Current Status of Biotechnology in Health

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Abstract: The aim of this review was to discuss scientific advancements in the area of biotechnology in relation to its application in health. Health biotechnology uses chemistry of living organisms through molecular biology and cell manipulation to develop new or alternative methods in order to find more effective ways of producing traditional products. Its synergy with nanotechnology, materials and information technology has led to the development of new and revolutionary applications that are likely to be adopted in health. Development and search for new vaccines, multiple drug delivery systems, gene therapy, forensic analysis, reduction in food toxins, supply of health related valuable products by the transgenic animals, cloning and human organ supply for transplantation, good quality food, disease resistant varieties of cereal crops, global food security, all are very essential for survival of mankind, are discussed in this review and possible by the careful use of biotechnology. Since better health is the very basic necessity of mankind, therefore it can be concluded that in the near future biotechnology will become major driving force in the field of health, beneficial especially for the inhabitants of underdeveloped countries like Pakistan.

Key words: Cell culture · Forensics · Genetic engineering · Gene therapy · Pharmacogenomics

INTRODUCTION

The Convention on Biological Diversity defines biotechnology, as “any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use”. While biotechnology applications date back to 6000 BC, developments since the 1970s in genomics, genetics, cell and tissue engineering have identified a range of possible novel applications and given the field new impetus. Its facilitation through nanotechnology, materials and information technology has fuelled research and development of new technologies with broad applications in health care, agriculture, environment and industrial production.

Parallel technological developments in biotechnology, nanotechnology, materials technology and cross facilitation with information technology are enabling the development of new concepts and applications in medicine, agriculture, mining, food processing and materials design. For pharmaceutical companies, the convergence of biotechnology and information technology has revolutionized drug discovery and design and reduced costs [1].

Global economics is driving international competition among biotechnology companies to develop new products and applications. The growing recognition of biotechnology as an economic and social growth factor has prompted governments in many countries to provide financial support to their local biotechnology companies to encourage research, development and commercialization of ideas and products [2].

The drive to ‘beat nature’ is often considered as a driver for biotechnology. Expectations of an aging population, untreated diseases and unresolved environmental problems have provided incentives for biotechnology companies to innovate and provide quality products and services [3].

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In the next 10 to 20 years, health care is expected to shift towards molecular and preventive medicine and the use of recombinant DNA (rDNA) and monoclonal technologies. Genetic testing, gene therapy and personalized medicine may become common practice. New surgical tools and techniques such as antiplasty, laser surgery and hybrid imaging techniques promise to be largely non-invasive. They will not only improve survivability, but could reduce patient costs related to lengthy hospital stays. Advances in cell and tissue regeneration promise to develop organic and artificial tissues for repair and replacement functions [1].

Nobel Peace Prize laureate Norman Borlaug says, “The first essential component of social justice is adequate food.” Increasingly, he and many others say plant biotechnology is one of several tools that can be used to produce not only adequate food, but food that is better for you. Plant biotechnology researchers are working to improve health in two important ways: By making more food available to meet basic dietary needs and by making better foods that are high in vitamins and have other healthy traits [4].

Biotechnology and Health
Enhanced Nutritional Aspects and Healthier Lives:
As important as plant biotechnology is in producing more food for a growing population, researchers are also developing healthier foods than can improve human health. In the 1930s, immigrants to the United States living in big cities were unusually prone to rickets; a bone disease caused by a deficiency of vitamin D. Poor diet was one reason. Another was that the tall, tightly packed-in tenement buildings where many immigrants lived blocked most direct sunlight, another key source of vitamin D. When food manufacturers began adding vitamin D to bread and milk shortly thereafter, rickets became very rare in the United States [4].

Field tests are underway for a decade by Purdue University and the U.S. Department of Agriculture's Agricultural Research Service on a cancer-fighting tomato with three times more lycopene, an antioxidant, than conventional varieties. Lycopene is known to trap harmful molecules that damage human body tissue and could lower the risk of breast and prostate cancers, as well as coronary heart disease. The development was discovered when attempting to lengthen the shelf life of tomatoes. This was recently chosen by American consumers as 2002’s top food biotechnology development [5].

