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The Impact of RED Biotechnology on Healthcare Advances

Abhay H Pande[1±], J Anakha[1]
[1]Department of Biotechnology, National Institute of Pharmaceutical Education and Research (NIPER), Sector 67, S.A.S. Nagar (Mohali)-160062, Punjab, India.
[±]Corresponding author: Abhay H Pande,
Department of Biotechnology, National Institute of Pharmaceutical Education and Research (NIPER), Sector 67, S.A.S. Nagar, (Mohali) -160062, Punjab, India.
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The Dawn of Biotechnology in Healthcare

Biotechnology is defined as 'a set of enabling techniques for bringing about specific human-made changes in DNA, or genetic material, in plants, animals, and microbial systems, leading to useful products and technologies' (UN, 2024). The use of biological substances became more prevalent in traditional medicine during the Middle Ages, bringing about tremendous improvements. As the use of herbal remedies increased, healers and apothecaries planted medicinal gardens to obtain a wide range of plants that could be prepared using traditional wisdom passed down through the generations, frequently combining elements of distillation and fermentation (Hargreaves, 2023). Honey was used by the ancient Egyptians to treat respiratory illnesses and as a wound treatment, while by 600 BC, the Chinese were treating boils with mouldy soybean curds. Additionally, it has been documented that Ukrainian peasants used mouldy cheese to treat wounds that were infected because the moulds emitted antibiotic-like compounds that killed bacteria and stopped the infection from spreading (Hargreaves, 2023; Science Learning Hub, 2024). The second stage of biotechnology development, known as classical biotechnology, spanned the years from 1800 to nearly the middle of the 20th century. The abundance of diverse observations in this era, strengthened by scientific evidence, has allowed the mysteries of biotechnology to be unravelled (Bhatia and Goli, 2018). The experiments and observations of Louis Pasteur led to the development of techniques like pasteurization, which greatly aided in food safety and disease prevention during the mid-19th century, when infant mortality from food poisoning exceeded 200 per 1000 livebirths annually in many countries (Currier, 2023). Moreover, Gregor John Mendel discovered genetic information in pea plants for the first time, laying

the foundation for modern biotechnology. Mendel's groundbreaking discoveries of dominant and recessive features, as well as the basic principles of genetics that are now known as the laws of heredity, came about as a result of his findings (Verma et al., 2011; Hargreaves, 2023). In addition, a number of fundamental ideas in biology were developed during the second half of the 1800s as scientists shifted their attention from the study of animals, organs, or tissues to the study of individual cells. It was at this time that Schleiden and Schwann demonstrated that all tissues originate from cells and that animals and plants have the same basic units of structure, cells, which combine to form complex organisms (Mayr, 1982). The long-held belief that new cells can form spontaneously from inanimate materials was refuted by studies conducted, among others, by Pasteur and Virchow, which showed that new cells can only develop from other cells. Later, the observations and discoveries by pioneers such as Boveri, Haeckel, and Flemming integrated the emerging fields of cytology and genetics, leading to the birth of the DNA era, which laid the foundation for modern molecular biology (Dahm, 2005; Verma et al., 2011; Bhatia and Goli, 2018). The invention of vaccinations is one of the many notable discoveries made during this time that highlights the significance of biotechnology in the medical profession. Variolation, the deliberate exposure of healthy individuals to smallpox, has been used since at least the 15th century in various parts of the world in an attempt to prevent sickness. Some sources even cite as early as 200 BCE for these procedures. Benjamin Jesty conducted experiments to test his theory that cowpox infection may shield a person against smallpox in the early 1770s. Later in the 1790s, Edward Jenner builds on this discovery by injecting 8-year-old James Phipps with matter taken from a cowpox sore on a milkmaid's hand. Phipps recovers completely and becomes the first person to receive a smallpox vaccination. Consequently, the word ‘vaccine’ was later created, derived from the Latin word ‘vacca’, which means cow (WHO, 2024). Louis Pasteur developed methods for immunizing against cholera and anthrax by using the infectious pathogens themselves, based on Jenner's research (The Institut Pasteur, 2024). At this point, it appeared that the biological sciences were approaching the exponential stage of development and growth. By the time the first antibiotic, penicillin, was discovered by Alexander Fleming near the end of the classical biotechnology era, biotechnology had already proven its worth in the healthcare sector (Bhatia and Goli, 2018; Britannica, 2024).

