Regenerative medicine: new opportunities for developing countries

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Abstract: There has been a major shift in burden of disease in developing countries. Although traditionally associated with industrialised nations, epidemic levels of non-communicable diseases, such as diabetes, cardiovascular diseases and cancer, now threaten the developing world and are straining health systems that are still struggling with persisting levels of infectious disease. Developing countries need innovative and affordable ways of dealing with this ‘double burden’. The emerging field of regenerative medicine may provide new opportunities to address these health needs if employed with the goal of improving global health equity. Several developing countries themselves have recognised the potential of regenerative medicine and have initiated Research and Development work in this field. We present here the results of a survey of regenerative medicine activities in developing countries, and argue that domestic Science and Technology capacity building and innovation in regenerative medicine can help developing countries to harness its benefits towards low-cost solutions for some of their most pressing health needs.

Keywords: regenerative medicine; developing countries; global health equity; double burden; stem cells; tissue engineering; gene therapy; organ replacement; innovative capacity.


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1 Introduction

An epidemiological transition has occurred in developing countries, such that traditional assumptions regarding their burden of disease are no longer valid. Once thought of as ‘Western diseases’, non-communicable diseases, such as diabetes, cardiovascular diseases and cancer, are rapidly increasing in low- and middle-income countries on top of the persisting threat of infectious disease. This phenomenon is so severe that the World Health Organization refers to non-communicable diseases in the developing world as “neglected epidemics” (WHO, 2003). Worldwide, non-communicable diseases now account for more deaths annually than infectious diseases. By 2020, it is estimated that 7 out of 10 deaths in developing countries will be attributable to non-communicable diseases (Boutayeb and Boutayeb, 2005). Developing countries now account for 80% of global cardiovascular disease-related deaths; two-thirds of the 171 million people worldwide affected by diabetes reside in developing countries; cancer rates are expected...
to increase by 73% in developing countries between 2000 and 2020, compared to a 29% increase in industrialised nations (Boutayeb and Boutayeb, 2005; Marshall, 2004). In addition, non-communicable diseases are affecting people at an earlier age in developing countries than in developed countries (Boutayeb and Boutayeb, 2005).

The burden of non-communicable diseases in developing countries is worsened by the connection between non-communicable and certain infectious diseases. Two billion people worldwide, for instance, have been infected with the hepatitis B virus, which can lead to cirrhosis, liver failure or hepatocellular carcinoma (Lavanchy, 2004). In addition, low- and middle-income countries account for almost 90% of the world’s deaths due to injury and trauma (Hofman et al., 2005) and for 80% of the world’s disabled population, the vast majority of whom have little or no access to rehabilitation facilities. These conditions could all benefit from methods of addressing the impaired bodily function that they produce.

Developing countries need innovative and affordable ways of addressing this ‘double burden’ of communicable and non-communicable disease. Prolonged and costly care of non-communicable diseases is draining limited resources from families and the healthcare system, as well as halting the economic productivity of contributing members of the workforce (Boutayeb and Boutayeb, 2005; Commission on Macroeconomics and Health, 2001). As levels of non-communicable diseases rise in developing countries, they contribute further to the current global inequity in health. In developing countries, those who develop chronic disease will frequently die prematurely due to inadequate treatment, while those in industrialised nations can afford costly measures to manage their disease (Boutayeb and Boutayeb, 2005).

Science and technology by themselves cannot resolve the complex development challenges faced by developing countries, nor do they address the lifestyle and socio-political factors that are key contributors to the global increase in the rates of non-communicable disease. The 2005 report of the UN Millennium Project Task Force on Science, Technology and Innovation emphasises, however, that science and technology are important components of a comprehensive strategy to improve health in developing countries (UN Millennium Project, 2005). Regenerative medicine is an emerging field that may offer innovative ways of addressing the health needs of developing countries. To ensure that regenerative medicine is utilised to improve global health equity rather than to contribute further to the problem, developing countries themselves must become active in the field. Several developing countries have already initiated work in regenerative medicine. We provide here a survey of regenerative medicine activities in developing countries and argue that domestic Science and Technology capacity building and innovation in regenerative medicine can help developing countries to harness its benefits towards the development of low-cost solutions for some of their most pressing health needs.