In India, mustard seeds have been enhanced so they contain more beta carotene by Monsanto Company, in cooperation with Michigan State University, USAID and the Tata Energy Research Institute in India, which could help alleviate vitamin A deficiencies. The project was developed in part to respond to a greater effort to enlist private sector collaboration in the Global Vitamin A partnership program, which was initiated by then First Lady Hillary Clinton. Mustard seed oil is the second most commonly used oil in India and since it is in an oily medium, it is expected to have good bioavailability [6].

Several research teams are working to improve rice, a staple food for half the world’s population, by putting more nutrition into each grain. Enhanced “golden rice” may help reduce childhood blindness, while new iron-rich rice could have a truly global impact, one in three people worldwide do not get enough of the nutrient [7]. “Golden Rice” the rice genetically enhanced to express carotenoids, has received much media attention because of its potential to supply a desperately needed nutrient, vitamin A, to millions of malnourished people [8]. Developed in the 1990s by researchers in Germany and Switzerland with financial support from the Rockefeller Foundation, the laboratory lines of Golden Rice must now be transferred to local rice varieties. Initial efforts are focused on India, but arrangements have also been established in South East Asia, China, Africa and Latin America to transfer the technology [9]. Golden Rice was originally produced by transformation of the Japonica variety Taipei 309 and the technology was subsequently shown to be functional in different cultivars of rice that are relevant in Asia [10]. Although commercialization of Golden Rice is 2-3 years in the future, a commitment has been made to make the product available free of charge to small scale poor farmers of developing countries.

In developing countries, where vitamin A deficiency prevails, grain from Golden Rice is expected to provide Provitamin A important micronutrient sustainably through agriculture. Since its original production, the prototype Golden Rice has undergone intense research to increase the provitamin A content, to establish the scientific basis for its carotenoids complement and to better comply with regulatory requirements. Today, the current focus is on how to get Golden Rice effectively into the hands of farmers, which is a novel avenue for public sector research, carried out with the aid of international research consortia [11]. Although heavily publicized by the biotechnology industry, progress toward field testing and local adaptation of the rice has been slow for a variety of
Biofortification of candidate crops to enhance provitamin A content represents a recent strategy to combat vitamin A (VA) deficiency [14]. Orange fleshed sweet potato (OFSP) is a staple crop targeted for biofortification. Orange fleshed sweet potato (OFSP) is an important source of beta carotene [15, 16]. Efforts to biofortify sweet potato have focused on increasing beta carotene content and improving organoleptic qualities of commonly consumed varieties. Replacement of white fleshed sweet potato (WFSP) with orange fleshed varieties could benefit about 50 million children <6 years of age at risk of VA deficiency [17]. Recent human interventions have focused on different aspects of beta carotene bioavailability from OFSP. Using stable isotope methodology [18], bioconversion of sweet potato beta carotene was 13.4 µg beta carotene to 1 µg retinol in Bangladeshi men fed a daily snack of 80 g sweet potato. Liver reserves assessed with the modified relative dose response test improved with a daily portion of OFSP fed during school days to South African schoolchildren [19]. Likewise, serum retinol concentrations improved in young children after the introduction of OFSP into Mozambique [20]. During the last decade, a lot of efforts have been made to reduce Vitamin A deficiency VAD in developing countries. Food fortification, supplementation and dietary education programmes have been undertaken. A complementary approach is to enrich major staple foods with beta-carotene through plant breeding. For some crop species, such as maize and sweet potato, cultivars with high beta-carotene contents have been identified, which can be used in traditional breeding programmes [21].

In Kenya, the sweet potato is a staple food grown primarily by resource poor small farmers. The average plot is less than one-half acre and about half of the harvest is kept for home use. The sweet potato is a reliable crop because it can grow and stay underground and provides a “larder” of food if other foods are in short supply [22]. However, sweet potatoes can be infested with insects that carry a virus, “sweet potato feathery mottle virus” (SPFMV) that cannot be controlled by agricultural chemicals. Infested sweet potatoes have blemished and spoiled areas and the yields are a fraction of what could be realized if they did not have this pest. Finding a way to eliminate the effects of this virus could help Kenyan farmers assure a reliable supply of sweet potato for personal consumption as well as for sale [23]. In 1991, a collaborative research project was launched to solve the SPFMV problem. The members of this coalition were the Kenya Agricultural Research Institute (KARI), the US Agency for International Development (USAID), the University of Missouri and the Monsanto Company. The basic research phase was conducted in Monsanto’s laboratories, where Monsanto scientists, Dr Florence Wambugu and a number of other scientists from KARI conducted the transformation and regenerated virus-resistant plants. This project was actually launched to improve the nutritional value of sorghum for human consumption as well as to build African scientific capacity through the training of African scientists.

