Epidemics and the Health of African Nations

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Section Four

The Future of Health Systems in Africa

The last section of the book explores several interrelated issues that concern the future of health systems in Africa. A core emphasis is the potential of groundbreaking technological innovation in building strong health systems and addressing the efficient treatment of epidemics. It further addresses the issues around financing of health care, all with a view to building stable systems that will also embrace the poor and destitute. The common thread in this section is access to quality health care, first through faster and cheaper medical technologies and, second, through a form of national health insurance. To explore the potential of technological innovation in health systems, the first chapter maps briefly the state of health research in Africa and reveals the insufficient number of researchers on the continent. This is despite Africa bearing a large burden of disease.

Zamanzima Mazibuko and Steven Mufamadi explore the two
possible sides of research partnerships between Africa and international organisations – one being an extractive partnership that leaves the disadvantaged with no recognition, and the other being beneficial to Africa and promoting research relevant to the continent. Mazibuko and Mufamadi argue for the elevation of research and development and the use of technological innovation to address the burden of disease in Africa. The concept of ‘disruptive’ technologies is introduced as having the potential to provide affordable and efficient medical solutions. Nanotechnology is presented as the disruptive technology that has been shown to improve the efficacy of antiretroviral therapy and TB drugs. Nanotechnology has also been used for water treatment, which is essential for clean safe water and the prevention of waterborne diseases such as cholera. The chapter reveals the constraints in advancing nanoproducts from the laboratory into the market and the lack of participation from the pharmaceutical industry.

Financing of health care is crucial to achieving widespread access to quality health care. The two previous sections alluded to the gaps in financing of health care and the next chapter of this section explores health financing in the African context. Samuel Adu-Gyamfi reflects on the health financing in Ghana and Rwanda, two countries that have implemented some form of national health insurance. Adu-Gyamfi writes on the need for sub-Saharan governments to finance health care and to bridge the gap to health care access between the rich and the poor, through different forms of public health insurance. Ghana and Rwanda are used as case studies to determine the post-independence origins of public health insurance and the impact of socio-economic and political factors in the development of health insurance schemes.

Lastly, Alex van den Heever examines how prepared the South African health system is to counter epidemics. He analyses the current capacity of the health system and then assesses whether the proposed NHI framework will improve the capabilities of the existing health system. Indicators of capability are used to assess South Africa’s level of preparedness for any health-related incident.
INTRODUCTION

Various health-related interventions have been implemented in Africa with the aim to decrease mortality and improve health conditions caused by epidemics (and endemics) such as HIV/AIDS, tuberculosis, and cholera. And yet epidemics are still prevalent on the African continent. Part of the reason is because access to these health-related interventions has not been widespread. Also, the interventions have not been sustainable. This leaves the most vulnerable populations with the continued burden of disease (WHO, 2010). Resourceful and equitable health systems¹ are at the core

¹ According to WHO, health systems are ‘all organisations, people and actions whose primary intent is to promote, restore or maintain health. This includes efforts to influence determinants of health as well as more direct health-improving activities’. 
of addressing both infectious and non-communicable diseases (NCDs) on the continent (Temu et al., 2014). This is a conundrum, however, as the health systems in most African countries are weak (Olu, 2017). From the six building blocks required to strengthen health systems to a standard where they can handle disease outbreaks as well as chronic illnesses, this chapter explores ‘medical products, vaccines and technologies’ from the research and development (R&D) perspective.

With the highest burden of disease, worldwide, low- and medium-income countries’ (LMICs) contribution towards global medical research is the lowest (Franzen et al., 2017). According to a study by Rahman and Fukui (2003), sub-Saharan Africa produced only 0.8 per cent of global biomedical research publications. The Commission on Health Research for Development (COHRED) reported that less than 10 per cent of global health research funding has prioritised health conditions that account for 90 per cent of the global disease burden, an imbalance referred to as the ‘10/90 gap’ (COHRED, 1990). This means that not only have LMICs conducted insufficient research to deal with their burden of disease, but also that high-income countries (HICs) have channelled medical research funding towards diseases affecting the least disease-burdened global population. Almost two decades later, several LMICs still have insufficient health research capacity to improve population health (Franzen et al., 2017).

Health research is exceedingly valuable to society and has an important role to play in the reduction of global health imbalances. Through medical research, crucial information on disease trends and risk factors, effects of treatment and results of public health interventions, as well as costs of health care, can be determined (Nass et al., 2009). More so, research on technological innovations which can deliver faster and economic treatment and diagnosis should be at the forefront. Indeed, the control of infectious diseases can be achieved by effectively applying knowledge that already exists and by conducting clinical investigations on existing drugs and technologies. However, the search for more efficient medications and technologies must also remain a high priority. Emerging technologies present the possibility for African countries ‘leapfrogging’ into improved

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ii The six building blocks of health systems strengthening are: (1) Service delivery; (2) Health workforce; (3) Information; (4) Medical products, vaccines, and technologies; (5) Financing; (6) Leadership and governance
health care (McConnell et al., 2008). Technological innovation that is disruptive\textsuperscript{iii} and which overtly uses low-cost materials, methods, and applications for low-cost health care delivery is a way in which researchers can respond to the urgent need to make health care efficient and accessible in Africa. It is important, however, that the development of these new technologies considers the socio-economic challenges of African countries; in other words, it is important that the process is simultaneously gone about with sensitivity to local circumstances, goals, and capacities.

In this chapter nanotechnology is presented as an example of such a disruptive technology. Nanotechnology is an emerging and rapidly developing field. It has become one of the most important scientific fields of the 21\textsuperscript{st} century (Dube & Ebrahim, 2017). In the health care sector, nanotechnology has the potential to transform medicine by creating new drug delivery systems and diagnostics (Maksimovi, 2017). Nanomedicine, as it is termed, can potentially offer real breakthroughs by providing cost-effective health care, which is a crucial factor in making medicines and treatments accessible for all (Gudimalla et al., 2017).

This chapter therefore presents African innovation, particularly in medical technologies, as a key driver for health and economic development on the continent. To build this argument, the chapter is essentially in two parts – first it reviews, broadly, the state of research capacity and research and development (R&D) on the continent, as this is at the core of innovation. The tools required to get the African region to an acceptable research status are discussed, including financial intervention through partnerships with international organisations. In these partnerships lies great potential for accelerating health research in Africa in the provision not only of funding and resources, but skills too – although some have been known to be extractive and exploitive (Boum II et al., 2018). As part of the objectives of this chapter, several partnerships that are collaborative and benefit African researchers and institutions optimally are referenced.

The second part is an assertion that research and development of emerging and disruptive technology, specifically nanotechnology, can play a major

\textsuperscript{iii} Disruptive technologies have been described as scientific discoveries that transform the original product’s characteristics and provide the foundation for a novel and more competitive one. According to Clayton M. Christensen (1997) in his book *The Innovator’s Dilemma* disruptive technologies create new markets and value networks that ultimately disrupt traditional markets and leading firms and products.
role in providing affordable, effective medicine and disease prevention methods. It argues that it is essential to include disruptive technological innovation in research agendas. Examples of studies are presented that demonstrate nanotechnology’s potential to improve current treatments of some of the epidemic diseases prevalent on the continent. Further, examples of nano-enabled water treatments are discussed, given that access to clean and safe water is crucial in preventing or containing diarrhoeal diseases such as cholera. The last part of the chapter discusses the interventions required for nanotechnology development, commercialisation, and, ultimately, its successful and widespread use in communities.

The analysis in this chapter draws on high-level scholarly insights to draw new perspectives on nanotechnology in relation to epidemics in Africa. To obtain data for this chapter, keywords and phrases such ‘nanomedicine’, ‘nanotechnology’, ‘research capacity’, ‘research in Africa’, ‘science in Africa’, ‘research partnerships’, ‘nanotechnology commercialisation’, ‘nanotechnology research and development’ etc. were subjected to systematic searches for pertinent research conducted in this specialised field. Establishing research activity in several African countries proved challenging as data was not always available. Only in countries where a defined research strategy has been implemented was the data more accessible.

