American Journal of Business Practice 2997-934X, Vol 02, No. 12, 2025

Integrated Advances in Biomedical Innovation: From Artificial Intelligence and Microbial Genomics to Cancer Biology, Vaccine Science, and Emerging Environmental Technologies

Md. Shamim Al Mamun[1], Ezaz Ahmad Shah[2], Moin Uddin Patwary[3]
[1,2,3] Biochemistry & Molecular Biology, Tejgaon College, Dhaka, Bangladesh
E-mail: almamum71bd@gmail.com

Abstract: The merging of genomics and Artificial Intelligence (AI) is changing the landscape of biomedical science in a big way. We are moving from traditional methods to a more data-driven approach that emphasises precision medicine and the health of our planet. Genomics serves as a detailed map of life at the molecular level. At the same time, AI, primarily through Machine Learning (ML), helps us make sense of the vast amounts of data generated by technologies such as Whole Genome Sequencing (WGS) and single-cell profiling. This powerful combination is transforming how we diagnose and treat diseases. In the realm of infectious diseases, AI enables us to quickly identify pathogens without culturing them, enabling real-time tracking of threats such as Antibiotic Resistance Genes (ARGs). This capability is crucial in the fight against Antimicrobial Resistance (AMR). When it comes to cancer, AI plays a vital role in analysing complex tumour profiles, including the newly recognised role of the microbiome in cancer, helping identify targeted therapies, unravel drug resistance, and reveal potential new treatment avenues. AI also speeds up preventive measures through techniques such as "reverse vaccinology," which can predict the best antigens for tailored, multi-epitope vaccines. Beyond individual health, this integration is vital to the One Health framework, which emphasises the connection between human health and environmental well-being. For instance, we need to address algorithmic bias caused by data representation gaps, ensure AI systems are understandable to build trust among clinicians, and prioritise robust data security.

Keywords: Genomics, Artificial Intelligence (AI), Precision Health, One Health, Algorithmic Bias

This is an open-access article under the CC-BY 4.0 license

1. Introduction

The world of biomedical science is evolving rapidly, moving away from isolated fields and towards a more interconnected network. At the centre of this change are innovations in Microbial Genomics, Artificial Intelligence (AI), Cancer Biology, Vaccine Science, and Environmental Technologies. This is not just a small step forward; it's a significant shift that aims to revolutionise healthcare, making it faster, more precise, and proactively tackling global health challenges. Microbial genomics has changed the way scientists monitor pathogens and understand how they resist treatments or spread [1]. The ability to quickly sequence entire bacterial, viral, or fungal genomes provides a detailed molecular picture. However, the growing volume of data from modern sequencing often exceeding terabytes per study can be too vast for manual analysis. That's where AI comes in. When combined with sophisticated machine learning techniques, researchers can analyse