2 A new field presenting new opportunities

Regenerative medicine has the potential to dramatically improve our ability to fight disease and to repair the human body (Haseltine, 2003). It combines the knowledge and skills of several disciplines towards the aim of addressing impaired function in the body. Its goal is not just to replace what is malfunctioning, but to provide the elements required for in vivo repair, to devise replacements that seamlessly interact with the living body and
to stimulate the body’s intrinsic capacities to regenerate. Still a young field, regenerative medicine lacks a widely accepted definition (Mironov et al., 2004). We provide the following definition to capture its goals, targets and methods:

“Regenerative Medicine is an emerging interdisciplinary field of research and clinical applications focused on the repair, replacement or regeneration of cells, tissues or organs to restore impaired function resulting from any cause, including congenital defects, disease, trauma and aging. It uses a combination of several technological approaches that moves it beyond traditional transplantation and replacement therapies. These approaches may include, but are not limited to, the use of soluble molecules, gene therapy, stem cell transplantation, tissue engineering and the reprogramming of cell and tissue types.”

A key facet of the field of regenerative medicine is its interdisciplinary nature, incorporating expertise from disciplines such as stem cell biology, cell, tissue and organ transplantation, genetics and molecular biology and tissue engineering. As strides were taken to develop innovative solutions for impaired function in the body, disparate areas of research converged and combined their knowledge and expertise (Haseltine, 2003). This knowledge flow between several disciplines makes it possible to derive innovative approaches to health problems. The field of regenerative medicine exhibits the following characteristics: collaboration between a group of individuals with heterogeneous skills and experiences; a focus on applicability; the development of transdisciplinary solutions that go beyond any single contributing discipline; the involvement of actors external to the science and technology sectors due to an increased need for social accountability and the participation of a variety of organisations, including research universities, government institutions and industry, whose funding is derived from diverse sources. These characteristics are typical of Mode 2 knowledge production (Gibbons et al., 1994).

The US National Academy of Sciences has estimated that the potential US patient populations for stem cell-based therapies and hence for regenerative medicine, range in the millions. These estimates include 58 million patients for cardiovascular disease, 30 million patients for autoimmune diseases, 16 million patients for diabetes and 10 million patients for osteoporosis (Commission on Life Sciences, 2002). However, to our knowledge, the potential benefits for developing countries have not been included in these discussions of impact. This omission is unfortunate, severe and unacceptable, given that over two-thirds of the world’s population live in developing countries and that developing countries will bear most of the increasing burden of non-communicable diseases (Boutayeb and Boutayeb, 2005), the main target of regenerative medicine. In addition, prevalent infectious diseases in developing countries, as well as nutritional deficiencies, often lead to organ failure, and developing countries stand to benefit from the potential of regenerative medicine to remedy severe organ shortages and remove the need for costly immunosuppressant regimens.

On the basis of the literature regarding health innovation in developing countries (Juma and Yee-Cheong, 2005; Morel et al., 2005), as well as our own experience in studying successful biotechnology sectors in developing countries (Thorsteinsdóttir et al., 2004), we believe that building capacity and encouraging local innovation in regenerative medicine can help developing countries to harness its benefits to address some of the pressing health needs presented by the ‘double burden’. Local innovation is a
means by which developing countries can focus on local health needs sometimes neglected by the industrialised countries and multinational pharmaceutical companies (Commission on Intellectual Property, Innovation and Public Health, 2005). Health innovation in developing countries is increasingly recognised as a contributor to sufficiency and sustainability and as a complement to aid initiatives, which largely stem from the developed world (Morel et al., 2005). In case studies of the health biotechnology sectors of seven developing countries, a focus on local health needs was identified as a key element to their success. Building local capacity in health biotechnology was also found to increase the availability of health products to the populations in developing countries as well as to create new opportunities for economic development (Thorsteinsdóttir et al., 2004).