The extent of non-communicable disease (NCD) challenge in Africa is much higher than most people anticipate. Protein, vitamin and micronutrient deficiency based diseases have steadily been on the increase from the 1940’s in most African countries due to the prevalence of risk factors within communities, most notably, poor and unhealthy diet. NCD contribute to the high mortality rate in Africa. Nutrition is critical factor in the fight against non communicable diseases in Africa. Biofortification is widely viewed as important in the arsenal against NCD’s. It increases the levels of natural nutrients within plants that may be directly or indirectly consumed as food. The benefit is that staple crops, already familiar to rural communities, can be biofortified; this helps improve resistance to NCDs as well as the general health of the community. Sorghum is the sixth most planted crop in the world, grown on more than 100 million acres each year worldwide, producing about 60 million metric tons of grain each year. Sorghum grain is low in protein quality due to its low content of essential amino acids, such as lysine. It is also difficult to digest, which inhibits the absorption of nutrients. The reliance on sorghum as an important food in arid regions of Africa and Asia can result in problems associated with malnutrition, especially in children. The Africa Biofortified Sorghum Project seeks to provide a long term solution to the problem by creating a “super sorghum” that grows well in the harsh climate but also contains increased levels of essential nutrients, especially lysine and Vitamins A and E, as well as more available iron and zinc. The end result could improve the life and health of more than 300 million people. Science is part of a bundle of solutions that holds the key to creating sustainable agriculture and a more nutritious food supply in Africa. This innovative solution could have profound implications for the region and the world [24].
To be healthy, human beings require more than 20 mineral elements and more than 40 nutrients, particularly vitamins and essential amino acids, all of which can be supplied by an appropriate diet. However, human diets often lack one or more of these essential nutrients. Poor quality diets, characterized by high intakes of staple foods and low consumption of animal and fish products, fruits, legumes and vegetables (all rich sources of minerals and vitamins), cause micronutrient malnutrition. Biofortification, a new approach that relies on conventional plant breeding and modern biotechnology to increase the micronutrient density of staple crops, holds great promise for improving the nutritional status and health of poor populations in both rural and urban areas of the developing world [25-27]. Plant breeding to increase micronutrient density began to gain legitimacy when deficiencies in micronutrients such as Fe, I, Zn and vitamins were recognized as an issue of overwhelming global public health significance and one of the major development challenges of the 21st century. To capitalize on agricultural research as a tool for public health, in July of 2003 the Consultative Group on International Agricultural Research (CGIAR) established HarvestPlus: the Biofortification Challenge Program, thus adding food quality to its agricultural production research paradigm [28].

Biofortification research, a comprehensive program that spans from genetic crop improvement to research on the impact of biofortified crops on human health is conducted mainly under the auspices of HarvestPlus. HarvestPlus targets a multitude of crops that are a regular part of the staple based diets of the poor [19, 29]. The biofortification concept, with HarvestPlus at its nexus, is a new food based public health intervention initiative, aimed at controlling micronutrient deficiencies in poor countries. HarvestPlus focuses on three micronutrients that are recognized by the World Health Organization as limiting for human health: Fe, Zn and vitamin A. To accomplish this task, HarvestPlus has assembled an impressive multidisciplinary alliance of over 70 scientists at 46 institutions around the world. Ten CGIAR research centers form the nexus of development of biofortified crops. Twenty five national agricultural research system partners make up a research alliance that conducts adaptive and participatory breeding of promising varieties. Full fledged plant breeding programs are underway for six staple foods rice, wheat, maize, cassava, orange fleshed sweet potato and common beans that are consumed by the majority of the world’s poor in Africa, Asia and Latin America [28].

**Reduced Food Toxins and Allergens:** A paper from the American Phytopathological Society describes how one popular biotech corn variety, called Bt (Bacillus thuringiensis) corn, has unusually low levels of mycotoxins, a cancer causing agent. Mycotoxins enter corn through holes chewed by insect pests like the European corn borer pests that Bt corn, which releases a natural insecticide as it grows, is highly effective at repelling [30]. Food borne mycotoxins are secondary metabolites of fungi. Especially in maize, it has been shown that insect damage is one factor that contributes to mycotoxin contamination, because damage by insects encourages fungal colonization and insects themselves are a vector by which fungal spores move from plant to plant [31].

