 (a typical bednet costs $10) was a major reason for coverage being low between 2000 and 2005.[234] WHO adopted mass free distribution of bednets in 2007, which has increased bednet use dramatically. However, whether free distribution of bednets is a long-term solution is debated; some people call for diversity of supply so that mass free distribution is supplemented by subsidised and private bednet sales.[235]

Donor funding cannot be relied on to cover the cost of all beneficial health technology in resource-poor settings and means of pooling private resources should be developed. Two examples already in use are cross-subsidisation and microinsurance. Cross-subsidisation (users who can afford to pay more so that users who cannot afford care receive it for free or at a heavily discounted price) is used in the Aravind Eye Care System (Madurai, Tamil Nadu, India), which accommodates 330 paying patients and 920 free patients in its main hospital.[236] The fee paying patients receive higher standards of comfort (eg, beds rather than bamboo mats), but their payment enables many procedures (more than 60%) to be done for free.[237]

Similar to microfinance, microinsurance aims to aggregate a large number of poor consumers through their health insurance scheme. One company, MicroEnsure, has developed an insurance scheme that they anticipate

***Panel 12:* Factors affecting scale-up of innovations in health care**

According to Gavin Yamey[216]

- Attributes of the specific technology or service being scaled up
- Attributes of implementers
- Delivery strategy
- Attributes of the adopting community
- Socio-political context
- Research context

According to Rifat Atun and colleagues[217]

- The problem
- The intervention
- The adoption system
- Characteristics of the health system
- The broader context

Science Photo Library

Bednet

will cover 200 000 coffee growers and their families around Mount Kilimanjaro, Tanzania. The insurance contribution funds a capitated payment to health centres. Technology is involved, with mobile telephones used to register new members, and decision-making software for mobile telephones is being developed that will help health centres to follow treatment protocols. Set up with a grant from the Bill & Melinda Gates Foundation, MicroEnsure are moving towards sustainability without donor funding (Will G De Klerk, MicroEnsure, personal communication).[238] Cross-subsidisation and microinsurance are therefore two mechanisms whereby additional resources can be used while enabling equitable coverage of health care and health technology.

Disruptive technologies
Disruptive technologies are technologies that fundamentally alter existing markets, by providing a new product or service much cheaper than existing approaches; eg, mass production of the Ford Model T

Disruptive technologies for health care in high-income countries

Technology is a major driver of the unsustainable growth in health-care costs in high-income countries. Between a third and half of increases in total spending on health care in the USA between 1960 and 2007 have been ascribed to technological advances.[239] Will this pattern be replicated in resource-poor countries? This scenario seems a long way off—a huge difference exists between a country in sub-Saharan Africa seeking universal vaccination coverage and a high-income country buying the latest MRI scanner. Furthermore, greater use of effective health technologies in low-income and middle-income countries should benefit productivity to more than pay for the cost of the intervention. The key is to ensure that only effective technologies receive investment.

Rather than resource-poor countries replicating the expensive pattern of health technology use in high-income countries, frugal technology should provide disruptive innovations that make health care more cost effective in wealthy settings. Disruptive innovations for health care have been much discussed, especially in countries with high-cost health systems.[240] Although now associated with any radical innovation, the original idea of disruptive innovation was of cheaper and simpler to use products or services that were good enough to meet the demands of customers who could not afford state-of-the-art technology.[241] Some frugal technologies already have such an effect in high-income settings—for example, a portable MAC 400 ECG (General Electric).[242] This ECG is the product of a design team based in India who were given freedom to innovate. Its compact shape (it has no keyboard or screen) means that it weighs 1·3 kg, compared with stationary devices made for US hospitals ranging from 7 kg to 30 kg. It uses the same analysis software as high-end models such as the MAC 5500, but costs just a fifth of the price. Availability of such inexpensive portable ECGs could help to identify heart attacks that are missed in primary care or resource-poor settings.[243] Although designed for India, the MAC 400 is popular with primary care physicians in Germany who do not need a more expensive high-end machine.

Rapid diagnostic tests are another technology that have potential to be used worldwide although initially developed for resource-poor settings. Self-tests for chlamydia and human papillomavirus created for low-income and middle-income countries could be convenient and empower patients to test themselves in high-income countries.[244] The CD4 test could also be used in high-income countries, since lower cost per test, use of fingerprick instead of venous blood, and speed of the test results would improve the pathway of care for patients, reduce the number of clinic visits, and lessen costs overall.

Not only new products can be disruptive technologies. The response to the HIV epidemic in Africa has led to the development of technologies such as algorithmic HIV treatment guidelines, which could be used widely in high-income countries to standardise care and reduce unnecessary variation.[245] An example of how clinical practice has already changed is the adoption of the Ponseti method as the gold standard for treatment of club foot.[196] The method was first adopted in Malawi because of a shortage of orthopaedic surgeons, but delivered better results while being less intrusive and expensive than surgery. The Ponseti method is now becoming standard practice in high-income countries.

So, with technology for health, ideas do not flow one way from rich to poor settings. The transfer of technology from low-income and middle-income countries to high-income countries has been described as reverse innovation, but this label is unhelpful since it supports the notion of a flow of innovation from rich to poor, whereas a more dynamic and interactive approach to learning from best practice, wherever it originates, is needed. As such, wealthy countries should look to frugal technologies to make health care more affordable and convenient. Thus, frugal technology for health can have a truly global effect.

Conclusions and recommendations

Technology is making a substantial contribution to global health. Yet it could do much more. This report concludes by setting out recommendations to unlock the potential of technology. Some recommendations are overarching, whereas others are specific to particular organisations or certain health needs.

First, development of frugal technology that meets the needs of the world's poorest people should be emphasised. Those most in need in low-income and middle-income countries are not well served by hand-me-down technology from high-income countries. Technologies are needed that account for constraints in finance, health-care workers, and even reliable electricity supplies. Funding and support for frugal technology is needed and initiatives such as USAID's funding of 5-year programmes to develop health technologies for low-resource settings should be welcomed.[246]

Although poor people will be the primary beneficiaries of cheaper, simple technology, such technologies might

also help to reduce costs of health care in high-income countries. Simple diagnostic tests can enable patients to do tests themselves, reducing the need for health-care professionals as intermediaries. Process innovations from resource-poor countries can be applied to high-income countries to make technology much more cost effective. Technology for the poorest people can benefit all.

Second, technology alone is not enough. Technology should be combined with other innovations, such as effective delivery mechanisms and novel approaches to financing if it is to be scaled-up and have a substantial effect on global health. Broader innovation is crucial to ensure that technology is not just available but acceptable to the world's poorest people.

Panel 13: Recommendations for organisations

Ministries of health in low-income and middle-income countries

- Instigate a proportional system of independent and autonomous health technology assessment to ensure that cost-effective technologies are identified and implemented.
- Encourage rigorous assessment of health-care technology before funding or sanctioning scale-up, working with health-care technology companies and development non-governmental organisations.
- Strengthen regulation of health-care technology, especially drugs and medical devices.

International bodies (eg, WHO, UNICEF, standards organisations)

- Establish a binding international convention for biomedical research and development, as per the recommendation of WHO's Consultative Working Group on Research and Development: Financing and Coordination. Such a convention will create a framework to ensure that necessary health technologies for resource-poor countries are developed and are affordable.
- Ensure that international product standards are effective for poor people. International standards organisations must give greater consideration to the needs of low-income and middle-income countries and involve more members from resource-poor countries.