Red Biotechnology

Since the field of biotechnology has many uses and areas of interest, it is necessary to use colour classification to communicate and understand the many aspects of the field by grouping the different biotech applications based on their goals and purposes (DaSilva, 2004; Pande and Anakha, 2024). There are currently 11 formal biotechnology colours, and each one stands for a certain application of biotechnology, such as one in industry, environmental research, agriculture, or medical. This classification made its simpler to find areas of overlap and collaboration between various industries as well as to develop new technologies and applications (Barcelos et al. 2018; Pande and

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Anakha, 2024). Among these, red biotechnology, often known as medical biotechnology, is a branch of biotechnology that focuses on developing treatments and diagnostics through the application of biotechnological techniques (Elsayed et al. 2019; Pande and Anakha, 2024). Modern biotechnology began to emerge after World War II as a result of numerous discoveries, particularly in the field of medicine. When JD Watson and Francis Crick discovered the structure of deoxyribonucleic acid (DNA), it transformed the area of genetics and marked the beginning of modern healthcare biotechnology (Liao et al., 2023). A large number of fundamental concepts had been clarified by this point in time, and the scientific community around the world appeared to have nearly all of the instruments they needed for their applications at their disposal. This has accelerated the process of making significant scientific discoveries. These days, biotechnological instruments are an essential component of numerous industries, most notably healthcare because they are employed so extensively in disease treatment, diagnosis, and prevention (**Fig .1**).