There are different types of mycotoxins. Two of the most important ones in maize are aflatoxins and fumonisins. Aflatoxins, mostly produced by the fungus Aspergillus flavus were among the first mycotoxins discovered. They are the most potent chemical liver carcinogen known. Aflatoxins have a synergistic effect with the carcinogenic hepatitis viruses and they can also cause stunting in children and immune system disorders [32]. The effects on animals can be equally devastating. Fumonisins are produced by Fusarium verticilloides and Fusarium proliferatum on maize and other crops. High levels of fumonisins have been associated with esophageal cancer and neural tube defects in various parts of Africa, Central America and in Asia [33]. Animal effects include equine leukoencephalomalacia, porcine pulmonary edema and liver and kidney cancer in rodents. In a variety of field studies, Bt maize was shown to contain significantly lower levels of certain mycotoxins.

The technology has been particularly successful in lowering fumonisin contamination in a number of countries. Given that Bt target insects are not as important in predisposing plants to infection by A. flavus as they are for F. verticilloides and F. proliferatum, Bt technology has been less successful in reducing aflatoxins as compared to fumonisins [34].

Safety of Bt toxins in terms of toxicity and allergenicity towards mammals and other non-target organisms is well documented [35]. The salient features are: (1) Lack of receptors that bind to Bt toxins and instant degradation of Bt toxins in human digestive system make them innocuous to human beings. Community exposure to Bt toxins/spray formulations over a period of six decades has not resulted in any adverse effects. (2) Lack of homology to any allergenic protein/epitope sequences makes Bt toxins non-allergenic. (3) Consumption of foods
derived from Bt corn, potato, tomato and rice over the past one decade has not led to any adverse effects in the populations. (4) Federation of Animal Societies of USA (2001) observed that Bt crop products (corn) fed to chicken-broilers, chicken-layers, catfish, swine, sheep, lactating dairy cattle and beef cattle did not show any adverse effects on growth, performance, observed health of the animals and composition of meal, milk, eggs. Dairy cows fed with corn and Bt-corn did not exhibit any significant differences in lactation and ruminal fermentation. (5) Bt-sprays, Bt-crops and Bt-crop products are safe to non-target organisms such as soil microorganisms (protozoa and fungi) collembola, molluscs, crustaceans, spiders, aquatic insects, predators, parasitoids, arthropods, honey bees, lady bird beetles, earthworms, salamanders, bird species, small and large mammals.

One team of researchers recently succeeded in disarming the P34 gene in soybeans, an allergen that affects an estimated 6 to 8 percent of children and 1 to 2 percent of adults. Research suggests a single protein called Gly m Bd 3s0K/P34 is to blame. This is probably the first time a dominant human allergen has been knocked out of a major food crop using biotechnology [36]. Health professionals like the members of the non-profit American College of Nutrition are on record as supporting the use of biotechnology to “contribute to global food security,” as well as to “enhance the safety and nutritional value of the food supply” by removing anti-nutrients and allergens [7].

Life Saving Vaccines: Staple foods can be used to deliver inexpensive, effective vaccines for specific illnesses (edible vaccines), which could save some of the 15 million children who die each year from preventable diseases [37]. Researchers are experimenting with building a vaccine for hepatitis B, which attacks the liver, into bananas. When eaten, the vaccine is absorbed through the intestine into the bloodstream, producing antibodies in the same way as an injected vaccine. But the banana vaccine is expected to cost about 2 cents a dose, rather than $125 for an injection. Plus, it could be easily administered without the need for refrigeration or medical staff [38]. Potatoes have been developed to contain vaccines against a variety of diseases, including cholera [39], Norwalk virus [40] and hepatitis B [41]. A draw back from the use of potatoes as the vehicle is that they must be eaten raw. Issues such as proper distribution, quality control and control of access will need to be resolved.

Genomics and Disease Diagnosis: Automation in genomics has made genetic testing possible, with nanotechnology enabling the development of chip based diagnostic tools that can simultaneously screen and analyze entire genomes on a chip with speed and accuracy. These genomic tools include: DNA chips for rapid, efficient and simultaneous analysis of large numbers of genes including mutations in each of these genes to identify genetic diseases [42, 43].