Health-care technology companies

- Develop more frugal technologies accounting for the needs of the world's poorest people. For medical devices that are used repeatedly, technologies should be reliable in adverse environmental conditions, have reduced the number of custom components and non-essential functions, and provided built-in maintenance and troubleshooting aids.
- Support the effective use of health-care technology by making operation and service manuals available in the native language at the time of delivery, with electronic copies available via the internet.
- Make use of different pricing policies so that drugs with a global market (eg, those for non-communicable diseases) can be accessed by the poorest people.

Development non-governmental organisations

- Fund the commercialisation of health technology developed in the poorest countries.
- Encourage rigorous assessment of health-care technology before funding or sanctioning scale-up, working with health-care technologies companies and ministries of health.
- Prioritise funding of multidisciplinary research over research that is more narrowly focused.
- Aim to ensure that costs of research and development are not passed on to low-income and middle-income countries. Mechanisms should include both push strategies (eg, product development partnerships) and pull strategies (eg, advance market commitments).

Universities and research institutions

- Universities in high-income countries should support assessment of health-care technologies by the application of simulation and modelling techniques to resource-poor countries.
- They should also help to define needs and have a leading role in development of public–private partnerships to develop frugal technologies.
- Universities should quantify the wider economic benefits of health interventions in resource-poor settings.
- Universities in high-income countries and institutions in low-income and middle-income countries should form partnerships to share skills and knowledge to enable the development of frugal health technologies.
- Universities in low-income and middle-income countries should focus on development, including support of greater use of technology.[249]

Health-care systems in high-income countries

- Make use of frugal technology to reduce costs and increase convenience by giving an organisation such as the Organisation for Economic Co-operation and Development remit to identify and disseminate awareness of such technologies among its members. Policy makers should ensure that incentives are aligned (eg, payment mechanisms) and barriers overcome (eg, intransigence by health-care professionals) so that these innovations can be fully exploited.
- Use information and communication technology to support health care in resource-poor settings by sharing specialist knowledge and enabling training of local health-care workers.
- Only donate health technology if clear evidence shows that such a donation will be beneficial to the receiving institution.
- Support the use of health technology through partnerships between health-care organisations in high-income countries and their counterparts in low-income and middle-income countries, such as the Health Links initiative of the Tropical Health and Education Trust.[250]

***Panel 14:* Recommended innovations for specific health problems**

- Trials in low-income and middle-income countries should investigate whether successful use of mobile telephones to support smoking cessation in high-income countries can be replicated in a different setting.
- Scale-up use of the cardiac polypill in resource-poor settings.
- Use of computerised cognitive behavioural therapy in low-income countries should be tested.
- Cheaper and more rapid diagnostic tests for sickle-cell disease should be developed.

Third, those aiming to improve the health of poor people worldwide through beneficial technologies should not restrict their focus to health-care technology. Better crops, flushing toilets, and better roads will all improve health. Merit also exists in adoption of a multidisciplinary approach and combination of interventions such as improved sanitation and drugs to combat schistosomiasis or vitamin supplements and vaccinations for children. Health advocates should think broadly and creatively to make the most of technology's potential.

Fourth, if possible, existing available technology should be used to improve health. Adaptation of technology that is already in use in resource-poor settings is better than creation of another layer of complexity and expense by introduction of a health-specific solution. Particularly, mobile telephones have much potential because of their ubiquity. Often, people who do not have adequate sanitation have a mobile telephone, which can be used to improve health. More good quality evidence is needed for effective m-Health interventions to enable scale-up of beneficial programmes.

Fifth, as consideration is given to how development should be measured and encouraged after the MDGs, a key goal of future development should be to foster the ability to create and use beneficial technologies (including those for health) in all countries, no matter how poor. This recommendation could be measured by an updated version of the Technology Achievement Index, created for the UN Development Programme in 2001, which focused on the creation of technology, dissemination of innovations, and the advanced education and skills required to use the technology effectively.[247] Such an approach would fit with proposals that international development policy should be directed mainly at building technical competence rather than conventional relief activities in low-income countries.[248] This approach will support both the development of more frugal technologies for health and also enable the expanded use of existing technology. In addition to these five general recommendations are more targeted proposals for particular organisations (panel 13) and for particular health issues (panel 14).

All these recommendations emphasise that ensuring that health technology can have the greatest effect on the world's poor people requires concerted action by all parties. The benefits of health technology should be available to all, not only those in high-income countries. Access to life-saving health technology should not be restricted to those with the ability to pay. Tackling current market failures is therefore a task for all those with an interest in improvement of global health.

Contributors

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Conflicts of interest

We declare that we have no conflicts of interest.

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References

1 OECD Health Data—Frequently Requested Data. http://www.oecd.org/document/16/0,3746,en_2649_37407_2085200_1_1_1_37407,00.html (accessed Jan 12, 2012). 2011.

2 Predicting Future Demands for Radiotherapy. A Report for the National Radiotherapy Advisory Group—Scenario Subgroup. Version 3. http://ncat.nhs.uk/sites/default/files/scenario%20sub%20group%20report%20-%20jan%2007%20-%20fin.pdf (accessed Jan 13, 2012). 2007.

3 Wardlaw JM, Murray V, Berge E, Del Zoppo GJ. Thrombolysis for acute ischaemic stroke. *Cochrane Database Syst Rev* 2009; **4:** CD000213.

4 World Bank. World Bank Sees Progress Against Extreme Poverty, But Flags Vulnerabilities. http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0,,contentMDK:23130032~pagePK:64257043~piPK:437376~theSitePK:4607,00.html (accessed March 12, 2012). 2012.

5 WHO, UNICEF, UNAIDS. Global HIV/AIDS response—epidemic update and health sector progress towards universal access—progress report 2011. http://www.who.int/hiv/pub/progress_report2011/hiv_full_report_2011.pdf (accessed Jan 14, 2012).

6 Magnetic resonance: a peer-reviewed critical introduction. http://www.magnetic-resonance.org/MagRes%20Chapters/21_03.html (accessed Jan 12, 2012). 2012.

7 Kwankem Y, Poluta M, Heimann P, El-Nageh M, Belhocine M. WHO. Eastern Mediterranean series: health care technology management. Series 24, 2001. http://www.emro.who.int/dsaf/dsa41.pdf (accessed Feb 4, 2012).

8 Mitcham C. Thinking through technology: the path between engineering and philosophy. Chicago: University of Chicago Press, 1994.

9 WHO. Guidelines on hand hygiene in health care—first global patient safety challenge clean care is safer care. http://whqlibdoc.who.int/publications/2009/9789241597906_eng.pdf (accessed Jan 4, 2012). Geneva: World Health Organisation, 2009.

10 Goodman C. HTA 101. Introduction to health technology assessment. http://www.nlm.nih.gov/nichsr/hta101/hta101.pdf (accessed Jan 10, 2012). 2004.

11 Development Media International. How mass media can save a million lives. http://developmentmedia.net/index.html (accessed May 11, 2012). 2012.

12 mobiThinking. Global mobile statistics 2012. http://mobithinking.com/mobile-marketing-tools/latest-mobile-stats (accessed Jan 3, 2012).

13 Rice X. Kenya sets world first with money transfers by mobile. *The Guardian* March 20, 2007. http://www.guardian.co.uk/money/2007/mar/20/kenya.mobilephones (accessed Jan 4, 2012).

14 UN. The Millenium Development Goal Report. http://www.un.org/millenniumgoals/11_MDG%20Report_EN.pdf (accessed Jan 13, 2012). 2011.