HEALTH RESEARCH IN AFRICA

The need for locally driven and produced health research that is relevant for the African continent and that has cost-effective implementation remains urgent. African researchers, as scarce as they are, are better placed to outline which research issues need to be prioritised for the African population. In addition, African researchers need to be provided with an environment which allows them to conduct research efficiently. This section thus explores research capacity in Africa and the elements required to be put in place to enhance this capacity, including the partnerships that promote equitable research on the continent. It also offers nanotechnology as a possible solution for a cost-effective technological innovation that potentially has groundbreaking implications for health care in Africa.
African research institutes and research capacity
Impactful and valuable research requires good individual research skills and ability, suitable infrastructure, institutional and regulatory frameworks, investment, and the ability to contribute to global research and policy needs (Chu et al., 2014; Morel et al., 2018). To contextualise research in Africa, it is thus important to explore research capacity and availability as well as quality of infrastructure, what research is already being done, and where research is lacking. Research capacity in Africa, particularly in sub-Saharan Africa, is lagging behind other parts of the world (Morel et al., 2018). Among other reasons, this can be attributed to the loss of university staff to foreign institutions, lack of appropriate infrastructure, a policy environment that is not conducive for research, and insufficient funding. It must be noted, however, that research capacity varies widely across African countries (Morel et al., 2018).

Only 1 per cent of global investment in R&D is allocated to Africa, and only 0.1 per cent of the world’s patents are in Africa’s possession (Kariuki & Kay, 2017). A pilot study on the expenditure on health research in 42 sub-Saharan African countries over two years estimated that approximately USD 1.5 billion (USD 750 million per annum) was spent in this region (Kebede et al., 2014). This is approximately one-sixth of the total annual expenditure reported by the Global Forum for low- and middle-income countries in 2003 of USD 4.1 billion (Kebede et al., 2014). This dearth of investment is due on the one hand to the low numbers of researchers in Africa and, on the other, an infrastructure that is not conducive for research. In 2017, the continent had 198 researchers per million people, measured against 428 in Chile and more than 4,000 in the United Kingdom and United States (Kariuki & Kay, 2017). The percentage of Africans pursuing graduate study is three times lower than the global average. The number of researchers per capita in Africa is also unreasonably low. The continent would require an additional million new PhD graduates for it to reach the world average (Kariuki & Kay, 2017). Research capacity needs to be prioritised to improve Africa’s R&D and innovation landscape.

In brief, following reports that global health research is biased towards diseases affecting HICs (COHRED, 1990), various international organisations have been undertaking research in Africa,
mostly in the form of clinical trials but also, gradually, in genomics and biobanking projects (WHO, 2002; Adoga et al., 2014; Munung et al., 2017). Unfortunately, when institutions and organisations in HICs have funded research conducted in Africa, they have also largely been the lead researchers and sole publishers of this research, which is not always to the continent’s advantage (Crane, 2010).

Partnerships with international organisations have great potential in accelerating health research in Africa by providing funding, resources, and skills. However, these partnerships need to be wholly beneficial to African countries. They need to put African researchers at the forefront and not just be an extractive initiative for international organisations.

Funding that does not require African researchers to take the back seat in research conducted in Africa is what we should be aiming for. The Developing Excellence in Leadership, Training and Science (DELTAS) Africa scheme, which was initiated by the Wellcome Trustiv in partnership with the Alliance for Accelerating Excellence in Science in Africa (AESA)v and other partners, is exemplary in illustrating how international organisations can invest in health research in Africa. DELTAS supports the African-led development of researchers and research leaders in Africa, thus ensuring that science for Africa is led by Africa’s researchers, and that the science remains relevant to the needs of the continent (Table 1).

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iv The Wellcome Trust is a global charitable foundation that supports scientists and researchers all over the world to explore ideas in science, population health, medical innovation, the humanities and social sciences, and public engagement (https://wellcome.ac.uk/about-us).

v AESA is a funding platform that aims to develop science strategies and funding research in Africa. AESA seeks to develop research leadership and promote scientific excellence and innovation to overcome some of Africa’s developmental challenges that include the shortage of researchers to deal with its disease burden (https://aasciences.ac.ke/programmes/easa/alliance-for-accelerating-excellence-in-science-in-africa-aesa/).
Table 1: Health research programmes led by African researchers in African institutions (Supported by DELTAS)

<table>
<thead>
<tr>
<th>Name of Programme</th>
<th>Aim</th>
<th>Lead Researcher</th>
<th>Institution</th>
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<tbody>
<tr>
<td>Training Health Researchers into Vocational Excellence in East Africa -2 (THRiVE-2)</td>
<td>To transform East African universities into world class research hubs for key emerging health issues in the region.</td>
<td>Prof. Nelson Sewankambo</td>
<td>Makerere University College of Health Sciences in Uganda</td>
</tr>
<tr>
<td>Developing Excellence in Leadership and Genetic Training for Malaria Elimination in Sub-Saharan Africa (DELGEME)</td>
<td>Training graduates, doctoral fellows, and postdoctoral fellows in the genomics and bioinformatics of malaria.</td>
<td>Prof. Abdoulaye Djimdé</td>
<td>University of Science, Techniques and Technologies in Mali</td>
</tr>
<tr>
<td>African Science Partnership for Intervention Research Excellence (Afrique One-ASPIRE)</td>
<td>To expand research capacity in sub-Saharan Africa by focusing on ‘One Health’ – the concept that the health of animals, humans, and the environment is interconnected – as an approach to tackle major challenges in ecosystem health.</td>
<td>Prof. Bassirou Bonfoh</td>
<td>Centre Suisse de Recherches Scientifiques (CSRS) in Côte d’Ivoire</td>
</tr>
</tbody>
</table>
### Name of Programme

1. **Consortium for Advanced Research Training in Africa+ (CARTA+)**
   - **Aim**: Continue to develop a critical mass of multidisciplinary researchers who work in research-supportive environments in Africa, with the aim of improving public and population health.
   - **Lead Researcher**: Prof. Alex Ezeh & Prof. Sharon Fonn
   - **Institution**: African Population and Health Research Center (APHRC) in Kenya; University of the Witwatersrand in South Africa

2. **Initiative to Develop African Research Leaders (IDeAL)**
   - **Aim**: Keeping scientists at African institutions through a defined programme of recruitment, supervision, mentorship, multidisciplinary approaches, and clear career paths.
   - **Lead Researcher**: Dr Samson Kinyanjui
   - **Institution**: Kemri-Wellcome Trust Research Programme in Kenya

3. **African Mental Health Research Initiative (AMARI)**
   - **Aim**: Develop a cohort of outstanding mental health researchers in sub-Saharan Africa.
   - **Lead Researcher**: Dr Dixon Chibanda
   - **Institution**: University of Zimbabwe

4. **Sub-Saharan Africa Consortium for Advanced Biostatistics Training (S2ACABT)**
   - **Aim**: Address a fundamental gap in expertise in the area of biostatistics, a discipline that is essential for a broad range of research areas and crucial for developing robust research questions.
   - **Lead Researcher**: Prof. Tobias Chirwa
   - **Institution**: University of the Witwatersrand
### The Potential of Technological Innovation