Biochips to act as biosensors to monitor bacteria, viruses and other microorganisms in the environment and perform biological and chemical analysis on people. Lab-on-a-chip systems to perform laboratory functions and provide fast and accurate diagnostic information in real time [44]. The system has the potential to deliver multiple drugs in timed and measured doses and may become an alternative method in drug delivery. Society could benefit from the availability of multiple drug regimes in the treatment of various diseases [45]. Protein-encrusted chips to perform various functions quickly and cheaply. They could monitor specific microbes, disease cells and harmful chemicals in the environment. Soldiers could use these chips to detect chemical and biological agents and improve battlefield data collection [46]. Tests are currently being conducted to use protein chips to detect disease biomarkers and assess levels of toxicity of protein-based drugs [47]. It is expected these new technologies will result in significant performance improvements and health outcomes because of their emphasis on point-of-care and personalized treatment [48].

Treatment and Prevention of Diseases

Recombinant DNA Technology: Recombinant deoxyribonucleic acid (rDNA) is a genetic engineering technique used to artificially join pieces of deoxyribonucleic acid (DNA) from different organisms. In a study by the University of Toronto's Joint Centre for Bioethics, it was ranked among the most promising biotechnologies with potential to benefit global health within. However, the field of rDNA technology continues to rapidly expand, so many of its future benefits are still to be realized and in many cases recognized. There are many potential medical applications of this technology, although these can be categorized in two areas. (a) New forms of drugs: development of molecular based drugs such as new antibiotics that may solve current problems associated with antibiotic resistance to treatment and drugs to treat complex medical conditions such as Alzheimer’s disease, diabetes and obesity and (b) New forms of administration: design and development of
safer and more effective vaccines to control infectious diseases such as HIV/AIDS, malaria and tuberculosis. This technology could be used to improve the effectiveness of current vaccines. The possibility of inhalable drugs, powdered vaccines and plant based vaccines as an alternative to drug injection could make drug delivery cheaper and safer [49, 50].

Creating improved ways of delivering medicine has a number of substantial and immediate uses. Compared to traditional vaccines, these new vaccines offer the following advantages. (1) New means of delivery. (2) Economical to mass produce and transport. (3) Heat stable, eliminating the need for refrigeration. (4) Subunit vaccines (not attenuated) for increased safety. These vaccines cannot replicate in the host and are less likely to induce adverse immune reactions. (5) Enhanced compliance especially in children (e.g. edible vaccines) and (6) can be integrated with other vaccine approaches [51].

Modified Genome Animals: There are various definitions for the term transgenic animal. The Federation of European Laboratory Animal Associations defines the term as an animal in which there has been a deliberate modification of its genome, the genetic makeup of an organism responsible for inherited characteristics [52]. These animals are being produced for two common reasons: (a) Some transgenic animals are produced for specific economic traits. For example, transgenic cattle were created to produce milk containing particular human proteins, which may help in the treatment of human emphysema. (b) Other transgenic animals are produced as disease models (animals genetically manipulated to exhibit disease symptoms so that effective treatment can be studied). For example, Harvard scientists made a major scientific breakthrough when they received a U.S. patent (the company DuPont holds exclusive rights to its use) for a genetically engineered mouse, called OncoMouse or the Harvard mouse, carrying a gene that promotes the development of various human cancers [53].

There are many examples of animals being genetically altered to produce non-naturally occurring products. Cows and goats have been engineered to secrete human proteins in their milk. Pigs could become donors of xenografts for human transplants and relieve organ shortages [54]. Transgenic cows exist that produce more milk or milk with less lactose or cholesterol [55], pigs and cattle that have more meat on them [56] and sheep that grow more wool [57]. Scientists are attempting to produce disease-resistant animals, such as influenza-resistant pigs, but a very limited number of genes are currently known to be responsible for resistance to diseases in farm animals [58]. Products such as insulin, growth hormone and blood anti-clotting factors may soon be or have already been obtained from the milk of transgenic cows, sheep, or goats. Research is also underway to manufacture milk through transgenesis for treatment of debilitating diseases such as phenylketonuria, hereditary emphysema and cystic fibrosis [55, 59]. Tilapia, a fish of the cichlid family, has been engineered with a human gene to produce Factor VII, a substance vital for blood clotting [60].