15 Lessons from a frugal innovator. *The Economist* Apr 16, 2009. http://www.economist.com/node/13496367 (accessed Jan 3, 2012).

16 WHO. Medical devices: managing the mismatch: an outcome of the priority medical devices project. Geneva: World Health Organization, 2010.

17 WHO. Landscape analysis of barriers to developing or adapting technologies for global health purposes. Geneva: World Health Organisation, 2010. http://whqlibdoc.who.int/hq/2010/WHO_HSS_EHT_DIM_10.13_eng.pdf (accessed Jan 14, 2012).

18 Perry L, Malkin R. Effectiveness of medical equipment donations to improve health systems: how much medical equipment is broken in the developing world? *Med Biol Eng Comput* 2011; **49:** 719–22.

19 Howie SR, Hill SE, Peel D, et al. Beyond good intentions: lessons on equipment donation from an African hospital. *Bull World Health Organ* 2008; **86:** 52–56.

20 WHO. Guidelines for health care equipment donations. Geneva: World Health Organisation, 2000. http://www.who.int/hac/techguidance/pht/1_equipment%20donationbuletin82WHO.pdf (accessed Jan 27, 2012).

21 Prahalad CK. The fortune at the bottom of the pyramid: eradicating poverty through profits: 5th anniversary edition. New Jersey: Pearon Education, 2010.

22 Prahalad CK. The innovation sandbox. *Strategy and Business* Aug 28, 2006. http://www.strategy-business.com/article/06306?gko=caeb6 (accessed Jan 12, 2012).

23 Santa Clara University. The FIL core competencies. http://www.scu.edu/socialbenefit/innovation/frugal/corecomp.cfm (accessed Jan 13, 2012). 2011.

24 Free MJ. Achieving appropriate design and widespread use of health care technologies in the developing world. Overcoming obstacles that impede the adaptation and diffusion of priority technologies for primary health care. *Int J Gynaecol Obstet* 2004; **85** (suppl 1)**:** S3–13.

25 WHO. Compendium of new and emerging health technologies. http://whqlibdoc.who.int/hq/2011/WHO_HSS_EHT_DIM_11.02_eng.pdf (accessed Jan 3, 2012). 2011.

26 Zeschky M, Widenmayer B, Gassman O. Frugal innovation in emerging markets: the case of Mettler Toledo. *RMT* 2011; **54:** 38–45.

27 Matlin SA, Samuels GMR. The Global Health Research and Innovation System (GHRIS). *Lancet* 2009; **374:** 1662–63.

28 Simonetti R, Archibugi D, Evangelista R. Product and process innovations—how are they defined—how are they quantified. *Scientometrics* 1995; **32:** 77–89.

29 Chassin MR. Is health care ready for Six Sigma quality? *Milbank Q* 1998; **76:** 565–91.

30 Rabbani F, Lalji SN, Abbas F, et al. Understanding the context of balanced scorecard implementation: a hospital-based case study in Pakistan. *Implement Sci* 2011; **6:** 31.

31 Anand G. The Henry Ford of Heart Surgery. *The Wall Street Journal* Nov 25, 2009. http://online.wsj.com/article/SB125875892887958111.html (accessed Jan 23, 2012).

32 Gates B. Annual Letter from Bill Gates. http://www.gatesfoundation.org/annual-letter/2012/Documents/2012-annual-letter-english.pdf (accessed Jan 27, 2012). Bill & Melinda Gates Foundation, 2012.

33 Cutler DM, McClellan M. Is technological change in medicine worth it? *Health Aff (Millwood)* 2001; **20:** 11–29.

34 WHO. The World Health Report 1999—making a difference. http://www.who.int/whr/1999/en/index.html (accessed May 19, 2012).

35 Eight Goals for 2015. http://www.undp.org/content/undp/en/home/mdgoverview.html (accessed Jan 21, 2012). United Nations Development Programme, 2012.

36 Waage J, Banerji R, Campbell O, et al. The Millennium Development Goals: a cross-sectoral analysis and principles for goal setting after 2015. *Lancet* 2010; **376:** 991–1023.

37 UN. The Millenium Development Goals Report. Addendum Goal 4: Reduce Childhood Mortality. http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2011/11-31339%20(E)%20MDG%20Report%202011_HR_4%20Addendum%20NEW.pdf (accessed Jan 23, 2012). 2011.

38 The American National Redcross. Measles Initiative. http://www.measlesinitiative.org/portal/site/mi/menuitem.49e6575162334463c1062b10133f78a0/?vgnextoid=e79ed78aa7ca3210VgnVCM10000089f0870aRCRD&vgnextfmt=default (accessed Jan 14, 2012). 2009.

39 Innovating for every woman, every child. Thematic report: the global campaign for the health millennium development goals. http://www.who.int/pmnch/activities/jointactionplan/innovation_report_lowres_20110830.pdf (accessed Jan 13, 2012). 2011.

40 Niessen LW, ten Hove A, Hilderink H, Weber M, Mulholland K, Ezzati M. Comparative impact assessment of child pneumonia interventions. *Bull World Health Organ* 2009; **87:** 472–80.

41 International Vaccine Access Centre. Pneumonia progress report. http://worldpneumoniaday.org/wp-content/uploads/2011/11/ivac-2011_pneumonia_progress_report.pdf (accessed Jan 4, 2012). 2011.

42 Alliance for the Prudent Use of Antibiotics. http://www.tufts.edu/med/apua/index.shtml (accessed Jan 12, 2012).

43 Ashraf H, Jobayer M, Alam N. Treatment of childhood pneumonia in developing countries. http://www.intechopen.com/books/health-management/treatment-of-childhood-pneumonia-in-developing-countries (accessed Jan 23, 2012).

44 WHO. Global Pulse Oximetry Project. First International Consultation Meeting. 2008. http://www.who.int/patientsafety/events/08/1st_pulse_oximetry_meeting_background_doc.pdf (accessed Jan 5, 2012).

45 Pierce NF. How much has ORT reduced child mortality? *J Health Popul Nutr* 2001; **19:** 1–3.

46 Ruxin JN. Magic bullet: the history of oral rehydration therapy. *Med Hist* 1994; **38:** 363–97.

47 Bines JE. Rotavirus vaccines and intussusception risk. *Curr Opin Gastroenterol* 2005; **21:** 20–25.

48 Simonsen L, Viboud C, Elixhauser A, Taylor RJ, Kapikian AZ. More on RotaShield and intussusception: the role of age at the time of vaccination. *J Infect Dis* 2005; **192** (suppl 1)**:** S36–43.

49 Abdel-Kader H. International Medica Foundation reaches major milestone in developing heat-stable rotavirus vaccine. *Business Wire* May 23, 2011. http://www.pr-inside.com/international-medica-foundation-reaches-r2610790.html (accessed Jan 5, 2012).

50 Sanchez-Padilla E, Grais RF, Guerin PJ, Steele AD, Burny ME, Luquero FJ. Burden of disease and circulating serotypes of rotavirus infection in sub-Saharan Africa: systematic review and meta-analysis. *Lancet Infect Dis* 2009; **9:** 567–76.

51 Hill A. GlaxoSmithKline and Merck & Co have pledged to offer their rotavirus vaccines at discounted prices to developing countries 2011. http://www.inpharm.com/news/158751/gsk-and-merck-cut-vaccine-prices (accessed Jan 23, 2012).