<table>
<thead>
<tr>
<th>Name of Programme</th>
<th>Aim</th>
<th>Lead Researcher</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Saharan African Network for TB/HIV Research Excellence (SANTHE)</td>
<td>Strengthening the scientific research base for two diseases (HIV and TB) that account for a major burden of morbidity and mortality in Africa.</td>
<td>Prof. Thumbi Ndung’u</td>
<td>KwaZulu-Natal Research Institute for Tuberculosis and HIV (K-RITH) in South Africa</td>
</tr>
<tr>
<td>West African Centre for Cell Biology of Infectious Pathogens (WACCBIP)</td>
<td>Address the underlying causes of both communicable and non-communicable diseases in African populations.</td>
<td>Dr Gordon Akanzuwine Awandare</td>
<td>West African Centre for Cell Biology of Infectious Pathogens (WACCBIP) in Ghana</td>
</tr>
<tr>
<td>Malaria Research Capacity Development in West and Central Africa (MACARD)</td>
<td>Build on the achievements of the Malaria Capacity Development Consortium (MCDC) to provide PhD, early, and senior post-doctoral fellowships in areas of research relevant to malaria elimination.</td>
<td>Prof. Oumar Gaye</td>
<td>Université Cheikh Anta Diop (UCAD) in Senegal</td>
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By 2018, DELTAS had been supporting leading African researchers based in research institutions across 21 countries on the continent. Thus far, approximately USD 100 million has been granted to these researchers to enable them to implement groundbreaking research and training programmes. The research agenda is set by African researchers and direction is given to international researchers. Regional collaboration is encouraged and reinforced through these programmes. The Training Health Researchers into Vocational Excellence in East
Africa (THRiVE) programme, for instance, aims to strengthen regional research capacity through collaborations by academic institutions from Uganda, Rwanda, Tanzania, and Kenya. This type of collaboration has not been common between African institutions, as seen in a comparative study by Pouris and Ho (2014), and individual projects that become successful do not reach their full potential because they are not linked with all the relevant expertise from Africa.

One initiative that aims to establish a well-funded, systematic, and innovative collaboration of the R&D community on the continent is the Coalition for African Research and Innovation (CARI) (Photopoulos, 2018). Led by Africans, CARI is supported by AESA, which encourages collaboration among researchers, organisations, and governments across the continent to bring resources and allow synergy among existing investments to support research and development in Africa (AESA, 2017). The investments from the various stakeholders from the African continent and international community provide a platform that enables a common discussion regarding the R&D priorities for Africa, including the areas where limited resources should be invested (Photopoulos, 2018).

Role of technology and innovation in African health care and development

Globally, access to efficient and affordable health care is one of the most pressing issues. Increased life expectancy, a growing burden of chronic disease, and significant health inequalities (Doyal & Hoffman, 2009) make this even more urgent. Health care quality is measured by efficacy, evidence basis, patient centredness, and cost-effectiveness (Russo & Adler, 2015). The epidemics affecting the African population the most, such as HIV/AIDS and tuberculosis (TB), traditionally are managed with high doses of therapeutics over a long period of time (or lifetime). These therapeutics must be taken frequently, they often cause severe adverse effects, and they are expensive. Therefore, these treatments do not always meet the health care quality criteria as patient compliance is compromised, the treatments are not affordable, and the efficacy is not optimal.

That there are major gaps that need to be filled and that there is widespread uncertainty about the most cost-effective and efficient ways of administering health care is acknowledged. Emerging technologies such
as biotechnology and nanotechnology have been recognised as disruptive technologies that can change conventional health care. Disruptive technologies are innovative developments that establish new markets and standards within an existing market, therefore displacing prominent market leaders and products (Perrot, 2018). The development of these technologies should be sensitive to the syndemic nature of diseases and consider the socio-economic context of the population for whom they are being developed. HIV/AIDS patients, for instance, are likely to also suffer from other health conditions such as TB, and in several cases their ill-health will be worsened by poverty, undernutrition, or various other socio-economic factors. Technologies that diagnose multiple conditions and provide treatments concurrently would be highly valuable. Liberian biomedical scientist Dr Dougbeh Christopher Nyan developed a rapid test which can detect and simultaneously differentiate at least three to seven infections at the same time within 10 to 40 minutes (Jackson, 2018). This type of innovation would help address the management of co-infections that commonly occur in African settings.

Nanotechnology, an example of an innovative technology, promises to improve existing products and make them cheaper and more effective (Maine, 2014; Chang et al., 2015). Moreover, it has the potential to address many societal challenges experienced by developing countries. Scientists and technologists define nanotechnology as an applied science in which a material of nanoscale size (below 100 nm) presents characteristics that are unlike the bulk material (Lane & Kalil, 2005). These characteristics enable a product to be transformed into a more novel and competitive one, e.g. one that is faster, smaller, uses less material, is cheaper, etc. Several developing countries are pursuing nanotechnology strategies, proposing that nanotechnology has a role in alleviating poverty, reducing unemployment, and improving health (Perrot, 2018).

Nanotechnology research and development
A study by Woodson (2012) showed that 78 per cent of the publications on nanomedicine in Web of Science (WoS) from low-income countries
focused on diseases affecting their populations. In comparison, only 16 per cent of nanomedicine articles from very high-income countries deal with these diseases. Therefore, even though low-income countries’ nanomedicine publications are far fewer than those of high-income countries, the low-income countries’ research prioritises diseases which affect their populations. Indeed, since the mid-2000s African countries have included nanomedicine in their science and technology research agendas. The South African government, for example, established a nanotechnology initiative in 2005 to promote and enhance nanotechnology research and development, with health care as one of its six focus areas, spending about R170 million (USD 26 million) on this (Claassens & Motuku, 2006). Researchers in South Africa, therefore, have been conducting nanomedicine research for some time, with a focus on its use in enhancing treatment of diseases affecting LMICs (Dube & Ebrahim, 2017). Moreover, South Africa is one of 27 African countries that constitute the Nanosciences African Network (NANOAFNET), vii which was created in 2005. NANOAFNET aims to improve Africa’s global prominence and contribution in nanomedicine, as well as formulate cost-effective nanotechnologies to address urgent continental societal needs, including health sector needs. Among the NANOAFNET countries, South Africa, Ethiopia, Nigeria, Kenya, Morocco, Egypt, and Libya have nanomedicine publications. Tanzania and Cameroon are two other African countries that are conducting nanomedicine research.

Nanomedicine can provide solutions to conventional drug administration methods which are used broadly but provide unsatisfactory results. Research suggests that investment in the development of new and more efficient treatment is crucial in realising health care, but this is not occurring at a notable scale (Tiwari et al., 2012). The increase in R&D costs of such conventional drugs has resulted in a decline in the approval of new chemicals since the late 1950s (Tiwari et al., 2012). Investing in nanomedicine is thus an important and cost-effective alternative. Nanomedicine also has great potential for reducing the toxicity and improving the solubility and efficacy of therapeutics for infectious diseases such as TB, malaria, and HIV (Hayeshi et al., 2012),

vii  http://www.nanoafnet.tlabs.ac.za/
and NCDs like cancer (Din et al., 2017). Thus, for drug discovery and development to advance to where minimal returns, if any, can be expected, new approaches such as nanotechnology must be explored.

NANOTECHNOLOGY RESEARCH IN DISEASE MANAGEMENT

Across the globe, research is underway to determine the efficacy of nanotechnology in treating infectious diseases. This research, although not always fully fleshed out, has shown improvement when compared to conventional methods of treatment. A few studies are presented to demonstrate several ways in which nanotechnology can improve health care when it comes to some of the diseases prevalent in Africa.

Nanotechnology in HIV therapy

Combination antiretroviral therapy, or highly active anti-retroviral therapy (HAART), has effectually been successful in managing HIV/AIDS. Many challenges remain, however, which can and do result in unsuccessful therapy. Some of these challenges are: lifetime administration; high costs; poor patient compliance; major adverse effects caused by high and frequent dosages; the development of multiple resistant HIV strains caused by a high mutation rate; the presence of viral reservoir sites inaccessible to current drug delivery methods; low oral bioavailability; and poor drug pharmacokinetics (Adesina & Akala, 2015; Curley et al., 2017).