these massive genomic datasets quickly and effectively. This allows them to trace the spread of infections and understand evolutionary changes in greater detail. AI can examine thousands of pathogen genomes, identifying tiny genetic differences that reveal how a strain might spread worldwide or develop drug resistance [2]. This partnership speeds up the creation of new vaccines and treatment strategies by pinpointing key therapeutic targets that are essential for treating infections and are also stable enough not to mutate rapidly. For instance, AI can predict the structures of bacterial proteins and viral components from their genetic sequences, thereby accelerating drug and vaccine design [3]. This shift allows scientists to focus on anticipating and preventing outbreaks rather than just responding to them. In cancer biology, these integrated technologies are changing the game for early detection and treatment planning. Genomic profiling has moved from analysing just a few common mutations to exploring the full range of genetic signatures that drive an individual's cancer. This includes not only single-gene changes but also complex variations, gene fusions, and unique changes that reveal a tumour's weaknesses. Machine learning processes this wealth of genomic data alongside clinical information, such as imaging and treatment history, to provide predictive insights [4]. These models can forecast how well a patient might respond to specific treatments or estimate the chance of cancer returning, achieving a level of accuracy we haven't seen before. This paves the way for precision oncology, in which treatment decisions are based on a patient's cancer's specific genetic makeup rather than broad categories [5] [7]. AI is also key to analysing liquid biopsies, which detect tiny amounts of tumour DNA in the blood for non-invasive early diagnosis and ongoing monitoring of treatment success. This integration of AI, genomics, and advanced bioinformatics helps filter out noise and highlight significant signals from vast genomic data [6]. In parallel, vaccine science is also making tremendous strides thanks to the synergy of AI and advanced genomic analysis. Modern vaccine platforms like mRNA and viral vectors can be rapidly redesigned. AI plays a crucial role in determining which parts of a virus or bacterium are likely to provoke a strong, lasting immune response. This accelerates vaccine development timelines significantly compared to previous methods. Additionally, AI and genomics improve our ability to develop vaccines against rapidly evolving pathogens. As viruses mutate, genomic surveillance captures these changes, allowing AI to assess whether the current vaccine remains effective or needs to be updated. This creates a vital feedback loop of design, testing, and deployment of new solutions, which is crucial for being prepared for future pandemics [7]. Finally, emerging environmental technologies connect all these concepts. By integrating these advances, we can create a more comprehensive and practical healthcare landscape, ultimately enhancing public health and safety for everyone. The fusion of cutting-edge technologies in healthcare is paving the way for a transformative era in how we understand and respond to diseases. This combination not only shortens vaccine development timelines but also enhances their adaptability to rapidly evolving pathogens [8]. Concurrently, advancements in post-licensure surveillance technologies enable us to monitor vaccine performance and safety in real-time across diverse populations, ensuring that public health measures are effective and timely. In this integrated landscape, emerging environmental technologies play a crucial role. Tools such as sensors, remote monitoring systems, and AI-driven analytics help track ecological exposures that may influence disease risk. These technologies uncover patterns that link pollution, climate events, and shifts in microbial communities to human health outcomes [9]. By weaving together environmental data and biomedical insights, we gain a more comprehensive understanding of disease ecology, which is essential for supporting proactive public health strategies. Together, these advancements reveal an increasingly interconnected biomedical ecosystem. The combination of artificial intelligence, genomics, cancer research, vaccine innovation, and environmental technologies is steering healthcare toward a future that is not only faster but also more precise and responsive to global health threats. These tools help researchers identify correlations between environmental changes, such as climate shifts and ecosystem disruptions, and their impact on human health [10]. As we face the challenges of climate change, such as the expansion of pathogen ranges and the intensification of vector-borne diseases, this integrated perspective is becoming increasingly vital. While the promise of this interconnected biomedical ecosystem is immense, its full realisation poses significant challenges. One of the primary hurdles is the need for effective Data Integration and Interoperability. Vast arrays of disparate datasets, ranging from electronic health records to environmental sensor data and complex genomic profiles, often do not adhere to

standardised formats or have robust sharing protocols across institutions. This poses a barrier to creating a cohesive understanding of health and disease. Another key issue revolves around Model Transparency and Trust. Often referred to as the "Black Box" Problem, this concern arises because many powerful AI models, especially those relying on deep learning, obscure their decision-making processes [11]. To build confidence among clinicians and regulators, the development of Explainable AI (XAI) is essential. Furthermore, ethical considerations regarding Equitable Access are critical; we must address disparities in healthcare access to prevent the widening of global health inequalities as these advanced tools become more prevalent. Lastly, Regulatory Adaptation will be key in this evolving landscape [12]. Traditional regulatory frameworks can be too slow to keep pace with the rapid advancements in AI-driven innovations. We must establish new, flexible yet rigorous regulatory pathways to ensure these transformative technologies can be deployed safely and swiftly. Navigating these challenges is crucial for creating the holistic, predictive, and globally responsive biomedical system envisioned for the future of public health. Artificial intelligence is at the forefront of this revolution, reshaping biomedical innovation by significantly improving diagnostics, enabling personalised treatment plans, and transforming research methodologies. Its applications in healthcare are vast, ranging from analysing extensive electronic health records (EHRs) to interpreting complex diagnostic images [13]. This integration empowers healthcare professionals to deliver more accurate, timely care to patients. AI's transformative power stems from its ability to sift through massive datasets, enabling early and precise detection of diseases such as cancer and heart disease. In various instances, AI systems have shown diagnostic accuracy that outstrips traditional methods, even outperforming experienced radiologists in identifying malignancies in medical imaging. These developments affirm that AI is not merely an experimental tool; it is increasingly becoming a core component of real-world clinical applications, optimising workflows in hospitals, outpatient clinics, and home-monitoring settings [14]. Moreover, AI's role in advancing personalised medicine cannot be overstated. By leveraging patient-specific data, AI systems recommend tailored treatment plans that significantly enhance patient outcomes and promote a more patient-centred approach to healthcare. Additionally, AI-driven predictive analytics play a pivotal role in anticipating disease progression and identifying high-risk patients, ultimately allowing for improved long-term management of chronic conditions. Despite the immense promise of these technologies, challenges and ethical considerations remain that must be addressed as we move forward.