52 Gatt B. GSK offers to supply rotavirus vaccine to developing countries. *Bloomberg* June 6, 2011. http://www.bloomberg.com/news/2011-06-05/gsk-offers-to-supply-rotavirus-vaccine-to-developing-countries.html (accessed July 20, 2011).

53 Hofman JJ, Dzimadzi C, Lungu K, Ratsma EY, Hussein J. Motorcycle ambulances for referral of obstetric emergencies in rural Malawi: do they reduce delay and what do they cost? *Int J Gynaecol Obstet* 2008; **102:** 191–97.

54 WHO. How a new vehicle is saving mothers' and babies' lives in Malawi. *Making Pregnancy Safer* 2009; **7:** 3–4. http://www.who.int/hac/techguidance/pht/mps_newlsetter_feb2009.pdf (accessed Aug 31, 2012).

55 WHO. Recommendation for the prevention of postpartum haemorrhage. Geneva: World Health Organisation, 2006.

56 Public Private Partnership for the Development of Heat-Stable Oxytocin. MDG5 meshwork for improving maternal health. http://www.mdg5-meshwork.org/content/public-private-partnership-development-heat-stable-oxytocin (accessed Jan 5, 2012). 2011.

57 Haynes AB, Weiser TG, Berry WR, et al. A surgical safety checklist to reduce morbidity and mortality in a global population. *N Engl J Med* 2009; **360:** 491–99.

58 WHO. Safe childbirth checklist. WHO Programmes and projects, 2012. http://www.who.int/patientsafety/implementation/checklists/childbirth/en/index.html (accessed Jan 5, 2012).

59 Spector JM, Agrawal P, Kodkany B, et al. Improving quality of care for maternal and newborn health: prospective pilot study of the WHO Safe Childbirth Checklist Program. *PLoS One* 2012; **7:** e35151.

60 Draper BH, Morroni C, Hoffman M, et al. Depot medroxyprogesterone versus norethisterone oenanthate for long-acting progestogenic contraception. *Cochrane Database Syst Rev* 2006; **3:** CD005214.

61 Program for Appropriate Technology in Health. The radically simple Uniject injections system. http://www.path.org/our-work/uniject.php (accessed Aug 23, 2011). 2011.

62 Program for Appropriate Technology in Health. Increasing contraceptive options: providing depo-subQ provera 104™ in the Uniject™ Injection system. http://www.path.org/projects/uniject-dmpa.php (accessed Jan 15, 2012). 2011.

63 Concept Foundation. Access to hormonal contraception. http://www.conceptfoundation.org/hormonal-contraception.php (accessed Jan 5, 2012). 2009.

64 JustMilk. Combating mother-to-child HIV transmission. http://justmilk.org/ (accessed March 16, 2012). 2012.

65 International Aids Vaccine Initiative. Estimating the impact of an AIDS vaccine in developing countries. http://www.iavi.org/Information-Center/Publications/Pages/Estimating-the-Impact-of-an-AIDS-Vaccine-in-Developing-Countries.aspx.

66 Cohen MS, Chen YQ, McCauley M, et al. Prevention of HIV-1 infection with early antiretroviral therapy. *N Engl J Med* 2011; **365:** 493–505.

67 Calmy A, Klement E, Teck R, Berman D, Pecoul B, Ferradini L. Simplifying and adapting antiretroviral treatment in resource-poor settings: a necessary step to scaling-up. *AIDS* 2004; **18:** 2353–60.

68 AVERT. Reducing the price of HIV/AIDS treatment. http://www.avert.org/generic.htm (accessed Jan 5, 2011). 2011.

69 DeCock KM. WHO at the 2009 HIV/AIDS implementers' meeting. http://www.who.int/hiv/events/implementers2009_kdc/en/index.html (accessed July 27, 2012). 2009. World Health Organization.

70 WHO. New HIV recommendation to improve health, reduce infection and save lives. http://www.who.int/mediacentre/news/releases/2009/world_aids_20091130/en/index.html (accessed Jan 7, 2012). 2009.

71 WHO. Global price reporting mechanism for HIV, malaria and tuberculosis. http://www.who.int/hiv/amds/gprm/en/index.html (accessed Jan 7, 2012).

72 Walensky RP, Wood R, Ciaranello AL, et al. Scaling up the 2010 World Health Organization HIV treatment guidelines in resource-limited settings: a model-based analysis. *PLoS Med* 2010; **7:** e1000382.

73 WHO. World Malaria Report. http://www.who.int/malaria/world_malaria_report_2011/en/index.html (accessed March 12, 2012).

74 Murray CJ, Rosenfeld LC, Lim SS, et al. Global malaria mortality between 1980 and 2010: a systematic analysis. *Lancet* 2012; **379:** 413–31.

75 Eisele TP, Larsen D, Steketee RW. Protective efficacy of interventions for preventing malaria mortality in children in *Plasmodium falciparum* endemic areas. *Int J Epidemiol* 2010; **39** (suppl 1)**:** i88–101.

76 Akachi Y, Atun R. Effect of investment in malaria control on child mortality in sub-Saharan Africa in 2002–2008. *PLoS One* 2011; **6:** e21309.

77 Roll Back Malaria Partnership. Progress and impact series: a decade of partnership and results. http://www.rbm.who.int/ProgressImpactSeries/docs/report8-en.pdf (accessed 23 Jan, 2012). 2011.

78 Madala J. Net Works. http://www.africa.com/handeye/Net-Works,27.html (accessed Jan 5, 2012). 2012.

79 Ng'ang'a P, Jayasinghe G, Kimani V, et al. Bed net use and associated factors in a rice farming community in central Kenya. *Malaria J* 2009; **8:** 64.

80 Conway G, Delaney S, Waage J. Science and innovation for development. London, UK: Collaborative on Development Sciences, 2010.

81 Adeyi O, Atun R. Universal access to malaria medicines: innovation in financing and delivery. *Lancet* 2010; **376:** 1869–71.

82 Agnandji ST, Lell B, Soulanoudjingar SS, et al. First results of phase 3 trial of RTS,S/AS01 malaria vaccine in African children. *N Engl J Med* 2011; **365:** 1863–75.

83 Akachi Y, Zumla A, Atun R. Investing in improved performance of national tuberculosis programs reduces the tuberculosis burden: analysis of 22 high-burden countries, 2002–2009. *J Infect Dis* 2012; **205** (suppl 2)**:** S284–92.

84 Urdea M, Penny LA, Olmsted SS, et al. Requirements for high impact diagnostics in the developing world. *Nature* 2006; **444** (suppl 1)**:** 73–79.

85 Boehme CC, Nicol MP, Nabeta P, et al. Feasibility, diagnostic accuracy, and effectiveness of decentralised use of the Xpert MTB/RIF test for diagnosis of tuberculosis and multidrug resistance: a multicentre implementation study. *Lancet* 2011; **377:** 1495–505.

86 Foundation for Innovative New Diagnostics. FIND-negotiated prices for Xpert® MTB/RIF and country list. http://www.finddiagnostics.org/about/what_we_do/successes/find-negotiated-prices/xpert_mtb_rif.html (accessed Feb 2, 2012). 2010.

87 WHO. Towards universal access to diagnosis and treatment of multidrug-resistant and extensively drug-resistant tuberculosis by 2015. http://www.who.int/tb/publications/2011/mdr_report_2011/en/ (accessed Jan 5, 2012). 2011.

88 Glaziou P, Floyd K, Korenromp EL, et al. Lives saved by tuberculosis control and prospects for achieving the 2015 global target for reducing tuberculosis mortality. *Bull World Health Organ* 2011; **89:** 573–82.