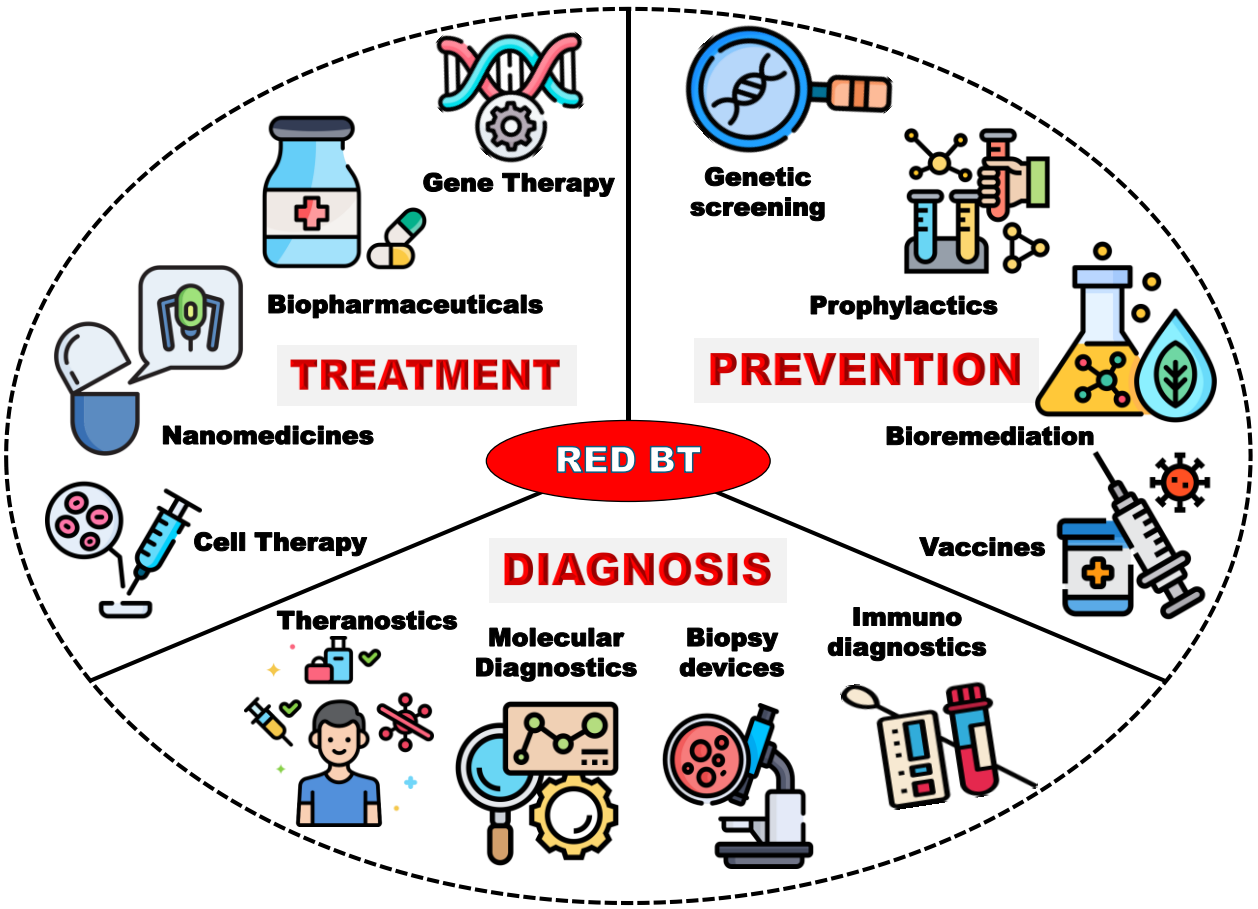

Figure 1. Application of Red Biotechnology (BT) in healthcare. The figure was created using free icons available from Flaticon at: flaticon.com

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Red Biotechnology in Diagnostic Applications

At both the individual and population levels, diagnostics are essential for determining the occurrence and aetiology of disease. With the use of diagnostics, medical professionals can gather precise data that can help with illness prevention, early detection, and monitoring. Furthermore, the development and execution of treatment plans as well as the optimization of treatment courses depend heavily on diagnostics (Rabinow, 2011). Many facets of genome structure and dynamics can now be examined in much greater detail because of advances in biotechnology. With the use of numerous biotech tools, it is now feasible to concurrently monitor the expression of numerous genes and investigate the interactions between different proteins that are essential to many aspects of biology (Sharma and Dwivedi, 2017). From modern sequencing methods like nanopore sequencing and next-generation sequencing (NGS) to the traditional pathogen detection techniques like mass spectrometry, polymerase chain reaction (PCR), biochemical or molecular testing, these biotech tools have demonstrated how they possess numerous potentials in the discipline of pathogen detection and diagnosis (Nafea et al., 2024). Another crucial biotechnology is immunoassays, which allow one to determine and measure the amount of antigens and/or antibodies present in a particular sample, such as serum, plasma, blood, etc. Immunoassays continue to be crucial for pandemic control even though real-time reverse transcription-polymerase chain reaction (rRT-PCR) is the preferred biotechnology technique for diagnosing and screening infection. Immunoassays were utilized as first-line screening tests in places with limited medical resources, as well as additional techniques for identifying cases missed by rRT-PCR. Furthermore, they serve as essential resources for both the assessment of vaccine efficacy and retrospective epidemiological surveys (Wang et al., 2023). Additionally, there have already been a number of molecular multiplex syndromic panels available to identify microbial infections in the brain/spinal cord, gastrointestinal tract, respiratory tract, and blood. Using clinical samples, these panels employ a rRT-PCR technique to concurrently amplify and detect the nucleic acids of several infections and drug resistance mechanisms (Wang et al., 2023). Additionally, point-of-care testing - which includes portable, user-friendly diagnostic tools - is made possible by biotechnology. Typical examples include home pregnancy tests and blood glucose monitors, which are useful in remote or resource-constrained environments as they provide fast results (Price, 2001). Furthermore, biotechnological advancements contributed to the development of biosensors, such as glucose sensors and wearable electronics, which continuously monitor a variety of physiological parameters and provide real-time health data. Since the introduction of smartphones and other portable electronics, wearable sensors have drawn a lot of attention in this technology age due to their potential to offer valuable data about one's overall health and performance (Kim et al., 2019). Significant advancements in cancer management have been made possible by the advent of theranostic, which uses biotechnology to simultaneously identify and treat a disease (Song et al., 2024). Utilizing