2. Materials and Methods

This study employed a comprehensive narrative review approach to synthesize recent advancements at the intersection of artificial intelligence, genomics, microbial biology, cancer research, vaccine science, and environmental health. Relevant peer-reviewed articles were systematically identified from major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar, with a primary focus on publications from the last decade to ensure topical relevance. Keywords such as *artificial intelligence*, *machine learning*, *genomics*, *microbial genomics*, *precision medicine*, *cancer biology*, *vaccine development*, and *environmental health technologies* were used in various combinations. The selection process prioritized original research articles, high-impact reviews, and authoritative guidelines that demonstrated clear methodological rigor and relevance to biomedical innovation. Data extraction focused on technological approaches, analytical frameworks, biomedical applications, and reported outcomes. The collected literature was then thematically analysed and integrated to identify converging trends, emerging challenges, and future research directions within the One Health framework, enabling a holistic interpretation of how AI-driven genomics and related technologies are reshaping modern biomedical science.

3. Results

The Revolution of Microbial Genomics: AI, Diagnostics, and Therapeutic Advancement

Microbial genomics has become an essential part of clinical microbiology, especially with the recent advancements in genomic technologies and artificial intelligence (AI) (Figure 2). By

Figure 2. Key technologies of synthetic biology in industrial microbiology [54]

analysing microbial genomes more thoroughly, researchers can gain essential insights into pathogen identification, virulence factors, and antimicrobial resistance (AMR) traits [15]. This enhances how we manage clinical cases and respond to public health challenges during outbreaks. Traditionally, detecting pathogens involved the lengthy process of growing live organisms in culture, but now we're seeing a shift towards 'culture-free' genomic approaches. These methods use molecular techniques to directly extract and analyse DNA from clinical samples, speeding up detection. AI is a game-changer in tackling the complexities and vast amount of data in microbial genomics. As genomic data continues to grow, AI can help with complex tasks, such as whole-genome sequencing analysis and metagenomic pathogen identification [16]. It also aids in modelling genomic data using computational linguistics approaches. Importantly, AI algorithms help researchers interpret intricate microbial interactions, allowing for the identification of microbial signatures associated with various diseases. By merging AI with genomic analysis, we can gain deeper insights into how pathogens spread and better understand complex microbial ecosystems. The combination of genomic data and AI is also revolutionising vaccine and immunotherapy development. The shift to a genomics-focused approach enables rapid identification of new vaccine targets and the design of subunit vaccines tailored for specific immune responses while ensuring safety [17]. Moreover, advanced AI models can predict how the immune system will react, which is vital given the complexity of cytokines and chemokines in immune responses. This innovative blend of genomics and AI holds great potential for creating more effective and safer vaccines and treatments for infectious diseases and various cancers.

Cancer Biology and Microbial Genomics: Integrated Future Directions

The convergence of microbial genomics, artificial intelligence (AI), and cancer biology is shaping the future of cancer diagnosis and treatment, even as we navigate various challenges. Cancer is a complex disease marked by uncontrolled cell growth, and its development is influenced by the interactions between cancer cells and their surrounding environments [18]. These interactions can affect many aspects of the cancer cells, including their genetic makeup. Recent advancements in sequencing technologies, such as Next-Generation Sequencing (NGS) and microarrays, have significantly improved our understanding of the genetic changes underlying cancer (Figure 3).