89 Bill & Melinda Gates Foundation. Profiles of Progress: Ghana. http://www.gatesfoundation.org/agriculturaldevelopment/Pages/ghana-profiles-of-progress-global-development.aspx (accessed March 28, 2012). 2012.

90 Nestel P, Bouis HE, Meenakshi JV, Pfeiffer W. Biofortification of staple food crops. *J Nutr* 2006; **136:** 1064–67.

91 Center for Global Development. Millions saved: proven successes in global health. http://www.cgdev.org/doc/millions/Millions_Saved_07.pdf (accessed Jan 13, 2012). 2007.

92 UNICEF, WHO. Progress on drinking water and sanitation 2012 update. http://www.unicef.org/media/files/JMPreport2012.pdf (accessed March 25, 2012). 2012.

93 Thye YP, Templeton MR, Ali M. A critical review of technologies for pit latrine emptying in developing countries. *Crit Rev Environ Sci Technol* 2011; **41:** 1793–819.

94 Sanitation Ventures. Project Tiger. http://www.sanitationventures.com/innovation-project-tiger.htm (accessed Jan 23, 2012). 2011.

95 Esrey C. Rethinking sanitation: panacea or pandora's box. In: Chorus I, Ringelband U, Schlag G, Schmoll O, eds. Water Sanitation & Health. IWA Publishing, 2000.

96 WHO. First WHO report on neglected tropical diseases: working to overcome the global impact of neglected tropical diseases. http://www.who.int/neglected_diseases/2010report/en/ (accessed Aug 23, 2011). 2010.

97 Hotez PJ, Molyneux DH, Fenwick A, et al. Control of neglected tropical diseases. *N Engl J Med* 2007; **357:** 1018–27.

98 WHO. The Global Burden of Disease: 2004 update; 2008. http://www.who.int/healthinfo/global_burden_disease/2004_report_update/en (accessed Jan 4, 2012).

99 Mathers CD, Loncar D. Projections of global mortality and burden of disease from 2002 to 2030. *PLoS Med* 2006; **3:** e442.

100 General Assembly. Prevention and control of non-communicable diseases. http://www.un.org/ga/search/view_doc.asp?symbol=A/66/83&Lang=E (accessed Jan 24, 2012). United Nations, 2011.

101 WHO. Preventing chronic diseases: a vital investment. http://www.who.int/chp/chronic_disease_report/contents/foreword.pdf (accessed Jan 23, 2012). 2005.

102 WHO. Political decleration of the high-level meeting on the general assembly on the prevention and control of non-communicable diseases. New York: United Nations. 2011. http://www.un.org/ga/search/view_doc.asp?symbol=A/66/L.1 (accessed Dec 5, 2011).

103 Free C, Knight R, Robertson S, et al. Smoking cessation support delivered via mobile phone text messaging (txt2stop): a single-blind, randomised trial. *Lancet* 2011; **378:** 49–55.

104 WHO. Report of the Global Tobacco Epidemic, 2008: The MPOWER package. http://www.who.int/tobacco/mpower/mpower_report_full_2008.pdf (accessed Jan 5, 2012). 2008.

105 Rodgers A, Patel A, Berwanger O, et al. An international randomised placebo-controlled trial of a four-component combination pill ("polypill") in people with raised cardiovascular risk. *PLoS One* 2011; **6:** e19857.

106 Lonn E, Bosch J, Teo KK, Pais P, Xavier D, Yusuf S. The polypill in the prevention of cardiovascular diseases: key concepts, current status, challenges, and future directions. *Circulation* 2010; **122:** 2078–88.

107 Anderson BO, Cazap E, El Saghir NS, et al. Optimisation of breast cancer management in low-resource and middle-resource countries: executive summary of the Breast Health Global Initiative consensus, 2010. *Lancet Oncol* 2011; **12:** 387–98.

108 Denny L, Quinn M, Sankaranarayanan R. Chapter 8: Screening for cervical cancer in developing countries. *Vaccine* 2006; **24** (suppl 3)**:** S3/71–77.

109 Sankaranarayanan R, Nene BM, Shastri SS, et al. HPV screening for cervical cancer in rural India. *N Engl J Med* 2009; **360:** 1385–94.

110 WHO. World Health Organization guidelines: use of cryotherapy for cervical intraepithelial neoplasia. http://whqlibdoc.who.int/publications/2011/9789241502856_eng.pdf (accessed Jan 4, 2012). Geneva: World Health Organization, 2011.

111 QIAGEN Group. The careHPVTM Test. http://www.qiagen.com/about/whoweare/qiagencares/the-carehpv-test.pdf (accessed Jan 4, 2012). 2009.

112 Mittra I. Breast cancer screening in developing countries. *Prev Med* 2011; **53:** 121–22.

113 Coughlin SS, Ekwueme DU. Breast cancer as a global health concern. *Cancer Epidemiol* 2009; **33:** 315–18.

114 Shulman LN, Willett W, Sievers A, Knaul FM. Breast cancer in developing countries: opportunities for improved survival. *J Oncol* 2010; **2010:** 595167.

115 Shyyan R, Sener SF, Anderson BO, et al. Guideline implementation for breast healthcare in low- and middle-income countries: diagnosis resource allocation. *Cancer* 2008; **113** (8 suppl)**:** 2257–68.

116 Eniu A, Carlson RW, El Saghir NS, et al. Guideline implementation for breast healthcare in low- and middle-income countries: treatment resource allocation. *Cancer* 2008; **113** (8 suppl)**:** 2269–81.

117 Nantulya VM, Reich MR. The neglected epidemic: road traffic injuries in developing countries. *BMJ* 2002; **324:** 1139–41.

118 WHO. Global status report on road safety: time for action. http://www.who.int/violence_injury_prevention/road_safety_status/2009/en/ (accessed Jan 5, 2012). 2009.

119 O'Neill B, Mohan D. Reducing motor vehicle crash deaths and injuries in newly motorising countries. *BMJ* 2002; **324:** 1142–45.

120 Prince M, Patel V, Saxena S, et al. No health without mental health. *Lancet* 2007; **370:** 859–77.

121 WHO. Mental health and development: targeting people with mental health conditions as a vulnerable group. http://whqlibdoc.who.int/publications/2010/9789241563949_eng.pdf (accessed Jan 5, 2012). 2010.

122 WHO. mhGAP intervention guide for mental, neurological and substance use disorders in non-specialized health settings: Mental Health Gap Action Programme (mhGAP). http://whqlibdoc.who.int/publications/2010/9789241548069_eng.pdf (accessed Jan 3, 2012). 2010.

123 Patel V, Araya R, Chatterjee S, et al. Treatment and prevention of mental disorders in low-income and middle-income countries. *Lancet* 2007; **370:** 991–1005.

124 Foroushani PS, Schneider J, Assareh N. Meta-review of the effectiveness of computerised CBT in treating depression. *BMC Psychiatry* 2011; **11:** 131.

125 Kaltenthaler E, Parry G, Beverley C, Ferriter M. Computerised cognitive-behavioural therapy for depression: systematic review. *Br J Psychiatry* 2008; **193:** 181–84.

126 Naeem F, Gobbi M, Ayub M, Kingdon D. Psychologists experience of cognitive behaviour therapy in a developing country: a qualitative study from Pakistan. *Int J Ment Health Syst* 2010; **4:** 2.