Combination of Pharmacology and Genetics: New technological advances in high throughput DNA and messenger RNA (mRNA) analysis and efficient processing of this data are enabling rapid generation of patient information. This development has created pharmacogenomics, a new field that combines pharmacology and genetics to study how individual genetic profiles determine drug response. Pharmacogenomics will enable physicians to deliver tailored treatment to their patients and promises safe drugs with fewer side effects, thereby eliminating prescription related medical errors [61, 62].

Anticipated Benefits of Pharmacogenomics Include: (1) Pharmaceutical companies will be able to create drugs based on the proteins, enzymes and RNA molecules associated with genes and diseases. This will facilitate drug discovery and allow drug makers to produce a therapy more targeted to specific diseases. This accuracy not only will maximize therapeutic effects but also decrease damage to nearby healthy cells. (2) Current methods of basing dosages on weight and age will be replaced with dosages based on a person's genetics. This will maximize the therapy's value and decrease the likelihood of overdose. (3) Knowing one's genetic code will allow a person to make adequate lifestyle and environmental changes at an early age so as to avoid or lessen the severity of a genetic disease. Likewise, advance knowledge of particular disease susceptibility will allow careful monitoring and treatments can be introduced at the most appropriate stage to maximize their therapy. (4) Vaccines made of genetic material, either DNA or RNA, promise all the benefits of existing vaccines without all the risks. They will activate the immune system but will be unable to cause infections. They will be inexpensive, stable, easy to store and capable of being engineered to carry several strains of a pathogen at once.
(5) Pharmaceutical companies will be able to discover potential therapies more easily using genome targets. Previously failed drug candidates may be revived as they are matched with the niche population they serve. The drug approval process should be facilitated as trials are targeted for specific genetic population groups, providing greater degrees of success. The cost and risk of clinical trials will be reduced by targeting only those persons capable of responding to a drug. (6) Decreases in the number of adverse drug reactions, the number of failed drug trials, the time it takes to get a drug approved, the length of time patients are on medication, the number of medications patients must take to find an effective therapy, the effects of a disease on the body and an increase in the range of possible drug targets will promote a net decrease in the cost of health care. (7) Instead of the standard trial and error method of matching patients with the right drugs, doctors will be able to analyze a patient's genetic profile and prescribe the best available drug therapy from the beginning. Not only will this take the guesswork out of finding the right drug, it will speed recovery time and increase safety as the likelihood of adverse reactions is eliminated. Pharmacogenomics has the potential to dramatically reduce the estimated 100,000 deaths and 2 million hospitalizations that occur each year in the United States as the result of adverse drug response [63, 64].

**Therapy Involving Stem Cell:** Cell culture technologies involve growing of stem cells outside living organisms to produce transplantable tissues for therapeutic purposes. Stem cells have the ability to develop into more than one form of human tissue. They may be sourced from embryos or adult stem cells, with the former having greater scope for types of cells produced [65]. For example, adult stem cells have developed into bone and blood cells. It has been reported that stem cells from bone marrow can also develop into brain cells. This discovery has improved the prospects of using adult stem cells to repair damaged or diseased brains of patients suffering neurological diseases and stroke [66].

Tests on mice using embryonic stem cells have shown promising results with potential clinical applications in the treatment of human neurodegenerative diseases such as Alzheimer’s and Parkinson’s disease, diabetes (type 1 Juvenile diabetes), spinal cord injury and hemophilia [67]; bone and cartilage diseases such as osteoarthritis, heart conditions, cancer and immune diseases, multiple sclerosis and lupus [65]. However, the current controversy surrounding embryonic stem cell therapy has restricted its application. In Australia, only harvested stem cells from surplus IVF embryos can be used for research causing some constraints on the development of this field [68].

**Genes Involved in Treatment:** Gene therapy is based on the premise that those diseases that are caused by faulty genes can be treated when the faulty gene is replaced with a normal version. Gene therapies could control, prevent or even cure particular diseases [69].

There are broadly, two types of gene therapy. (a) Germ line gene therapy involves transfer of sperm cells and egg cells of the reproductive system. Since the creation in 1996 of Dolly the sheep from an adult stem cell, cows, goats, pigs and mice have all been cloned [70]. However, animal cloning has yet to overcome a number of hurdles. Many of the cloned sheep, cattle, goats and mice are reported to have died before birth or were born with severe abnormalities. Dolly died prematurely in February 2003 aged six years from arthritis and lung disease [71, 72]. In humans, this form of therapy could eliminate inherited genetic diseases before birth and save subsequent generations. However, the prospect of engineering identical human beings has raised moral, ethical, religious and scientific issues. Many countries have legislated to prohibit its human application. (b) Somatic cell gene transfer involves transfer of adult cells and could treat various types of cancers, cystic fibrosis, diabetes and acquired infectious diseases such as HIV/AIDS and tuberculosis. Its application in human tissue transplantation could reduce organ rejection, as the recipient is also the cell donor. Compared to adult stem cells, embryonic stem cells offer the greatest potential. However, due to various legal and ethical concerns, the extent of use is currently limited.