The cost of new health-related technologies is an important issue for developing countries, as governments and individuals often have very limited resources and cost is intricately linked to access the treatment. Although it is too premature to provide cost analyses for applications of regenerative medicine, we must recognise that affordability will be a key determinant of the impact that regenerative medicine has on the general population of developing countries. It is possible to speculate that if developing countries themselves are active in regenerative medicine, they might have a greater motivation than industrialised nations to design affordable and accessible products. Studies of biotechnology sectors in developing countries have shown that local innovation in science and technology can lead to more affordable treatments for the populations of developing countries (Thorsteinsdóttir et al., 2004). For instance, when the Indian biotechnology company Biocon began selling their human recombinant insulin product on the market in India, the amount they charged for one 5-ml vial of insulin was almost half of that charged by Eli Lilly and Novo Nordisk. In another case, India’s Shantha Biotechnics has developed a recombinant hepatitis B vaccine that sells for only 0.4 US dollar per dose as compared to imported vaccines, which sell for 8–10 US dollar per dose (Juma and Yee-Cheong, 2005). It is estimated that drug production costs in India are approximately 50% less than those in the US (Morel et al., 2005). Certain manufacturers in developing countries also recognise the large market presented by the poor in developing countries, and specifically target this market with low-cost products suited to their health needs (Prahalad, 2004).

3 Methodology

To begin to fill the empirical gap regarding regenerative medicine for developing countries, we performed a survey of regenerative medicine activities in developing countries. We built on earlier experiences in studying nanotechnology for the developing world (Court et al., 2004). As a first step, a keyword search defining regenerative medicine was established to standardise search parameters between researchers and to ensure that relevant activities were comprehensively captured. A list of six main keywords was compiled based on those used in regenerative medicine publications and on the above definition: regenerative medicine, tissue engineering, cell therapy, gene therapy, tissue regeneration and stem cells. Different forms of these main keywords were then identified (e.g. stem cell lines, stem cell therapy), a process called vertical analysis. Lateral analysis, a process to identify a second set of terms that are
frequently associated with the main keywords (e.g. cardiomyocytes, therapeutic cloning, cord blood cells), followed vertical analysis. The complete set of keywords identified is available from the authors upon request.

To survey regenerative medicine activities in developing countries, an internet search was coupled with a literature search and supplemented by occasional personal communication with contacts in developing countries. This strategy attempts to maximise the capture of regenerative medicine activities, as researchers from developing countries are under-represented in health-related academic publications (Paraje et al., 2005; Sumathipala et al., 2004), and industry activities are not often captured in academic publications.

We (specifically G. Perry and J. Renihan) performed searches on all countries listed by the World Bank as low- and middle-income. This listing contains 154 countries and does not include South Korea or Singapore. The researchers divided the countries between themselves, one beginning with middle-income countries, the other with low-income countries. For every country, each of the main keywords was coupled with the country name and used in Google to search the internet. An element of subjectivity was involved, as search results were then compared with the definition of regenerative medicine given above and with the list of secondary keywords frequently associated with the main keywords, to determine whether each hit constituted regenerative medicine. Discussions between the researchers occurred frequently throughout to maximise consistency and to clarify unclear cases. Any disagreement between the two researchers regarding whether a particular case constituted regenerative medicine was discussed in a larger group, with continual reference to the definition.

Following the internet searches, a literature search was conducted using ISI Web of Science (1945–2005) to capture institutional affiliations and publications not identified with Google. Similar search methods to those employed in Google were used, substituting keywords and country names in the Topic and Address fields, respectively, of Web of Science. In many cases, the literature search identified institutions already captured through Google searching, thus validating the results of the internet search. We recognise these primarily internet-level results as preliminary; however, they fill a complete void in existing knowledge regarding regenerative medicine activities in the developing world.