Nanotechnology has the potential to address challenges presented by current treatments and possibly failed and future therapeutics as well (Curley et al., 2017). It presents the possibility of the improved safety of drugs by reducing doses or providing targeted drug delivery systems (Tiwari et al., 2012; Din et al., 2017). Nanomedicine strategies that are being explored for delivery of antiretroviral drugs range from oral nanomedicines, long-acting injectable nanomedicines, and targeted nanomedicines (Curley et al., 2017). Solid drug nanoparticle (SDN) formulations are being investigated for enhancement of the bioavailability of poorly water-soluble drugs. In vivo pharmacokinetics studies of SDN formulations containing efavirenz showed that they could
achieve similar pharmacokinetics to the standard Sustiva® formulation with a 50 per cent lower dose (McDonald et al., 2014). Long-acting injectable nanomedicines aim to address poor drug-regimen compliance that results in failure of treatment (Havlir & Gandhi, 2015). A study involving 56 healthy volunteers administered a cabotegravir-containing long-acting injectable nanomedicine. The treatment sustained exposure for up to 24 weeks and cabotegravir was well tolerated with no grade 2–4 injection site reactions reported (Spreen et al., 2012).

Targeted nanomedicines are developed in HIV therapy for drugs to reach inaccessible viral reservoir sites (Mallipeddi & Rohan, 2010). The blood–brain barrier presents a challenge for therapeutics to reach the brain. For delivery to the brain, magnetic azidothymidine 5’-triphosphate liposomal nanoformulations have been developed. When a magnetic field was applied in an in vitro model of the blood–brain barrier, the transcellular apparent permeability was increased compared to a free drug (Saiyed et al., 2010).

**Nanotechnology in TB therapy**

As with antiretroviral treatment, TB treatment faces challenges when it comes to patient compliance, drugs that are not targeted, and side-effects. Frequent dosing and prolonged treatment duration are major considerations when nanoformulations are developed for TB treatment.

As such, in a study, rifampin (RMP), isoniazid (IHN), and pyrazinamide (PZA) were encapsulated by poly(lactide-co-glycolide) (PLG) nanoparticles (NPs) for oral delivery (Pandey et al., 2005). After a single dose of drug-loaded PLG NPs in mice for 6 to 9 days, drug levels were maintained above the least inhibitory concentration (MIC90) in the plasma. Free drugs were not found in the plasma within 12 to 24 hours after oral administration. Only subsequent to administration of 46 doses were free drugs able to generate the same effects as nano-enabled drugs (Pandey et al., 2005). In another study, ethambutol-encapsulated nanoparticles were administered simultaneously with encapsulated RMP, IHN, and PZA (Ahmad et al., 2006). Following a single dose of drug-loaded NPs to mice, therapeutic drug concentrations were retained in the plasma for 9 days, 7 days, and 11 days in the case of rifampicin, ethambutol and isoniazid/ pyrazinamide respectively. Contrastingly, the
plasma did not contain any free drugs within 12 hours of intravenous or oral administration (Ahmad et al., 2006).

Injectable nanomedicines are also being developed for TB treatment. Nanoformulations of PLG drug-nanoparticles containing RMP, INH, and PZA were injected subcutaneously into mice. Sustained therapeutic drug levels were observed in plasma for 32 days and in lungs or spleen for 36 days. To achieve the same results oral free drugs had 35 doses (Pandey & Khuller, 2004). In another study, nanotechnology was incorporated with clofazimine, an anti-TB drug for mycobacterial infection, in order to address its insolubility problem. Clofazimine was formulated as a nanosuspension with a particle size of 385 nm. Subsequent to intravenous administration, colony-forming unit count in the liver, spleen, and lungs of mice infected with *M. avium* had decreased (Peters et al., 2000).

These studies established that it is possible for nanomedicine to decrease the doses required to achieve the desired effect of the drug. They have also demonstrated the importance of nanotechnology to overcome the solubility problems and toxicity of drugs.

**Nanotechnology in the prevention of infections**

As much as treating and containing diseases is a priority, prevention would be more efficient and in the long run more cost effective. The properties nanotechnology offer allow for the effective and economical treatment of water. This section explores the implications of water treatment using nanotechnology in preventing the spread of diseases.

**Nanotechnology in water treatment**

The importance of clean water in curbing epidemics, the prevention of certain diseases, or re-infections cannot be understated. Diarrhoeal diseases caused by the use of contaminated water are among the biggest causes of illnesses and death in sub-Saharan Africa (Montgomery & Elimelech, 2007; Nwabor et al., 2016; see also Chapter 3). Access to clean water remains a huge issue in sub-Saharan Africa. According to the World Health Organization (WHO), approximately half of
the 663 million people in the world who lacked access to reliable and clean water in 2015 lived in sub-Saharan Africa (WHO, 2015). Thus, sub-Saharan Africa suffers from water-borne diseases, like cholera, habitually. Between 2000 and 2015, 83 per cent of cholera deaths reported by WHO occurred in sub-Saharan Africa (Lessler et al., 2018). The lack of safe and affordable water severely affects vulnerable groups, including persons with compromised immune systems such as HIV/AIDS patients (Kamminga & Wegelin-Schuringa, 2005).

The supply of clean water is thus even more imperative for HIV/AIDS patients to prevent opportunistic infections from polluted water. Preventing water-borne infections that may further weaken the immune system is crucial in reducing HIV- and AIDS-related morbidity and mortality (Makaudze et al., 2012). Adequate water supply and sanitary facilities are of the utmost importance for HIV-infected people to maintain a healthy status as long as possible. Clean water for people living with AIDS will reduce their chances of getting diarrhoea and skin diseases (which are opportunistic infections); and being able to take their medication with clean water is especially important for this vulnerable population group (Kamminga & Wegelin-Schuringa, 2005; Makaudze et al., 2012).

Centralised purification and expansion of existing piped water distribution systems are resource intensive and time consuming (World Bank Group, 2017). Realistically, therefore, providing safe water widely in sub-Saharan Africa is not going to occur speedily, so a large number of people will continue to be without safe water. Solutions that are decentralised, self-sustaining, and targeted to the most vulnerable groups in order to improve health as well as enhance development should therefore be implemented expeditiously.

One of the approaches to the provision of clean water being investigated in a number of countries is nanotechnology as it holds great potential in providing innovative water treatment. The characteristics of nanomaterials make them apposite for treating water, either as an improvement of current techniques (which are costly and time consuming) and/or as part of completely novel methods for treating domestic, industrial, and mining wastewater (Hashem, 2014; Kunduru et al., 2017). Fundamentally, nanotechnology provides
advanced performance and economic water and wastewater treatment solutions (Hashem, 2014; Kunduru et al., 2017). Nano-enabled devices are durable, multifunctional, and have a large surface to volume ratio which allows for manipulation of the interaction with pollutants and/or bacteria (Chong et al., 2010; Kunduru et al., 2017). Nanotechnology can offer a customised solution for the removal of a targeted contaminant or for removing several contaminants (Kanchi, 2014; Anjum et al., 2016). The latter is optimal for water purification as water contains a variety of widely dispersed contaminants.

**Examples of nanotechnology use in water treatment**

Tea bag water filter: The ‘tea bag’ filter is a small water filter developed to fit into the neck of a bottle. It promises to provide an affordable water purification method in remote areas or where the water supply is contaminated (Smit, 2010). The tea bag filter sachets are developed from the same material as rooibos tea bags, only they contain activated carbon instead of tea (Makoni, 2010a). A thin film of biocides encapsulated within tiny nanofibres coats the inside surface of the tea bag material. This feature ensures that the filter traps the bacteria, which are then killed by the biocide coating, something that is not found in traditional water filters (Makoni, 2010a; Smit, 2010). The tea bag filter was developed by a team at the University of Stellenbosch, South Africa, to provide an innovative and effective decentralised point-of-use technology (Smit, 2010). Moreover, it is biodegradable due to the structure of the nanofibres and thus poses no risk to human health or the environment.