127 WHO. Telemedicine: opportunities and developments in member states: report on the second global survey on eHealth. http://www.who.int/goe/publications/goe_telemedicine_2010.pdf (accessed Jan 15, 2012). 2009.

128 Weinberg J, Kaddu S, Gabler G, Kovarik C. The African Teledermatology Project: providing access to dermatologic care and education in sub-Saharan Africa. *Pan Afr Med J* 2009; **3:** 16.

129 Hazin R, Qaddoumi I. Teleoncology: current and future applications for improving cancer care globally. *Lancet Oncol* 2010; **11:** 204–10.

130 Antillon F, Baez FL, Barr R, et al. AMOR: a proposed cooperative effort to improve outcomes of childhood cancer in Central America. *Pediatr Blood Cancer* 2005; **45:** 107–10.

131 Cohen D, Sevadalis N, Taylor D. Emergency preparedness in the 21st century: training and preparation modules in virtual environments. *Rescusitation* 2012; published online May 29. http://dx.doi.org/10.1016/j.resuscitation.2012.05.014.

132 Chirac P, Torreele E. Global framework on essential health R&D. *Lancet* 2006; **367:** 1560–61.

133 Grace C. Comparative advantages of push and pull incentives for technology development: lessons for neglected disease technology development. *Global Forum Update on Research for Health* 2009; **6:** 147–51.

134 Wilson P. Giving developing countries the best shot: an overview of vaccine access and R&D. http://www.msf.or.jp/info/pressreport/pdf/06_04_MSFOxfam_Vaccine_Report_A4_Web_FINAL.pdf (accessed Jan 12, 2011). Oxfam International. 2010.

135 Egger M, May M, Chene G, et al. Prognosis of HIV-1-infected patients starting highly active antiretroviral therapy: a collaborative analysis of prospective studies. *Lancet* 2002; **360:** 119–29.

136 Zachariah R, Reid SD, Chaillet P, Massaquoi M, Schouten EJ, Harries AD. Viewpoint: Why do we need a point-of-care CD4 test for low-income countries? *Trop Med Int Health* 2011; **16:** 37–41.

137 Imperial College London. CD4 Initiative. http://www3.imperial.ac.uk/cd4 (accessed Feb 4, 2012). 2012.

138 Grand Challenges in Global Health. http://www.grandchallenges.org/Pages/Default.aspx (accessed Jan 23, 2012). 2012.

139 Gold ER, Kaplan W, Orbinski J, Harland-Logan S, N-Marandi S. Are patents impeding medical care and innovation? *PLoS Med* 2010; **7:** e1000208.

140 Simiyu K, Daar AS, Singer PA. Global health. Stagnant health technologies in Africa. *Science* 2010; **330:** 1483–84.

141 WHO. WHO test schedule for oxygen concentrators. Geneva: WHO Publications, 1991.

142 WHO. Oxygen therapy in the management of a child with an acute respiratory infection. Geneva: World Health Organization, 1995.

143 WHO. Informal consultation on clinical use of oxygen: meeting report 2–3 October. Geneva: World Health Organization, 2008.

144 Hoaglin M, Eifler A, McDermott A, Motan E, Beithon P. Integrated digital x-ray system for the WHIS-RAD. http://worldhealthimaging.org/WHIS-RAD_finalreport.pdf (accessed Feb 4, 2012). Africa Field Report. 2006.

145 WHITIA. Essential health technologies for safety net providers. http://www.worldhealthimaging.org/Global_Health.html (accessed March 28, 2012). 2009.

146 Parati G, Kilama M, Faini A, et al. A new solar-powered blood pressure measuring device for low-resource settings. *Hypertension* 2010; **56:** 1047–53.

147 Engineering World Health: Projects that matter. http://216.92.64.45/uploads/docs/11-12%20EWH%20Projects%20that%20Matter.pdf (accessed Jan 23, 2012). 2011.

148 X Prize Foundation. http://www.xprize.org (accessed Jan 12, 2012).

149 Kazatchkine M, Atun R, Lansang MA. A "pull" mechanism for innovation and new products. In: Global Forum update on research for health. Geneva: Global Forum for Health Research, 2009; **6:** 138–41.

150 Ridley DB, Grabowski HG, Moe JL. Developing drugs for developing countries. *Health Aff (Millwood)* 2006; **25:** 313–24.

151 GAVI Alliance. Pneumococcal AMC: innovative financing mechanism accelerates global roll out of vaccine against world's leading cause of child deaths. http://www.gavialliance.org/funding/pneumococcal-amc/ (accessed Jan 12, 2012). 2012.

152 Scudellari M. Are advance market commitments for drugs a real advance? *Nat Med* 2011; **17:** 139.

153 Cernuschi TF, McAdams E, Jones S, Fihman A, Schwalbe J. GAVI Alliance White Paper: Pneumococcal AMC: Lessons learnt on disease and design choices and processes. Geneva: GAVI Alliance, 2011.

154 WHO. Sickle-cell disease: a strategy for the WHO Africal region. Geneva: World Health Organization, 2010.

155 Rahimy MC, Gangbo A, Ahouignan G, Alihonou E. Newborn screening for sickle cell disease in the Republic of Benin. *J Clin Pathol* 2009; **62:** 46–48.

156 The Royal Society. Tanzanian scientist wins Royal Society Pfizer Award for Sickle Cell Disease research. http://royalsociety.org/news/Tanzanian-scientist-Pfizer-Award/ (accessed Jan 23, 2012). 2011.

157 Taskforce on Innovative International Financing for Health Systems. More money for health, and more health for money. http://www.hanshep.org/resources/further-reading/taskforce-for-innovative-international-financing-for-health-systems-2009-report/ (accessed Jan 12, 2012). 2009.

158 WHO. Intellectual property protection: impact on public health. *WHO Drug Info* 2005; **19:** 236–41.

159 Attaran A. How do patents and economic policies affect access to essential medicines in developing countries? *Health Aff (Millwood)* 2004; **23:** 155–66.

160 Goemaere E, Lotrofska M, Marchandy Y, Hoen E. Patent status matters. *Health Aff (Millwood)* 2004; **23:** 279–80.

161 WHO. Report of the Consultative Expert Working Group on Research and Development: financing and coordination. Research and development to meet health needs in developing countries: strengthening global financing and coordination. http://www.who.int/phi/CEWG_Report_5_April_2012.pdf (accessed April 13, 2012). 2012.

162 UNAIDS, WHO, UNDP. Using TRIPS flexibilities to improve access to HIV treatment. Policy brief. http://www.unaids.org/en/media/unaids/contentassets/documents/unaidspublication/2011/JC2049_PolicyBrief_TRIPS_en.pdf (accessed Jan 14, 2012). 2011.

163 WHO. Public health, innovation and intellectual property rights: report of the Commission on Intellectual Property Rights, Innovation and Public Health. http://www.who.int/intellectualproperty/en/ (accessed Jan 12, 2006). 2006.

164 WHO. Report of the Consultative Expert Working Group on Research and Development: financing and coordination (CEWG) third meeting Geneva. http://www.who.int/phi/news/cewg_2011/en/index.html (accessed Jan 12, 2012). 2011.

165 Kickbusch I, Silberschmidt G, Buss P. Global health diplomacy: the need for new perspectives, strategic approaches and skills in global health. *Bull World Health Organ* 2007; **85:** 230–32.

166 Institute E. Top 10 hospital technologies: C-Suite watch list for 2009 and beyond. https://www.ecri.org/Press/Pages/Top_10_Hospital_Technologies.aspx (accessed Jan 12, 2012). 2009.