4 Regenerative medicine activities in developing countries

We found regenerative medicine activity in 31 low- and middle-income countries. Table 1 gives a summary of these findings, indicating for each country whether we found regenerative medicine activity in any of five areas: dedicated government funding, goods and services, companies, publications and academic institutions. Dedicated Government Funding denotes that government funds were earmarked specifically for regenerative medicine. Goods and Services was defined to include both products (e.g. bioengineered skin) and services (e.g. umbilical cord blood banking) available for purchase. Companies indicates private companies involved in regenerative medicine. Publications denotes peer-reviewed publications in academic journals, while Academic Institutions describes the presence of universities and research institutes conducting regenerative
medicine research. It should be noted that Table 1 indicates the presence of activity in a certain area, but does not describe levels of activity within an area. Countries were organised into four groups based on the areas of regenerative medicine in which they show activity:

1. activity in all categories
2. all categories except for dedicated government funding
3. companies and academic activity, but no goods and services
4. academic activity only.

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Table 1  Regenerative medicine activities in low- and middle-income countries (continued)

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*Though Cuba has no private companies, certain public sector institutions in Cuba carry out activities that are characteristic of private sector firms in other countries. The Genetic Engineering and Biotechnology Centre (CIGB), for instance, is currently engaged in clinical trials of their product Citoprot P, which induces tissue regeneration in diabetic ulcers and has conducted pilot gene therapy clinical trials for lower limb ischaemia and advanced myocardial ischaemia.*

**Note:** Cell therapy services are provided in Barbados, Dominican Republic and Ecuador, but are backed by US physicians and are not supported by publications. As these isolated occurrences are the only regenerative medicine activity in these countries, it was not considered significant enough to include.

We present here a more detailed description of six countries currently active in regenerative medicine: Argentina, China, India, Iran, Malaysia and South Africa. These countries were chosen because they show interesting and diverse activities in regenerative medicine, as well as representing various geographic regions of the world. In addition to detailing their activity, a brief description of the regulatory environment with respect to embryonic stem cell research is included for each country, as regulatory policies can have an important impact on where in the world research is conducted and in
which areas of regenerative medicine countries are active (Daar, 2005; Knowles, 2004; Preti, 2005). Narratives such as these are a first step towards understanding how developing countries are building capacity in regenerative medicine and using regenerative medicine to address some of their local health needs.

4.1 Argentina

Like many Latin American countries, Argentina’s policy on embryonic stem cell research is relatively restrictive (Isasi et al., 2004). Similar to Brazilian law, embryonic stem cell research is permitted in Argentina, but the derivation of embryos via therapeutic cloning is prohibited in addition to a ban on human reproductive cloning (Isasi et al., 2004; Nelson, 2005; Wheat and Matthews, 2004). Both these countries demonstrate that it is possible to conduct regenerative medicine research under a relatively restrictive regulatory environment. While Brazil has devoted significant funds towards a primary focus on bone-marrow-derived stem cell therapies for heart disease (Massarani, 2004), Argentina is pursuing diverse activities in adult stem cell and gene therapies for a wide range of diseases. A multidisciplinary medical team from the San Nicolás Clinic in Buenos Aires and the Bone Marrow Transplant Centre in Rosario, has treated over 100 heart patients with stem cells derived from their own bone marrow, and recently performed a similar procedure in a diabetic patient to restore pancreatic insulin production.

Several academic institutions in Argentina are actively researching gene therapies to address impaired function in the body. The National University of Córdoba has published results of gene therapy experiments in mice for the treatment of rheumatoid arthritis, which show that in 75% of treated cases joints appear normal as compared to the severe arthritis developed in the majority of the group that received no treatment (Rabinovich et al., 1999). The Universidad Nacional de La Plata and Universidad Nacional de Rosario are both involved in gene-based strategies for the treatment of cancers.

Argentinean researchers have been active in large-scale, successful, international collaborations in regenerative medicine. The Benetti Foundation in Rosario, an organisation dedicated to education and research for the treatment of heart disease, collaborated with researchers from the McGowan Institute of Regenerative Medicine in Pittsburgh and the Baylor University Medical Centre in Dallas to undertake the first prospective randomised trial of adult stem cell therapy for heart failure patients. Researchers say that this multi-centre clinical trial provides the first convincing evidence that adult stem cell transplantation is a viable treatment for severe congestive heart failure (Pilcher, 2004). Another collaboration, between Dr. Gustavo Rodolfo Goya of INBIO La Plata School of Medicine, University of La Plata and researchers at the University of Chicago, has received a Fogarty International grant to investigate the potential for the gene therapy to treat neurodegenerative diseases.