Capillary ultrafiltration: The capillary ultrafiltration (CUF) technology is a membrane and filter system used for potable and industrial water purification. It has a pore size of 35 nm in diameter, allowing it to remove bacteria and viruses, colour, and metal oxides (SAASTA, 2011). It can also be used for pre-treatment of seawater and the treatment of industrial water and wastewater (Zamxaka & Riley, 2010). The CUF was developed by a team at Stellenbosch University in partnership with the Water Research Council to provide cost-effective systems to replace expensive imported equivalents (SAASTA, 2011). Currently, the CUF technology provides water treatment solutions
for rural areas, especially for those municipalities seeking to provide new water services (SAASTA, 2011).

Nanofilters: The nanofilter is a sand-based water filter that utilises nanomaterials to remove contaminants such as heavy metals, fluoride, and biological toxins, while the sand traps the remaining fragments (Obiukwu, 2015; BITRI, 2018). This novel technology was developed by a Tanzanian innovator, Askwar Hilonga, and offers affordable water purification (BITRI, 2018). In 2015, the nano-enabled device, which can be shared by a community and can produce up to 60 litres of safe drinking water per day, sold for USD 130 per device (Obiukwu, 2015). This is without electrical or solar power, nor any UV or chemical treatment (Obiukwu, 2015). The nanofilter can be customised according to the water condition in a particular area as water conditions differ depending on pollutants found in the water, human activities, and the geological formation of soil and rocks.

CONSTRAINTS OF NANOTECHNOLOGY

Notwithstanding the advantages of nanotechnology, there are some constraints to its research and development and also to getting the technologies onto the market. Nanotechnology is an emerging field and thus requires more research (and investment) before it can be embraced fully by governments, the private sector, and society. For instance, although formulating nanotechnology products can be economical, acquiring the initial equipment for developing these products can be costly. In this regard, this section explores some of the barriers to realising the full potential of nanotechnology.

Investment in nanotechnology

Investing in any new technology is important for its development and ultimately its commercialisation. A report compiled by the Nanotechnology Research Group indicated that African countries are slow or are not prioritising the adoption of nanotechnology despite the potential it holds. South Africa, Egypt, and Nigeria are all making strides towards nanotechnology development (Rateng, 2017), while some other African countries – Botswana being one – are
at the developmental phase of nanotechnology-based solutions (Sunday Standard, 2017). Lack of investment by the majority of countries in Africa has been identified as the major obstacle to embracing this technology (Rateng, 2017). According to Ezema et al. (2014), if Africa is to succeed in the development of nanotechnology, there needs to be a multidisciplinary collaboration or partnership between government ministries, agencies, institutions, the private sector, and donor agencies. This will help African countries to gather the resources that are required towards nanotechnology development.

South Africa is striving to be at the forefront of nanotechnology development and commercialisation in Africa. The government has developed a strategy and allocated funding to enhance technological innovation in the country. The success of South Africa in nanotechnology development is powered by government funding, specifically the Department of Science and Technology (DST) and support programmes such as the Technology Innovation Agency (TIA) and the Industrial Development Corporation (IDC). Spanning 10 years from 2005 until 2015, the government invested over ZAR 400 million (about USD 28.6 million) towards nanotechnology R&D, human capacity building, and infrastructure (National Nanotechnology Equipment Programme). For infrastructure investment, the focus was on nanotechnology research equipment, cleanrooms, and piloting facilities (Dube & Ebrahim, 2017). South Africa’s success in nanotechnology development is further supported by alliances or partners, particularly from the BRICS countries (Brazil, Russia, India, China, South Africa). These are among the major players and constitute the hub of nanotechnology (Molapisi, 2012).

Although many countries in Africa are demonstrating an interest in nanotechnology research, their national projects and financial support emanate mostly from governments (UNITAR, 2012). When it comes to financial support for nanotechnology innovation and/or commercialisation, South Africa and Morocco have a financial support structure and strategy for industrialisation. Morocco’s government strategy focuses on university-industry collaboration through the InnovAct programme (UNESCO, 2016). The South African government is focusing on the establishment of nanotechnology industrialisation through the New Industries
Strategic Business Unit (SBU) from the IDC Industrial Development Corporation (IDC, 2015).

Big pharmaceutical companies are in a favourable position to finance or invest in nanotechnology-based products and to fuel the nanomedicine market, given that they have good infrastructure, big budgets, and the expertise in areas such as clinical trials, intellectual property, regulation, and marketing. However, according to the Joint Research Centre of the European Commission (JRC-EURO), big pharmaceutical companies have a low interest in investing in emerging nanotherapeutics. This is due to the high acquisition costs, which can result in low financial rewards and/or negative returns. Attracting investment in nanomedicine from big pharmaceutical firms will therefore require standardised cost effectiveness with reimbursements (Bosetti, 2015). An increase in the investment capital of nanomedicine R&D in Africa could facilitate the production of affordable health and pharmaceutical solutions in Africa. Additionally, finding the best model to support small and medium enterprises (SMEs) could assist towards job creation and boost economic growth in Africa.

**Nanotechnology infrastructure**

Lack of proper infrastructure affects the progress in nanotechnology research, especially in developing countries (Naseri & Davoodi, 2011; Mazumder et al., 2014). Although nanotechnology promises inexpensive pharmaceutical products and diagnostic and medical devices, the research in nanotechnology requires very expensive equipment.\(^{viii}\) The equipment is critical for the research but it is

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\(^{viii}\) Examples of some of the current cutting-edge equipment for nanotechnology characterisation available in African universities, research councils, and industries are Transmission Electron Microscopes (TEM), Scanning Electron Microscopes (SEM), Focused Ion Beam Scanning Electron Microscopes (FIB-SEM), Atomic Force Microscopes (AFM), Optical microscopes, Photoluminescence Spectrometers, UV/VIS Spectrometers, Nanoparticle size analysers, Nanolog Spectro-Fluorometers, EvoVac and NexDep for thin film deposition equipment, and many more (CSIR, 2018; MAScIR, 2018). The Centre for High Resolution Transmission Electron Microscopy at Nelson Mandela University is the home of the following instruments: The JEOL JEM-ARM200F double Cs-corrected Transmission Electron Microscope (ARM-TEM); JEOL JEM 2100 LAB6 TEM, an Analytical TEM; JEOL JSM-7001F, an analytical FEG SEM, the FEI Helios NanoLab DualBeam 650, and a nanoindenter (Chretem – Nelson Mandela University, 2018).
expensive to maintain and quickly becomes outdated. This makes it more difficult for researchers, particularly in Africa, to keep up with researchers around the world.

Although the South African government has, over the years, financially supported nanotechnology infrastructure (National Nanotechnology Equipment Programme), it is currently facing financial constraints in sustaining the investment. In 2015, DST in partnership with the Council for Scientific and Industrial Research (CSIR) launched a new nanotechnology production facility for the up-scaling, processing, and testing of plastics and cosmetics. The lack of world-class infrastructure, the centralisation of nanotechnology facilities, and laboratories that are not fully funded will delay local nanotechnology R&D from reaching the clinic and marketplace. Furthermore, lack of the nanotechnology infrastructure to support start-ups, SMEs, and entrepreneurs will continue to affect business growth in nanotechnology in Africa.