167 Royal Brompton and Harefield NHS Foundation Trust Neonatal Incubator Appeal. http://www.justgiving.com/RBH-IncubatorAppeal/ (accessed June 10, 2011). 2010.

168 Amadi HO, Mokuolu OA, Adimora GN, et al. Digitally recycled incubators: better economic alternatives to modern systems in low-income countries. *Ann Trop Paediatr* 2007; **27:** 207–14.

169 Amadi HO, Azubuike JC, Etawo US, et al. The impact of recycled neonatal incubators in Nigeria: a 6-year follow-up study. *Int J Pediatr* 2010; **2010:** 269293.

170 Voltaire. Le Begueule, Conte Moral. 1772; Kessinger Publishing, 2009.

171 Drummond MF, Sculpher MJ, Torrance GW, O'Brien BJ, Stoddart GL. Methods for the economic evaluation of health care programmes, 3rd edn. Oxford: Oxford University Press, 2005.

172 Sehgal V, Dehoff K. Panneer G. The importance of frugal engineering. *Strategy and Business* 2010; **12:** 1–5.

173 Medical Device and Diagnostic Industry. Manufacturing medical devices with confidence in China. http://www.mddionline.com/article/manufacturing-medical-devices-confidence-china (accessed March 28, 2012). 2010.

174 Lister M. Transfer of medical technology to developing countries. *Indian Journal for the Practising Doctor* 2004; **1:** 69–74.

175 Sree Chitra Tirunal Institute for Medical Sciences & Technology (SCTIMST), Trivandrum. http://www.sctimst.ac.in (accessed Aug 26, 2011). 2012.

176 Oxfam urges India to remain 'Pharmacy of the Developing World'. http://www.oxfamindia.org/content/oxfam-urges-india-remain-%E2%80%98pharmacy-developing-world%E2%80%99 (accessed July 9, 2012).

177 Waning B, Diedrichsen E, Moon S. A lifeline to treatment: the role of Indian generic manufacturers in supplying antiretroviral medicines to developing countries. *J Int AIDS Soc* 2010; **13:** 35.

178 LaForce MF, Ravenscroft N, Djingarey M, Viviani S. Epidemic meningitis due to Group A *Neisseria meningitidis* in the African meningitis belt: a persistent problem with an imminent solution. *Vaccine* 2009; **27** (suppl 2)**:** B13–19.

179 Jennings M. Bednet production in Tanzania—successes and threats. http://www.mdg-review.org/index.php/sections/39-healthcare/238-bednet-production-in-tanzania-successes-and-threats (accessed March 23, 2012). 2011.

180 Bloom DC, Weston M. The value of vaccination. *World Economics* 2005; **6:** 15–39.

181 Resch S, Korenromp E, Stover J, et al. Economic returns to investment in AIDS treatment in low and middle income countries. *PLoS One* 2011; **6:** e25310.

182 The World Bank. Africa. http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/0,,menuPK:258649~pagePK:158889~piPK:146815~theSitePK:258644,00.html (accessed Jan 12, 2012). 2012.

183 WHO. Innovative technologies that address the global health concerns. http://whqlibdoc.who.int/hq/2010/WHO_HSS_EHT_DIM_10.12_eng.pdf (accessed Jan 12, 2012). 2010.

184 WHO. World Health Statistics, 2009. http://whqlibdoc.who.int/publications/2009/9789241563819_eng.pdf (accessed Jan 11, 2012).

185 Bhutta ZA, Chopra M, Axelson H, et al. Countdown to 2015 decade report (2000–10): taking stock of maternal, newborn, and child survival. *Lancet* 2010; **375:** 2032–44.

186 The Medicines Transparency Alliance Zambia. Disclosure status of Pharmaceutical Sector data. http://www.medicinestransparency.org/fileadmin/uploads/Documents/countries/Data_disclosure_PDFs/MeTA_Zambia_Data_Disclosure_Survey.pdf (accessed Jan 10, 2012). 2010.

187 MEDIKits. Smithsonian's Cooper-Hewitt, National Design Museum. http://www.designother90.org/cities/solutions/medikits (accessed Jan 5, 2012). 2011.

188 Child and Family Wellness Shops. The Healthstore Foundation. http://www.healthstore.org/overview.html (accessed Jan 12, 2012). 2003.

189 Republic of Kenya Ministry of Health. Assessment of the pharmaceutical situation in Kenya: a baseline survey. http://apps.who.int/medicinedocs/documents/s16425e/s16425e.pdf (accessed Jan 12, 2012). 2003.

190 Frew SE, Liu VY, Singer PA. A business plan to help the 'global South' in its fight against neglected diseases. *Health Aff (Millwood)* 2009; **28:** 1760–73.

191 Tran J. Next billion: development through enterprise. 'Very Simple' Business Model: Product Franchising. http://www.nextbillion.net/blogpost.aspx?blogid=688 (accessed July 3, 2011). 2007.

192 Godlee F, Pakenham-Walsh N, Ncayiyana D, Cohen B, Packer A. Can we achieve health information for all by 2015? *Lancet* 2004; **364:** 295–300.

193 Internet World Stats. Internet usage statistics for Africa. http://www.internetworldstats.com/stats1.htm (accessed Jan 12, 2012). 2011.

194 WHO. HINARI. http://www.who.int/hinari/about/en/ (accessed Feb 5, 2012). 2012, Geneva.

195 WHO. Sharing eHealth intellectual property for development. http://www.who.int/kms/initiatives/shipdinitiative/en/index.html (accessed Jan 5, 2012). 2012.

196 Crisp N. Turning the World Upside Down: The Search for Global Health in the 21st Century, 1st edn. London: RSM Books, 2010.

197 De Jong R. Health care chronicles: helping developing countries get radiology ready. http://www.dotmed.com/news/story/14859 (accessed Feb 2, 2012). 2011.

198 Malkin RA. Design of health care technologies for the developing world. *Annu Rev Biomed Eng* 2007; **9:** 567–87.

199 Mullan F, Frehywot S. Non-physician clinicians in 47 sub-Saharan African countries. *Lancet* 2007; **370:** 2158–63.

200 Khambete N. Personal Communication. 2011.

201 UNICEF. Rwanda. http://www.unicef.org/infobycountry/rwanda_statistics.html (accessed June 11, 2011). 2012.

202 Engineering World Health. BMET Training in Rwanda. http://www.ewh.org/index.php/programs/BMET/rwanda (accessed June 11, 2011). 2011.

203 International Energy Agency. Access to Electricity. http://www.iea.org/weo/electricity.asp (accessed May 13, 2011). 2011.

204 Apple J, Vicente R, Yarberry A, et al. Characterisation of particulate matter size distribution and indoor concentration from kerosene and diesel lamps. *Indoor Air* 2010; **20:** 399–411.

205 E.quinox. http://www.e.quinox.org (accessed Jan 3, 2012). Imperial College London.

206 The Shakerscope. http://www.shakerscope.com/theshakerscope.htm (accessed June 12, 2011). 2005.

207 Chung JW, Meltzer DO. Estimate of the carbon footprint of the US health care sector. *JAMA* 2009; **302:** 1970–72.

208 Barone MA, Ndede F, Li PS, et al. The Shang Ring device for adult male circumcision: a proof of concept study in Kenya. *J Acquir Immune Defic Syndr* 2011; **57:** e7–12.

209 Gyekye K. Technology and culture in a developing country. In: Fellows R, ed. Philosophy and Technology. Cambridge University Press, 1995.