Although the majority of Argentina’s regenerative medicine activity is in the public domain, there is some private sector involvement. The Argentinean pharmaceutical company Craveri devotes a portion of its Research and Development work towards developing new therapies based on tissue engineering and gene therapy, while proposals for Thercell Argentina include the provision of cell technologies to treat cardiovascular disease and blindness, and researchers at Pharmatrix are engaged in studies on islet encapsulation technologies for pancreatic cell therapies.
4.2 China

In December 2003, China’s Ministry of Science and Technology and Ministry of Health released the country’s Ethical Guiding Principles on Human Embryonic Stem Cell Research. This document prohibits human reproductive cloning but allows therapeutic cloning, creating an environment in which regenerative medicine research could thrive (Yang, 2004). China’s government has begun investing heavily in regenerative medicine, launching programmes such as the Key Project of State High-Tech ‘Stem Cell and Tissue Engineering for Regenerative Medicine’, and funding government institutions such as the Tissue Engineering Research and Development Centre, as well as academic researchers and industry. China’s investment is beginning to show results. The Tissue Engineering Research and Development Centre has 14 pending patents and has published 45 papers on topics that include their successful results in generating bone and cartilage implants capable of inducing reparative effects in rabbits, dogs and sheep. The Stem Cell Base, for which facilities will be completed in 2010, has already gathered 6000 human tissue samples and aims to be Asia’s largest stem cell bank, capable of treating 200 patients a year. The Chinese Academy of Medical Sciences has launched phase 1 trials for the treatment of leukaemia using stem cells in tandem with bone marrow.

Industry involvement is also growing, with the help of government support. SinoCells has received $7.25 million in government funding to pursue its research on stem cell treatments for corneal disease. Another Chinese company, Moist Exposed Burn Ointment (MEBO) International Group has established the Beijing Rongxiang Institute of Regenerative Medicine Co., which is actively investigating methods of accelerating the regeneration and repair of wounds, particularly through its product MEBO. Shenzhen SiBiono GeneTech produced the first commercialised gene therapy product in the world in 2003 with its gene therapy cancer treatment for solid tumours Gendicine (Pearson et al., 2004).

China’s hospitals are key players in its regenerative medicine sector. Some are already using therapies clinically, such as at the Chaoyang Hospital where cells derived from fetal tissue have been employed in over 450 operations to repair neurological damage in conditions such as Amyotrophic Lateral Sclerosis (ALS), spinal cord injury and Parkinson’s disease. Controlled clinical trials, however, have yet to be performed (Mooney, 2004). Academic institutions involved in regenerative medicine include Shanghai No. 2 Medical University and Harbin Medical Sciences University (Cohen, 2003). Additionally, researchers from Tsinghua University are involved in teaching a training course entitled ‘Principles and Practice of Tissue Engineering’ at the Harvard-MIT Division of Health Science and Technology. China seems to have only limited international regenerative medicine collaborations, such as between Wuhang University and John Hopkins in Singapore to design functional scaffolds for tissue engineering. In a 2004 Nature commentary, Xiangzhong Yang emphasised the need for China to increase international collaborations to become a world leader in regenerative medicine (Yang, 2004).

4.3 India

Regenerative medicine in India is backed by strong support from the federal government through clear regulatory policies, as well as financial initiatives. India’s policy on stem cell research, laid down by the Department of Biotechnology, bans human cloning but...
permits therapeutic cloning provided that appropriate safety measures and informed consent procedures are followed.\textsuperscript{21,22} In January 2005, the Department of Biotechnology launched a national programme for stem cell research that includes research clusters in six cities and involves both government and academic research institutes (The Financial Express, 2005). This national programme follows the launch in 2002 of another large-scale stem cell research project by the Council of Scientific and Industrial Research (CSIR), involving seven national research institutions. The CSIR team is actively researching stem cell therapy for the repair of the liver, heart and cornea, as well for the creation of insulin-producing cells. Plans include the establishment of a facility in Hyderabad to house cell and tissue engineering facilities.\textsuperscript{23}