**Lack of public awareness and public perception on nanomedicine**

For an emerging technology to be successful, public acceptance and uptake of the technology is crucial, yet many international surveys have shown that the majority of the public has limited knowledge or no awareness about nanotechnology (Sechi et al., 2014). In an attempt to increase public awareness, nanotechnology communities around the world have established initiatives that aim for facilitation of public engagement with the science (NPEP, 2018; Jones, 2009; Nisbet & Markowitz, 2015). The American Association for the Advancement of Science (AAAS) describes public engagement with science as a great opportunity for mutual learning between both scientists and non-scientists or members of the public (Nisbet & Markowitz, 2015). Some citizens who are familiar with nanotechnology have concerns regarding the uncertainty around the potential toxicity of nanomedicine to human health and the environment. Essentially, the public is unsure about the benefits versus the risks of nanotechnology (Waldron et al., 2006; Bankole et al., 2014; Beumer, 2017). Poor communication on the benefits and risks of nanomedicine and/or negative public perception can hinder the development and diffusion of the technology.
South Africa established its own Nanotechnology Public Engagement Programme (NPEP) in 2008. NPEP is an initiative funded by the DST, and implemented and administered by the South African Agency for Science and Technology Advancement (SAASTA), a business unit of the National Research Foundation (NRF). The main objective of the NPEP is to increase the public’s awareness and knowledge of nanotechnology and educate them about the benefits and risks of nanotechnology innovations to enable them to make an informed decision. To this end several programmes have been established. One of these is school debates at national level as a platform to give the public an opportunity to debate issues around nanotechnology. Another is Nano Tour, which allows members of the public to visit industries and universities where nanotechnology facilities are in place, such as the Mintek Nanotechnology Innovation Centre (NIC), the University of the Free State (UFS) nanotechnology facility, and the CSIR production facility for nanotechnology materials. Other initiatives are: a role-model campaign, where nanotechnology scientists can interact with the public and talk about their work; a variety of media platforms, like community radio stations and vernacular language newspapers; and public dialogue through symposiums and workshops. In addition, NPEP also publishes online nanotech articles on a quarterly basis on its website (www.npep.co.za) and produces fact sheets that offer the public accurate information on nanotechnology. NPEP, in partnership with Nabio Consulting (Pty) Ltd, the Swiss Embassy in South Africa, the University of Basel, Switzerland, and the DST Science Forum, has also organised symposiums aiming to facilitate public engagement on nanomedicine development in South Africa and in Switzerland (NPEP, 2017). The symposiums engage the media on the discussions on nanomedicine and ensure that the public is informed about research development in the following areas: HIV/AIDS, TB, malaria, cancer, water, and energy (NPEP, 2018).

Lack of regulation of nanomedicines
The lack of regulation of nanomedicines could delay the acceleration of nanomedicines from research laboratory to the clinic and/or marketplace. The United States Food and Drug Administration
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(USFDA) recently approved the regulation of nanotechnology products (USFDA, 2018). The USFDA’s approach to the regulation focuses on the understanding of interactions of nanomaterials with biological systems, safety, effectiveness, and quality of products containing nanomaterials. Pharmaceutical regulatory agencies that are based in Africa and active in nanotechnology development include the South African Health Products Regulatory Authority (SAHPRA), the National Agency for Food and Drug Administration and Control (NAFDAC, Nigeria), the Egyptian Drug Authority (EDA), the Direction du Médicament et de la Pharmacie (DMP, Morocco), and the National Laboratory for the Control of Pharmaceutical Products (LNCPP, Algeria) (Ndomondo-Sigonda et al., 2017). African regulatory agencies currently don’t have regulatory frameworks/guidelines on nanomedicine and this could affect the commercialisation of nanomedicines. The approved guidelines by international agencies such as the USFDA and the European Medicines Agency (EMA, 2006) can, however, be used as reference points.

The need for the regulation of nanomedicines is due to the nature of materials at nanoscale (1–100 nm). They are highly reactive, can easily bypass biological barriers, and have the potential for high accumulation in human tissue/cells, which could have unexpected human toxicity (Senje, 2013). Some metal materials have been reported to have different properties at nanoscale. For example, gold and silver nanoparticles have been reported to have medicinal benefits at nanoscale. In the past decade, research has been conducted investigating their pharmaceutical potency using metallic nanomaterials as antimicrobial and anti-cancer agents (He et al., 2016; Ronavari et al., 2018). The impact of some of these nanomaterials on human health (and also their environmental risks) is still unknown, which necessitates the regulation of nanotechnology by African countries’ regulatory authorities in order to assure that the medicines containing nanomaterial are safe for human consumption.

Currently there are many nanodrugs that have received approval status from one or more regulatory authorities for commercial use (Fornaguera & García-Celma, 2017). This approval status is used to reassure patients and citizens, as well as physicians, that the particular medicine is safe for human consumption.
Due to unknown long-term impacts on health and the environment, many countries are starting to look at the establishment of a nano code of conduct for nanotechnology R&D to protect the researchers, consumers, and the environment. South Africa’s Department of Science and Technology (PSM, 2018) has this under consideration, with the following objectives:

- Proactively prevent the negative impact and/or undesired consequences of nanotechnology;
- Create an environment for safe and responsible nanotechnology R&D at university and industry;
- Deal with the potential risks of nanotechnology before they emerge; and
- Create an environment for sustainable development of nanotechnology.

COMMERCIALISATION OF NANOMEDICINE

Commercialisation of nanomedicine is necessary in order to achieve universal health care on the African continent. Pan-African and multilateral bodies are encouraging African countries to focus on producing local solutions to local problems and to commercialise their health innovation research. Singer et al. (2008) argues that African countries need to capitalise on local technology and local talent as a way to reduce international dependency for every technology they need. Local production could lead into affordable medicine. However, whether or not nanomedicine makes a significant impact on health care in the African region will depend on the success of commercialisation.

In order for African countries to commercialise their nanomedicine R&D and patents, they need to consider smart commercialisation strategies (Mufamadi, 2016). Such strategies might include:

**Licensing venture**: marketing technology or intellectual property (IP) in exchange for compensation.

**Spin-off venture**: transferring the IP to a new business venture
with the equity investment from a parent company. This is often spun out from university laboratories, research councils and industry.

**Start-up venture:** typically born from innovative business ideas (and different to the spin-off venture), this would depend on the type of investment and technology application. With this venture there is no parent company and so its launch would be a totally new and groundbreaking nanotechnology application. Often the founder/s and/or investors make a decision regarding the mode through which the company will capture value from the technology assets.

**Larger corporations venture:** forming alliances with larger corporations. Partnerships of this nature are often motivated by technology application, equity, infrastructure, and manufacturing and marketing capabilities.

**Alliance business venture:** investors decide on which technology should be designed and the application for which it should be designed – in most cases, technology is designed to meet market need.

**BRICS alliance venture:** BRICS countries would collaborate with each other to enhance the economic benefits.

**Africa to Africa alliance venture:** two or more African countries enter into joint ventures in a selected nanotechnology application. In this way they would foster intra-Africa partnerships, enhance one other’s achievements, and deliver economic benefits.

**Nanomedicine and nanopharmaceuticals in the commercial market**
A US health care nanotechnology (nanomedicine) 2018 market report indicated that US-based pharmaceutical companies believe that nanomedicines are the next big thing (Marketers Media, 2018). There
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are a few nanomedicine innovations in Africa which are currently in preclinical to clinical, prototype, and pre-commercialisation phases, focusing on combating communicable and non-communicable diseases (DST/Mintek NIC, 2016; Grobler, 2017; Venter et al., 2017).

The Nanotechnology Innovation Centre (NIC), established in 2007 and situated at Mintek, Johannesburg, has a few nanomedicine products that are already in a pre-commercialisation stage (DST/Mintek NIC, 2016). In the case of nanodrug delivery and/or nanopharmaceutical products, Nigeria and South Africa are showing promising results. Maduike and colleagues (2014) from Nigeria have reportedly produced nanomaterials made up of synthetic aluminium-magnesium silicate (AMS) with antiretroviral effects. The AMS nanoparticles are reported to have the potential to bypass physical barriers such as the mucous membrane of the gastrointestinal tract. In another study Maduike et al. (2017) reported that HIV-positive patients recover from HIV post-treated with Antivirt® (Medicinal synthetic Aluminium-magnesium silicate). In an interview with the *New Telegraph*, Maduike indicated that some Nigerian HIV patients showed HIV-negative results with no antigens and antibodies (Madike & Orji, 2017). In a recent clinical trial, conducted by Venter et al. (2017) from the Wits Reproductive Health and HIV Institute (Wits RHI) and OPTIMIZE consortium, researchers reported that they have developed candidate universal antiretroviral (optimised) drugs with a potential to reduce the cost of ART-HIV first line and second line drug by half. In 2010, the CSIR teams reported the development of a pre-clinical efficacy study on a TB nanodrug with the potential to change a daily dose into a weekly dose over a four-week period (Makoni, 2010b).