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microfluidic platforms, such as liquid biopsy microdevices, microfluidic immunohistochemistry, and paper microfluidic devices, is another development in cancer diagnosis. Liquid biopsies can be used to quantify and analyse several cancer biomarkers with these platforms (Iliescu et al., 2019; Asci et al., 2023). Red biotechnology has therefore significantly improved diagnostics throughout the years, facilitating the development of a variety of diagnostic instruments and methods that result in early detection and improved outcomes for patients, eventually improving the standard of healthcare globally.

Red Biotechnology in Treatment Applications

Prior to the 1980s, the majority of therapeutics were chemical or small molecule drugs. However, as biotechnology advanced, small start-up biotechnology companies began investigating biologics, and today, both pharmaceutical and biotech companies heavily prioritize biologics for product sales and research and development (R&D) (Evens and Kaitin, 2015). Thus, biotechnology has transformed the way diseases are treated during the last few decades by offering inventive solutions that improve the effectiveness and precision of treatments. Biotechnology helped in the development of a novel segment of therapeutics called 'biopharmaceuticals' which are currently leading the healthcare due to its improved efficacies and less toxicity compared to chemical drugs. Monoclonal antibodies, vaccines, recombinant proteins, stem cell or nuclei acid-based therapies, nano-based drugs, other biomaterials, etc. are replacing chemical drugs as the primary means of treating a number of disorders, including autoimmune diseases, genetic disorders, neuroinflammatory complications, different types of cancer, metabolic disorders, and others (Abinay and Viswanathan, 2021). Recombinant proteins are a notable and significant biotechnology innovation. Following the 1982 approval of Humulin®, the first recombinant human insulin, the sector grew quickly, expanding the size of the market and increasing profits for pharmaceutical companies. It is primarily because biopharmaceuticals are considered to have a minimally harmful environmental impact, or in other words, they are a more favourable option for the health of our planet, given that the annual emergence of new diseases is driving a dramatic increase in the global consumption of therapeutics (Pharmaceutical Technology, 2017). One of the most in-demand biopharmaceuticals that has seen significant increase is monoclonal antibodies (mAb). Since the first therapeutic mAb was approved in 1986 to treat steroid-resistant acute allograft rejection in kidney transplant recipients, over 190 mAbs have been approved and are being actively marketed as of 2022 for the treatment of immunomodulatory, cancer, and other diverse disorders (Walsh and Walsh, 2022). While it was demonstrated that recombinant enzymes were more advantageous for industrial use, they also proved to be beneficial therapeutically in the treatment of a range of illnesses, such as cancer, cardiovascular diseases, and genetic issues (Sanchez et al., 2011). Vaccines are another type of biopharmaceutical, and the COVID-19 pandemic demonstrated how vaccines remained the dominant method of choice

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for combating infectious diseases and will continue to be a crucial therapy (Walsh and Walsh, 2022). Following the National Institutes of Health's Recombinant DNA Advisory Committee's 1988 approval of the first gene therapy, over 3000 clinical trials have been carried out to treat a range of genetic illnesses, including HIV, cardiovascular disease, rheumatoid arthritis, neurodegenerative disorders, multiple types of cancer, and cystic fibrosis (Cucchiarini, 2016; Abinay and Viswanathan, 2021). These trials have led to the FDA approval of many of them, with first being to enter the market was Kymriah (tisagenlecleucel), a genetically modified autologous T-cell immunotherapy, which was approved in August 2017 (FDA_1) for certain pediatric and young adult patients with acute lymphoblastic leukemia (ALL), and Luxturna (voretigene neparvovec-rzyl), which was approved in December 2017 (FDA_2) for children and adults with a hereditary form of vision loss that could lead to blindness. As a prospective treatment for degenerative, traumatic, hereditary, and autoimmune illnesses, stem cell therapy is another biotechnology tool that has the potential to completely transform medical practices (Gabr and El-Kheir, 2022). Currently, the only stem cell-based treatment that is approved by the FDA is Omisirge (omidubicel-onlv), which is hematopoietic stem cell transplantation to treat patients with blood cancers (FDA_3). These are only some of the examples of how red biotechnology has contributed to advancements in therapeutics and other treatment approaches and thus, by harnessing the power of biological systems, red biotechnology continues to drive progress in medical science, leading to more effective treatments and better patient outcomes.