Of the 15 institutions listed by the National Institutes of Health as eligible for funding from the US federal government, two are in India: the National Centre for Biological Sciences/Tata Institute of Fundamental Research and the private company Reliance Life Sciences Cell Biology Centre.\textsuperscript{24} There are five regenerative medicine-focused companies in India. Reliance Life Sciences produces ReliCord, a product of stem cell-enriched umbilical cord blood and is currently developing ReliSeal, a product that uses plasma derivates to speed haemostasis and tissue sealing following the surgery.\textsuperscript{25} Nichi-In bio-Sciences Ltd. produces Mebiol Gel, a synthetic material resistant to infection whose potential uses include acting as a matrix for the regeneration of tissue.\textsuperscript{26}

The charity hospital and WHO Collaborating Centre for the Prevention of Blindness, the L.V. Prasad Eye Institute, has treated blindness in over 125 patients with adult stem cell therapy for corneal repair (Sangwan et al., 2003), while several academic institutions are active in regenerative medicine, including Christian Medical College, Acharya Nagarjuna University and Guru Gobind Singh Indraprastha University. In addition to conducting research activities, these institutions are also engaged in training in regenerative medicine. Guru Gobind Singh Indraprastha University, for instance, includes the topic ‘Stem Cells in Health Care’ in the curriculum for the Masters of Technology degree.\textsuperscript{27} An exchange programme with the University of California San Francisco is also underway to train Indian university faculty in stem cell research.\textsuperscript{28} Collaborations with international researchers additionally include such initiatives as the Indo-UK Stem Cell Workshop,\textsuperscript{29} and the Indo-Australian Conference on Biomaterials, Implantable Devices and Tissue Engineering.\textsuperscript{30}

4.4 Iran

In 2003, the Royan Institute Reproductive Biomedicine Research and Clinical Centre established Iran’s first human embryonic stem cell line, in collaboration with Australian researchers (Reichhardt et al., 2004). This achievement made Iran the tenth country in the world to publish such a stem cell line.\textsuperscript{31} While Iran does not yet have specific laws in place concerning embryonic stem cell research, the production of this human embryonic stem cell line was approved by Ayatollah Seyed Ali Khamanei (Reichhardt et al., 2004). The Royan Institute has since expanded its work to include studies investigating the potential for stem cells to differentiate into various cell types, including insulin-secreting cells, nerve cells, hepatocytes and osteoblasts.\textsuperscript{32} Other research institutes involved in regenerative medicine include the Molecular Medicine Network of Iran, and the Iran Polymer and Petrochemical Institute. The Iran Polymer and Petrochemical Institute has completed several successful projects in the realm of tissue engineering, with a particular
focus on developing novel polymeric biomaterials to act as biodegradable scaffolds. This institute also provides academic training in polymer engineering that includes topics of relevance to regenerative medicine, such as novel drug delivery systems and novel applications of polymers.33

The academic institution Shahid Behesti University of Medical Sciences in Tehran has been actively applying regenerative medicine treatments to help restore sight to patients who were victims of mustard gas attacks during the Iran–Iraq war. Depending on the severity of the blindness, limbal stem cell transplantation, in combination with corneal transplantation or alone, has helped restore partial or complete vision to dozens of victims (Kinkead, 2003). Iranian researchers have also been active in publishing on topics such as cartilage tissue engineering (Mirzadeh et al., 2000) and extracellular matrix effects on stem-cell-derived cardiomyocytes (Baharvand et al., 2005). This search did not identify any regenerative medicine companies in Iran.

4.5 Malaysia

As stated at the UN in discussions leading up the UN Declaration on Human Cloning, Malaysia’s position on embryonic stem cell research supports a ban on human reproductive cloning while remaining open to the potential benefits of therapeutic cloning provided that it is adequately regulated.34 Malaysia’s federal government has invested heavily in biotechnology in recent years, launching the BioValley Initiative in 2001 to establish a concentration of biotechnology-devoted research institutions, universities and companies within the Multimedia Super Corridor (MSC). Regenerative medicine, in the form of stem cell research, is included in this initiative.35 The National Heart Institute of Malaysia has taken an early lead in the country in stem cell research, performing the country’s first cardiovascular stem cell transplant in 2003 using direct injection of bone marrow stem cells into the injured heart (Masilamany and Kam, 2004).