The high burden of drug resistance on communicable diseases and the rapid growth of NCDs such as cancer, diabetes, and cardiovascular diseases, around the world and in Africa, require urgent medical intervention – nanomedicine (Juma & Wisdom, 2018). A JRC-EURO report observed that the commercialisation of nanomedicine in Europe was seemingly being driven by start-ups and SMEs (Wagner et al., 2006) and that large pharmaceutical and medical device companies showed low interest in investing in nanomedicine. The business model of start-ups and SMEs for bringing nanomedical products to the market, however, mostly depends on big pharmaceuticals and/or medical device corporations being willing
to license their established technology. Big pharmaceutical firms find it easy to invest in established technology and to then facilitate the clinical trials and to provide their distribution networks. According to Tsuzuki, the success of nanotechnology will depend on the interaction between multiple stakeholders, R&D and product development, intellectual property, health and safety, regulation and standardisation, and public engagement (Tsuzuki, 2013). Moreover, Mazzucato (2011) insists that governments should take the investment risk where there is uncertainty in areas of R&D and when the private sector is not willing. She observes that in countries where there is economic dynamism, it has been the state, and not the private sector, that has supported risky research areas and created this dynamism (Mazzucato, 2011).

The increase in the pharmaceutical efficacy, the improved bioavailability of nano-sized drugs, and targeted delivery systems were the major focus of the approved nano-enabled drugs that have gained the attention of big pharmaceutical companies in the past decade. The advantage of using nanodrugs is not only in advancing efficacy but also in the reduction of side-effects associated with the bulk counterpart therapeutics currently in use. Most of the FDA-approved nanodrugs are in oncological therapeutics (Morigi et al., 2012). These include PEGylated liposome-encapsulating doxorubicin (Doxil, FDA approved in 1995) for ovarian cancer and the albumin-bound form of paclitaxel (Abraxane, FDA approved in 2005) for various cancers (Wang et al., 2013; Fornaguera & García-Celma, 2017). At present there are few nanopharmaceutical products that are FDA approved and/or in the commercial marketplace (Table 2).

Table 2: Examples of nanomedicines that are in the commercial market

<table>
<thead>
<tr>
<th>No</th>
<th>Product</th>
<th>Type of Nanoformulation</th>
<th>Application</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Doxil</td>
<td>PEGylated liposome – Doxorubicin hydrochloride</td>
<td>Ovarian cancer</td>
<td>JNJ</td>
</tr>
<tr>
<td>2</td>
<td>Abraxane</td>
<td>Albumin nanoparticles – Paclitaxel</td>
<td>Various cancers, e.g. breast cancer</td>
<td>Celgene</td>
</tr>
<tr>
<td>No</td>
<td>Product</td>
<td>Type of Nanoformulation</td>
<td>Application</td>
<td>Company</td>
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<tr>
<td>3</td>
<td>Rapamune</td>
<td>Nanocrystal – Rapamycin</td>
<td>Immuno-suppressive</td>
<td>Pfizer</td>
</tr>
<tr>
<td>4</td>
<td>Somavert</td>
<td>Polymer NPs – Pegvisomant</td>
<td>Acromegaly</td>
<td>Pfizer</td>
</tr>
<tr>
<td>5</td>
<td>Avinza</td>
<td>Nanocrystal NPs – Morphine sulfate</td>
<td>Psychostimulant</td>
<td>Pfizer</td>
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<tr>
<td>6</td>
<td>Focalin</td>
<td>Nanocrystal NPs – Dexamethasone HCl</td>
<td>Psychostimulant</td>
<td>Novartis</td>
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<tr>
<td>7</td>
<td>Ritalin LA</td>
<td>Nanocrystal NPs – Methylphenidate HCl</td>
<td>Psychostimulant</td>
<td>Novartis</td>
</tr>
<tr>
<td>8</td>
<td>Emend</td>
<td>Nanocrystal – Aprepitant</td>
<td>Antiemetic</td>
<td>Merck</td>
</tr>
<tr>
<td>9</td>
<td>PegIntron</td>
<td>Pegylated IFN alpha-2b</td>
<td>Hepatitis C</td>
<td>Merck</td>
</tr>
<tr>
<td>10</td>
<td>Pegsys</td>
<td>Pegylated IFN alpha-2a</td>
<td>Hepatitis B and Hepatitis C</td>
<td>Genentech</td>
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<tr>
<td>11</td>
<td>Caelyx</td>
<td>PEGylated liposome – Doxorubicin</td>
<td>Solid tumors</td>
<td>Janssen</td>
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<tr>
<td>12</td>
<td>Invega sustenna</td>
<td>Nanocrystal – Paliperidone palmitate</td>
<td>Schizophrenia</td>
<td>Janssen</td>
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<td>13</td>
<td>Copaxone</td>
<td>Glatiramer acetate</td>
<td>Multiple sclerosis</td>
<td>Teva Pharma</td>
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<tr>
<td>14</td>
<td>Myocet</td>
<td>Liposome – Doxorubicin</td>
<td>Various tumors</td>
<td>Teva Pharma</td>
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<td>15</td>
<td>AmBisome</td>
<td>Liposome – Amphoteric B</td>
<td>Fungal infections</td>
<td>Astellas Pharma</td>
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<td>16</td>
<td>Marqibo</td>
<td>Vincristine – Sphingomyelin -based liposomes</td>
<td>Leukemia and melanoma</td>
<td>Talon Therapeutics</td>
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<tr>
<td>17</td>
<td>Resovist</td>
<td>Iron oxide nanoparticles coated with carboxydextran</td>
<td>Liver and spleen lesion imaging</td>
<td>Bayer</td>
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<tr>
<td>18</td>
<td>Tricor</td>
<td>Nanocrystal – Fenofibrate</td>
<td>Hypercholesterolemia</td>
<td>Abbott</td>
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<td>19</td>
<td>Plegridy</td>
<td>Pegylated IFN beta-1a</td>
<td>Multiple sclerosis</td>
<td>Biogen</td>
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<td>20</td>
<td>Neulasta</td>
<td>Polymer NPs – Pegfilgrastim</td>
<td>Chemotherapy-induced neutropenia</td>
<td>Amgen</td>
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<table>
<thead>
<tr>
<th>No</th>
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<th>Application</th>
<th>Company</th>
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<tbody>
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<td>21</td>
<td>AmBlsome</td>
<td>Liposomal amphotericin B</td>
<td>Fungal and protozoal infections</td>
<td>Gilead Sciences</td>
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<td>22</td>
<td>Rebinyn</td>
<td>Polymer NPs – Coagulation factor IX</td>
<td>Haemophilia B</td>
<td>Novo Nordisk</td>
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<tr>
<td>23</td>
<td>Eligard</td>
<td>PEGylated polymeric NPs – Leuprolelina</td>
<td>Prostate cancer</td>
<td>Tolmar</td>
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<tr>
<td>24</td>
<td>DaunoXome</td>
<td>Lipid encapsulation of daunorubicin</td>
<td>HIV-associated Kaposi’s sarcoma</td>
<td>Galen Ltd.</td>
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<tr>
<td>25</td>
<td>Rexin-G</td>
<td>Targeting protein/ phospholipid microRNA</td>
<td>Various cancers, e.g. sarcoma</td>
<td>Epeius Biotechnologies</td>
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<td>26</td>
<td>Estrasorb</td>
<td>Micellar estradiol</td>
<td>Menopause</td>
<td>Novavax</td>
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<tr>
<td>27</td>
<td>Abelcet</td>
<td>Liposomal amphotericin B lipid complex</td>
<td>Fungal infections</td>
<td>Sigma-Tau</td>
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<tr>
<td>28</td>
<td>DepoCyt</td>
<td>Liposomal cytarabine</td>
<td>Meningitis</td>
<td>Sigma-Tau</td>
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<td>29</td>
<td>Oncaspar</td>
<td>PEGylated asparaginase</td>
<td>Leukemia</td>
<td>Enzon Pharma</td>
</tr>
<tr>
<td>30</td>
<td>Megace ES</td>
<td>Nanocrystal – Megestrol</td>
<td>Anti-anorexic</td>
<td>Par Pharma</td>
</tr>
</tbody>
</table>