210 Allegranzi B, Memish ZA, Donaldson L, Pittet D. Religion and culture: potential undercurrents influencing hand hygiene promotion in health care. *Am J Infect Control* 2009; **37:** 28–34.

211 Muslim World League. Resolutions of the Islamic Fiqh Council. Proceedings of the Six Resolutions of the 16th Session, Makkah Mukarramah, Saudi Arabia. http://www.themwl.org (accessed Jan 4, 2012). 2002.

212 Cabinet Office. Applying behavioural insight to health. http://www.cabinetoffice.gov.uk/sites/default/files/resources/403936_BehaviouralInsight_acc.pdf (accessed Aug 23, 2011). 2010.

213 Cabinet Office and Institute for Government, MINDSPACE: Influencing Behaviour through public policy. 2010.

214 Chandisarewa W, Stranix-Chibanda L, Chirapa E, et al. Routine offer of antenatal HIV testing ("opt-out" approach) to prevent mother-to-child transmission of HIV in urban Zimbabwe. *Bull World Health Organ* 2007; **85:** 843–50.

215 Creek TL, Ntumy R, Seipone K, et al. Successful introduction of routine opt-out HIV testing in antenatal care in Botswana. *J Acquir Immune Defic Syndr* 2007; **45:** 102–07.

216 Yamey G. Scaling up global health interventions: a proposed framework for success. *PLoS Med* 2011; **8:** e1001049.

217 Atun R, De Jongh T, Secci F, Ohiri K, Adeyi O. Integration of targeted health interventions into health systems: a conceptual framework for analysis. *Health Policy Plan* 2010; **25:** 104–11.

218 Bloom G, Ainsworth P. Beyond scaling up: pathways to universal access to health services. http://steps-centre.org/wpsite/wp-content/uploads/Beyond_Scaling_Up_web.pdf (accessed Jan 12, 2012). 2010.

219 WHO. Health technology assessment of medical devices. http://whqlibdoc.who.int/publications/2011/9789241501361_eng.pdf (accessed June 13, 2012). 2011.

220 Shelton JD. Twenty criteria to make the best of scarce health resources in developing countries. *BMJ* 2011; **343:** d7023.

221 Barlow J, Bayer S. Raising the profile of simulation and modelling in health services planning and implementation. *J Health Serv Res Policy* 2011; **16:** 129–30.

222 Tediosi F, Maire N, Penny M, Studer A, Smith TA. Simulation of the cost-effectiveness of malaria vaccines. *Malaria J* 2009; **8:** 127.

223 Reyburn H, Mbakilwa H, Mwangi R, et al. Rapid diagnostic tests compared with malaria microscopy for guiding outpatient treatment of febrile illness in Tanzania: randomised trial. *BMJ* 2007; **334:** 403.

224 Thomson J. Web of deceit. http://www.efna.net/pdfs/publications/ScienceAndSociety/S_S%20Issue%2001.pdf (accessed June 12, 2011). *Science and Society*, Autumn 2010.

225 Sanofi-Aventis. Drug counterfeiting. http://ec.europa.eu/internal_market/indprop/docs/conf2008/wilfried_roge_en.pdf (accessed Jan 4, 2012). 2011.

226 WHO. Expert Committee on Specifications for Pharmaceutical Preparations. http://whqlibdoc.who.int/trs/WHO_TRS_704.pdf (accessed Jan 5, 2012). 1984.

227 WHO. Spurious/falsely-labelled/falsified/counterfeit (SFFC) medicines. www.who.int/medicines/services/counterfeit (accessed Jan 5, 2012). 2012.

228 WHO. International Medical Products Anti-Counterfeiting Taskforce. http://www.who.int/impact/en/ (accessed June 11, 2012). 2011.

229 Kannan S. Counterfeit drugs targeted by technology in India. http://www.bbc.co.uk/news/business-15208595 (accessed Jan 5, 2012). 2011.

230 Dass R, Gajjar B. Anti-counterfeit technologies for spurious drugs in India. *International Journal of User-Driven Healthcare* 2011; **1:** 42–52.

231 Medicines and Healthcare products Regulatory Agency (MHRA). Counterfeit medicines and devices. http://www.mhra.gov.uk/Safetyinformation/Generalsafetyinformationandadvice/Adviceandinformationforconsumers/Counterfeitmedicinesanddevices/index.htm (accessed Jan 3, 2012). 2012.

232 US Office of Health and Consumer Goods. Medical Devices Industry Assessment. http://ita.doc.gov/td/health/medical%20device%20industry%20assessment%20final%20ii%203-24-10.pdf (accessed Jan 12, 2012). 2010, Washington, DC.

233 The Lancet. Striving for universal health coverage. *Lancet* 2010; **376:** 1799.

234 Sachs JD. Sustainable developments. Good news on malaria control. *Sci Am* 2009; **301:** 29.

235 Lengeler C, deSavigny D. Programme diversity is key to the success of insecticide-treated bednets. *Lancet* 2007; **370:** 1009–10.

236 Aravind Eye Care System. http://www.aravind.org/Clinics/aehMadurai.aspx (accessed Jan 3, 2012). 2011.

237 Rangan K. Aravind Eye Hospital, Madurai, India: in service for sight. Harvard Business Review, 1993.

238 Microensure: Health Insurance. 2011. http://www.microensure.com/products-health.asp (accessed June 15, 2011).

239 Smith S, Newhouse JP, Freeland MS. Income, insurance, and technology: why does health spending outpace economic growth? *Health Aff (Millwood)* 2009; **28:** 1276–84.

240 Christensen C, Bohmer R, Kenagy J. Will disruptive innovations cure healthcare? Harvard Business Review, 2000.

241 Christensen C, Hwang J, Grossman JH. The Innovator's Prescription. New York: MCGraw Hill, 2009.

242 General Electric Company. MAC 400 Resting ECG analysis system fact sheet. http://www.gehealthcare.com/euen/healthymagination/pdf/Factsheet_MAC400.pdf (accessed Jan 3, 2012). 2007.

243 Sequist TD, Marshall R, Lampert S, Buechler EJ, Lee TH. Missed opportunities in the primary care management of early acute ischemic heart disease. *Arch Intern Med* 2006; **166:** 2237–43.

244 Fry C, Marjanovic S, Yaqub O, Chataway J. Health innovation transfer from south to north. http://www.rand.org/content/dam/rand/pubs/documented_briefings/2011/RAND_DB616.pdf (accessed Jan 12, 2012). RAND Europe. 2011.

245 Rabkin M, El-Sadr WM, Mugyenyi P, Ramatlapeng MK, De Cock KM. Lessons from Africa. *J Acquir Immune Defic Syndr* 2010; **55** (suppl 2): S141–43.

246 USAID Request for applications: the technologoes for health program. 2011. http://www.fundsforngos.org/united-states/usaid-request-applications-technologies-health-program/ (accessed Jan 5, 2012).

247 UN. Human Development Report 2001. Making new technologies work for human development. http://hdr.undp.org/en/media/completenew1.pdf (accessed Jan 12, 2012). 2001.

248 Juma C. Going for growth: science, technology and innovation in Africa. London: The Smith Institute, 2005.

249 Juma C. We need to reinvent the African university. http://www.scidev.net/en/opinions/we-need-to-reinvent-the-african-university.html (accessed Jan 3, 2012). 2005.

250 Tropical Health and Education Trust. http://www.thet.org/health-links/resources-for-links/about-links/ (accessed Jan 12, 2012). 2012.