Among academic institutions, Universiti Kebangsaan Malaysia is engaged significantly in regenerative medicine and has established both a Stem Cell Research Laboratory, as well as a Tissue Engineering Laboratory. Among their activities, these laboratories have successfully derived neural cells from bone marrow mesenchymal stem cells, engineered cartilage to form the ear and trachea and constructed human bilayer skin. These laboratories have produced a large set of publications in peer-reviewed journals.36 The Universiti Sains Malaysia is also a major player in Malaysia’s regenerative medicine sector. In addition to housing the nation’s only tissue bank, the university has established memoranda of agreement to collaborate with Cuba’s International Centre of Neurological Restoration (CIREN) to undertake activities in stem and neural cell research.35,37

The regenerative medicine private sector in Malaysia is focused on stem cell banking and its applications. StemLife was established in 2001 as Malaysia’s first private stem cell bank, offering both cord blood and adult stem cell banking. Since that time, the company has announced plans to launch medical research activities in addition to banking.38 A second medical biotechnology company in Malaysia, CryoCord, also specialises in cord blood banking and stem cell research, and has plans to establish itself throughout South East Asia.39
4.6 South Africa

South Africa’s *National Health Bill*, revised in June 2003, bans reproductive cloning but permits therapeutic cloning providing that authorisation is obtained from the Ministry of Health and that it follows strict regulatory criteria (Ministry of Health, 2003). The government of South Africa has pledged strong financial support for its National Biotechnology Strategy, which includes stem cell research under its umbrella (Jones, 2004). Both the Council for Scientific and Industrial Research and the Medical Research Council are carrying out work in regenerative medicine, though there is no government funding specifically earmarked for regenerative medicine in South Africa.40

Numerous academic institutions are involved in regenerative medicine research, including the University of Capetown Cardiovascular Research Unit, the University of Stellenbosch and the Centre for Tissue Engineering of Tshwane University of Technology. These institutions are involved in projects as diverse as biomaterial therapies, stem cell development in space and human artery regeneration by site-directed signalling.41–43 The Bone Research Laboratory, a collaboration between the South African Medical Research Council and the University of Witwatersrand, hold numerous patents for biomaterials and implants for bone repair and regeneration, as well as extensive publications in the realm of bone tissue engineering.44

Industry in South Africa is also active in regenerative medicine. Bone SA, a leading supplier of allograft bone in South Africa, has engaged in a partnership with Tshwane University of Technology to create the Centre for Tissue Engineering. This non-profit scientific centre was sponsored and co-founded by Bone SA, who over the past eight years have donated over R2.5 million in funding to tertiary institutions.42 Another company, Altis Biologics Ltd., is in the process of commercialising its novel implant to induce bone regeneration for the treatment of bone injuries in humans,45 while Lazaron Biotechnologies Cord Stem Cell Bank offers umbilical cord blood banking services,46 and their projections include revenues of approximately R53 million by the year 2009.47

5 Conclusions and future directions

Although regenerative medicine remains a relatively new field, it is rapidly becoming a key area of focus for science and technology sectors around the world. Major players include the US, UK, Germany, Japan and Canada. In the US, the state of California alone has pledged approximately US $300 million a year for the next ten years to establish and fund the California Institute for Regenerative Medicine.48 Even newly industrialised countries, such as South Korea and Singapore, are among the leaders in this field. In 2004, Singapore’s Biomedical Research Council and the Juvenile Diabetes Research Foundation International announced SS$5.2 million in funding for research on human pluripotent stem cells. Singapore’s many companies, government research institutes and universities involved in regenerative medicine are engaged in areas such as bioengineered skin substitutes, umbilical cord blood banking and therapeutics derived from human embryonic stem cells.49 South Korea, meanwhile, is a world leader in stem cell research, gaining attention for such high-profile results as the successful treatment of a spinal cord victim in 2004, returning her ability to walk after the treatment with cord blood stem cells (Tae-Gyu, 2004).
Regenerative medicine: new opportunities for developing countries