**Bioinformatics:** Bioinformatics is a new field that has emerged to provide analytical and computational tools for biological research. It draws elements from computer science, mathematics, physics, medicine and biology. These tools will store, search and analyze genomic and other biological data [73] and provide valuable information that may lead to new drug development, more rapid diagnosis and better health outcomes [74].

The rationale for applying computational approaches to facilitate the understanding of various biological processes includes: (a) A more global perspective in experimental design and (b) the ability to capitalize on the emerging technology of database-mining, the process by which testable hypotheses are generated regarding the
function or structure of a gene or protein of interest by identifying similar sequences in better characterized organisms [75].

**Human Organ Supply and Biomaterial Engineering:**

Animals such as baboons or pigs could be genetically modified and cloned to grow organs or tissues for human transplantation. This technique could alleviate supply shortages of human organs, save and prolong the lives of recipients. However, organ rejection and ethical concerns of using animals to grow human organs constitute a barrier to xenotransplantation. Advances in cell and tissue regeneration promise biomaterials with superior advantages to synthetic materials due to their compatibility to the human body. This technique has already produced skin products for wound treatment and clinical tests are being conducted on new cartilage and functional tissue to treat heart disease. It will also enable using stem cells to replace dead or damaged tissue, which could assist in the treatment of wounds and accelerate healing. Artificial tissues have included bioactive polymers to act as meshes, sponges, or hydrogels to stimulate tissue growth and ceramics for bone regeneration [1].

**Forensics:** The discriminating power of DNA fingerprinting technology has contributed significantly to law enforcement, particularly in solving serious crimes such as rape and murder. New DNA technologies can match minute biological samples to their sources. Aided by computer technology, DNA databanks have assisted in criminal investigations that led to prosecution in unsolved cases [76]. DNA testing has been instrumental in correcting miscarriages of justice for innocent individuals accused of crimes. This was highlighted in the U.S. Department of Justice Report on 28 cases reviewed where DNA tests later exonerated individuals convicted on the basis of eyewitness testimonies. Had DNA tests been conducted on physical evidence, their innocence would have been proven much earlier [77]. DNA testing is said to have 99 percent accuracy and has been instrumental in cases involving disputed paternity. Fathers have used it to deny or reduce child support payments. It has also enabled children to prove their biological heritage [78]. DNA has assisted in the identification of aircraft and war victims using personal items containing tiny amounts of human genetic material (e.g. skin or hair). For instance, DNA testing identified most of the victims of the World Trade Center disaster in New York in September 2001. The US Defense Department used DNA to identify remains of missing soldiers who died during the Vietnam War, Korean War and World War II [79]. It was also used to identify victims who died during the Bali bombing in October 2002 [80].

**CONCLUSION**

Rapid developments in biotechnology promise significant health improvements including: molecular based drugs and vaccines to control variety of infectious and genetic diseases, advanced diagnostic tools for accurate genetic testing and risk prevention, non-invasive surgical techniques to minimize pain, gene therapy to treat immune and age related diseases and enhance non-disease traits, tissue and cell based therapies to replace damaged skin, muscle and other body functions and implantable biochips for in vivo health monitoring and controlled drug release. Genomic based applications could eradicate many common and untreatable diseases, improve the quality of human health and extend life expectancy and enhance human physical and cognitive capabilities. Genetic modification could produce transgenic crops with enhanced nutritional value, pesticide and herbicide resistance and extended shelf storage and crops that can grow faster and tolerate harsh environments. Other possibilities include plant derived vaccines and farm animals that have been genetically engineered to resist disease, enhance production and produce human proteins to treat diseases. The realization of these applications will depend on a variety of factors such as social and cultural acceptance of technological change, levels of technology and infrastructure investment in respective countries, market drivers and other structural determinants. Technological impacts may also vary between the developed and developing countries.

**REFERENCES**