Red Biotechnology in Preventive Applications

Immunization has become a critical component of public wellness and disease prevention as vaccinations are fundamental to preventative healthcare. With the advent of vaccines, diseases that formerly posed a serious threat to morbidity and death have almost eradicated. Life expectancy and quality of life have both grown as a result of immunization (Gagneur et al., 2019). Lifelong immunization has been prioritized by the WHO, and the 2030 Sustainable Development Goals include it as a fundamental component. As a matter of fact, the World Health Assembly passed the Global Vaccine Action Plan in 2012 with the intention of preventing millions of lives by 2020 through increased global vaccination uptake and access. The global elimination of polio is the primary goal this action plan seeks to accomplish (Ginglen and Doyle, 2023). The term "bioterrorism" has gained prominence in the current time and there is a real concern because studies have demonstrated that individuals, terrorist groups, and criminals can and will use infectious agents to cause harm to civilization. Therefore, in the context of biological emergencies, the concept of biosecurity has grown in significance, and biotechnology techniques are crucial for bolstering biosecurity efforts (Pande and Anakha, 2024a). Pathogen detection is an essential component of biosecurity that allows for the management of biological emergencies. Early detection facilitates the development and administration of personalized medicines and immunizations to improve patient outcomes and decrease the intensity

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of outbreaks, as well as proper containment and isolation practices (Renault et al., 2021). Early pathogen identification has been demonstrated to be effectively achieved with the use of biotechnology technologies such as next-generation sequencing (NGS) and biosensors. Furthermore, our understanding of the severity of epidemics is enhanced by biosurveillance systems that track pathogen identification and resistance using NGS and central cloud-based analysis (Pande and Anakha, 2024b). Biotechnology has also transformed disinfection and decontamination techniques by providing effective and focused ways to eliminate infectious microorganisms. The development of bio-decontamination methods using biological materials has also been facilitated by biotechnology (Rastogi and Wallace, 2020; Pande and Anakha, 2024c). Consequently, biotechnology has become an indispensable tool in our battle against biological emergencies, assisting us with disinfecting procedures, early pathogen detection, as well as vaccine development.

Conclusion

One of the major areas in biotechnology is the medical sector, and as the significance of biotechnology has grown, red biotechnology has emerged as a prominent field. This area of biotechnology now accounts for a substantial portion of research efforts and has led to numerous breakthroughs in healthcare. The growing emphasis on health and wellness continues to drive the demand for biotechnological tools, which play a critical role in developing diagnostics, therapeutics, and preventive measures. Red biotechnology encompasses various applications such as drug development, gene therapy, personalized medicine, and regenerative medicine. These advancements have revolutionized the way we approach treatment and prevention, offering new hope for managing and curing diseases. However, the rapid progress in red biotechnology also brings to light several ethical and legal challenges. The manipulation of genetic material and the implementation of biotechnological innovations in medicine raise complex issues related to privacy, informed consent, and the potential for misuse. For example, the use of genetic data must be carefully regulated to protect individuals' privacy and prevent discrimination. Additionally, ethical dilemmas arise in gene editing and other advanced techniques, necessitating robust guidelines to ensure responsible use. Legal frameworks must continuously adapt to address these evolving challenges. It is crucial to establish and enforce regulations that safeguard both individual rights and societal interests, ensuring that biotechnological innovations are used ethically and equitably. By navigating these ethical and legal complexities, we can maximize the benefits of red biotechnology while minimizing potential risks and ensuring its responsible integration into healthcare.

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