The results of this survey of regenerative medicine activities in developing countries demonstrate that even though regenerative medicine is still an emerging field worldwide, developing countries are actively engaged in its pursuit. This survey identified regenerative medicine activities in 31 low- and middle-income countries. This study is a first step towards understanding how developing countries are building capacity in regenerative medicine and using regenerative medicine to address some of the health needs presented by the double burden of disease. Such an understanding can facilitate the development of health and Science and Technology policy both in the developed and developing world that targets regenerative medicine capacity-building initiatives effectively and accurately towards developing world needs. We suggest that such policy should focus on five key areas: identifying key challenges, securing funding, encouraging collaborations, harnessing the potential of diasporas and developing global governance mechanisms.

We suggest beginning with a single key challenge to focus global efforts and to counter scepticism regarding the applicability of regenerative medicine for the developing world. For example, developing novel methods of insulin replacement to combat the global diabetes epidemic would be a valuable goal. The Oxford Health Alliance, an international collaboration focused on raising awareness and influencing policies with regard to the global epidemic of chronic disease, could play a leadership role in identifying and rallying the international community around this challenge. The developed world has a role to play in ensuring that a portion of international aid money incorporates the threats posed by non-communicable diseases, and could focus segments of this funding towards initiatives to develop regenerative medicine solutions for challenges such as diabetes. In addition, foundations such as the Juvenile Diabetes Research Foundation International, could provide funding and increase awareness of the global impact of diabetes, while developed country governments could provide incentives to the private sector to devote a portion of their Research and Development towards producing regenerative medicine therapies that are accessible and affordable to the developing world. The developed world should also promote collaborations, such as training courses, joint grant-writing initiatives and research partnerships. The different levels of regenerative medicine activity in developing countries found in this study also highlights an opportunity for collaborations between developing countries to share knowledge and experience, and to assist certain countries to move beyond academic research to the creation of goods and services capable of benefiting their populations. In addition to formal collaborations, both developed and developing countries should establish policies that encourage knowledge repatriation by diasporas, and should also become active in establishing an international network to explore and inform policy on the potential risks and benefits of regenerative medicine for the developing world.

To further fill the empirical gap regarding the potential impact of regenerative medicine for developing countries, we are currently conducting a foresight study with scientific experts in developing countries to identify the applications of regenerative medicine that they believe are the most promising for improving health in developing countries. We have also begun detailed case studies of selected developing countries active in regenerative medicine. As with previous studies of successful biotechnology sectors in developing countries (Thorsteinsdóttir et al., 2004), these case studies will help to highlight strategies and conditions that can contribute to the successful application of regenerative medicine. Such case studies will overcome the limitations of this, primarily internet-based study, and allow for a more in-depth exploration of emerging themes.
For instance, this study shows that universities are playing a major role in the development of regenerative medicine. Case studies could help to answer questions such as how university–industry partnerships are managed and the level of funding that universities are devoting to training in regenerative medicine. For developing countries that wish to build capacity in regenerative medicine, a familiarity with the experiences of other such countries can provide valuable lessons.

Acknowledgements

We gratefully acknowledge the valuable comments of Dr. Fabio Salamanca-Buentello and Dr. Béatrice Séguin on earlier versions of this paper. Grant support was provided by a Canadian Institutes of Health Research (CIHR) NET grant (RMEthinet) and by the Canadian Program on Genomics and Global Health. The Canadian Program on Genomics and Global Health is primarily supported by Genome Canada through the Ontario Genomics Institute and the Ontario Research and Development Challenge Fund. Matching partners are listed at http://www.geneticsethics.net. HG is supported by a CIHR Canada Graduate Scholarship Masters Award. ASD is supported by the McLaughlin Centre for Molecular Medicine. PAS is supported by a Canadian Institutes of Health Research Distinguished Investigator award.

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**Notes**


4 Source: http://esa.un.org/unpp.

5 Source: Personal communication 28 August 2005.


18 Source: http://www.mebo.com/En/r&q=overview.asp.


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37 Source: http://www.usm.my/usm/misc/usmlink/v2n2/m5.html.
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