Source: Wang et al., 2013; Fornaguera & García-Celma, 2017

Nanotechnology entrepreneurship

In Africa, despite a large number of nanotechnology research outputs, the commercialisation of nanotechnology is very slow (Makhoba & Pouris, 2017; Mboyi et al., 2017). A study by Maine (2014) showed that entrepreneurial skills can be an important tool in facilitating the commercialisation of nanotechnology in the 21st century. Although the study’s focus was on academic entrepreneurs, its broader application is useful to consider. If academic researchers were to be trained in entrepreneurship – the principles, practices, and skills – and given the tools, they would be in a strong position to commercialise their university’s technologies and/or patents (Wood, 2011; Pattnaik & Pandey, 2014). Traditional universities normally focus on training
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postgraduate students for knowledge generation, but recent trends show that many universities around the world are becoming increasingly interested in the commercial value of their research outputs and patents (Siegel & Wright, 2015; Mzekandaba, 2018).

Acquiring entrepreneurship skills would help academic nanotechnology researchers in a number of ways:
• to identify the commercial value of their nanotechnology research outputs;
• to translate their nanotechnology research work into commercial products;
• to identify the business opportunity in the optimisation of benefits and reduction of potential risks;
• to develop an appropriate business model to commercialise their prototypes;
• to navigate the funding space for nanotechnology ventures; and
• to evaluate the market potential of nanotechnology research.

Various African countries are now focusing on the technology transfer of their university innovations through their own technology enterprise for innovation support – finding licensees from the industry and/or creating spin-off ventures (De Beer, 2018). The advantage of a spin-off company from a university or research laboratory is that this will not only enable the university to commercialise their technologies, but also contribute towards economic development and job creation (Pattnaik & Pandey, 2014). In addition, university spin-offs may continue to receive support from their university enterprise until the company is able actively to sustain itself. Ghana is an example of an African country that is harnessing its science-based health innovation as a way to achieve affordable health solutions and/or to build strong health innovation systems for Ghanaians (Al-Bader et al., 2010).

According to Libaers and Wang (2012), the term ‘academic entrepreneurs’ refers to academics who participate in university research with a hope of commercialising their university-invented technologies. In African countries, where most nanomedicine patents originate from universities, such a strategy could be used to facilitate the
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commercialisation process. Whether academic researchers will make good entrepreneurs or not remains up for debate. They may be highly technically skilled and excel in inventing new technologies under the auspices of their university, but it also needs to be accepted that those technologies and patents will not necessarily be commercially viable or result in business success (Rahim et al., 2015; Siegel & Wright, 2015).

Nevertheless, having entrepreneurs in nanomedicine application could facilitate the creation of new business or start-up companies which will eventually create new jobs and benefit a large number of currently unemployed postgraduate students in nanoscience and nanotechnology. For old industries, the presence of entrepreneurs could facilitate the growth of existing companies. Incorporating nanomaterials into their current products and/or enabling those with new functionality and/or new properties could lead old industries to establishing new businesses or spin-off companies. Furthermore, the presence of entrepreneurs in the research consortium could help in capitalising on the existing nanomedicine patents and in making profit from them or creating new business ventures.

Nanotechnology cluster: a case for collaboration

If developing countries want to succeed in nanotechnology development, they need to consider clustering to create nanotechnology industries (Gkanas et al., 2013). Cluster theory was first described by the economist Alfred Marshall. In his book Principles of Economics (1890) he characterised clusters as a concentration of specialised industries in particular localities. The concept of industrial clusters was popularised by Michael Porter (1990) from Harvard University. African countries could use this concept to group nanotech start-up companies from similar industries and foster partnerships with one another. Nanotech clusters in Africa would create a platform for African governments to centralise or mobilise resources to finance a nanotechnology industry. In collaborating in this way a world-class infrastructure could be set in place and the commercialisation of nanotechnology realised. An opportunity could be created for local inventors to showcase their prototypes to pharmaceutical and medical device companies with a view to forming partnerships that would support prototype de-
development. Other advantages to nanotech clusters might include: assisting inventors/start-ups to reduce the cost of production and waste management; attracting foreign direct investment; enabling job creation and the sustainable development of nanotechnology.

Nanotechnology is supported by the African Union (AU) through the Science, Technology and Innovation Strategy for Africa (STISA, 2014). Creating clusters would assist in the AU’s implementation of its strategy and it would be in a position to be better informed about each country’s progress in nanotechnology development. African policymakers need to engage with organisations such as the African Science, Technology and Innovation Fund (ASTIF), Africa Health Strategy (AHS), the Accelerated Industrial Development of Africa (AIDA), Advancing Healthcare Innovation in Africa (AHIA), the African Network for Drugs and Diagnostics Innovation (ANDI), and global partners such as the Wellcome Trust and the Bill and Melinda Gates Foundation to access funding partners for health innovation solutions. Academia, inventors, and entrepreneurs should also be engaged in such policy discussion in order to accelerate the growth of nanotechnology. Africa needs an active cluster policy that promotes growth and development in a sustainable manner in the area of nanomedicine.

**CONCLUSION**

Despite all the health-related interventions introduced in Africa, epidemics are still prevalent on the continent. Generally weak health systems mean that quality health care remains inaccessible to the most vulnerable in many African countries. Health research, which is a component of building strong health systems, is crucial in improving the health status in Africa. However, the research capacity on the continent is insufficient.

The disease burden on African countries necessitates substantial investment in building research capacity on the continent. This includes the creation of an enabling environment for research to be conducted. Intracontinental partnerships among researchers, governments, and the private sector are important in enhancing research that is relevant to the continent. Furthermore, partnerships with the international community for research in Africa should be regulated to ensure that issues and illnesses
relevant to Africa are prioritised. Research undertaken on the continent should be led by African researchers. It should be receptive to the socio-economic conditions of the African populations. African innovation is key in promoting health and economic development on the continent and should thus be prioritised. More so, technological innovation can help Africa advance into improved health care.

Nanotechnology has been used in this chapter to build a case for disruptive technology in order to challenge the status quo and introduce efficient and affordable treatments. Studies have shown that nanotechnology can improve the efficacy of the existing drugs that are used for the treatment of HIV/AIDS, TB, cancer, and other diseases by reducing their toxicity, reducing the dosage required to achieve the desired effect, and improving their solubility. These factors are pertinent when it comes to patient compliance: with fewer side-effects and less frequent dosing, patients would be more inclined to stick to regimens and thus improve the efficiency of these treatments. It has also been demonstrated how nanotechnology can be used in addressing water-borne diseases such as cholera. Nanotechnology is an efficient and decentralised solution for the provision of clean and safe water to the most vulnerable.

As an emerging technology, nanotechnology requires large investment. Big pharmaceutical companies, which have the resources and existing infrastructure, are not always willing to take the investment risk for emerging technologies. Finding an effective and sustainable way to invest in nanotechnology should thus take precedence for African governments. To advance nanotechnology research in Africa, African countries must build networks between their nanotechnology research efforts, tertiary institutions, and the private sector. Building research capacity from within African countries is how Africa can ensure the development of relevant technologies that will address the burden of disease on the continent.

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