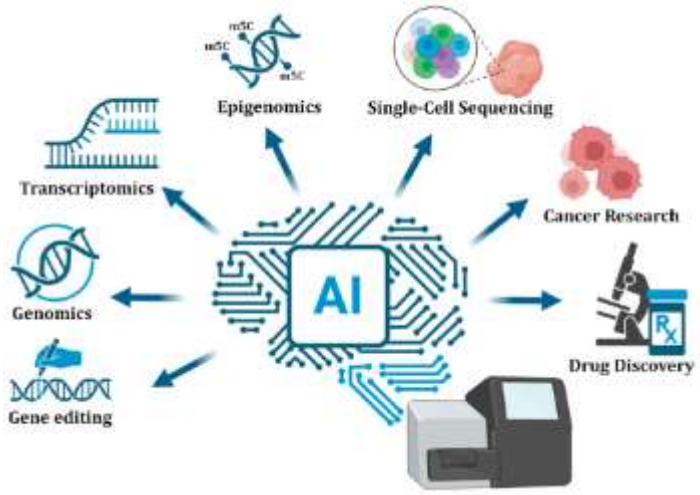

Figure 3. Integrating artificial intelligence in next-generation sequencing [55]

These tools enable us to identify and analyse mutations and alterations in cancer cells, which is crucial for accurate diagnosis and personalised treatment plans. Interestingly, research has highlighted the often-overlooked role of microorganisms in cancer. Studies indicate that around 15% of cancers, particularly in developing countries, can be linked to infections caused by bacteria and viruses [19]. These microorganisms can not only affect the occurrence of cancer but also influence how well specific therapies work by interacting with our immune system. Some bacteria and viruses can even help cancer cells thrive and resist treatment, underscoring the complex relationship between tumours and the microorganisms they host. AI plays a vital role in harnessing this vast amount of data. In microbial genomics, AI can accelerate analysis, enabling researchers to analyse whole genomes and understand microbial interactions more efficiently [20] (Table 2).

Table 2. Advancements in Microbial Genomics and Their Biomedical Impact

Domain	Advancement	Scientific Benefit	Reference
Pathogen Surveillance	Whole-genome sequencing and genomic epidemiology	Tracking transmission, mutation patterns, outbreak origins	[16]
Antimicrobial Resistance Research	Identification of ARGs through computational genomics	Guides new drug/vaccine target discovery	[18]
Culture-Independent Diagnostics	Metagenomic sequencing combined with AI models	Faster and more accurate pathogen detection	[22,25]
Microbial Ecology	Microbiome profiling via NGS and ML	Understanding host–microbe interactions in disease	[28]

When it comes to cancer treatment, AI is becoming invaluable in drug discovery, helping identify potential drug targets and speeding up development. To fully benefit from these advancements, we need to tackle several challenges. For microbial genomics, translating research findings into real-world clinical applications requires better data-sharing practices and more collaboration between data scientists and healthcare professionals. Additionally, in cancer genomics, accurately detecting microbial DNA in cancer cells remains a technical hurdle that we must overcome.

Looking ahead, creating a collaborative environment among researchers in microbial science, cancer biology, and synthetic biology will be crucial [21]. By deepening our understanding of how tumour microbiota interacts with cancer cells, we can develop innovative therapies that target these microorganisms. Combining these new treatments with traditional methods like chemotherapy and immunotherapy may lead to better outcomes and help combat treatment resistance. As we continue to advance in genomics and AI, it's equally important to maintain ethical standards like fairness and transparency, ensuring that AI is embraced as a reliable part of modern biomedical research (Table 1). This approach will ultimately lead to improved health outcomes for patients and enhance the overall quality of care.

Table 1. Applications of Artificial Intelligence in Modern Biomedical Research

Area	Key Contribution	Outcome	Reference
Genomic Analysis	AI-driven interpretation of whole-genome and metagenomic datasets	Faster pathogen identification and resistance profiling	[4]
Cancer Diagnostics	Deep learning applied to imaging and molecular signatures	Higher accuracy in early cancer detection	[7]
Precision Medicine	ML models integrating genomic and clinical data	Personalised therapy recommendations	[8]
Vaccine Development	AI-guided antigen prediction and epitope mapping	Rapid vaccine design for emerging pathogens	[9,11]

Advances in Vaccine Science Through Genomics and Artificial Intelligence

The world of biomedical science is undergoing a remarkable transformation, primarily driven by the exciting intersection of genomics, artificial intelligence (AI), and innovative environmental technologies. For instance, microbial genomics has revolutionised how scientists track pathogens and understand disease outbreaks before they escalate [22] (Figure 1). When AI gets involved,

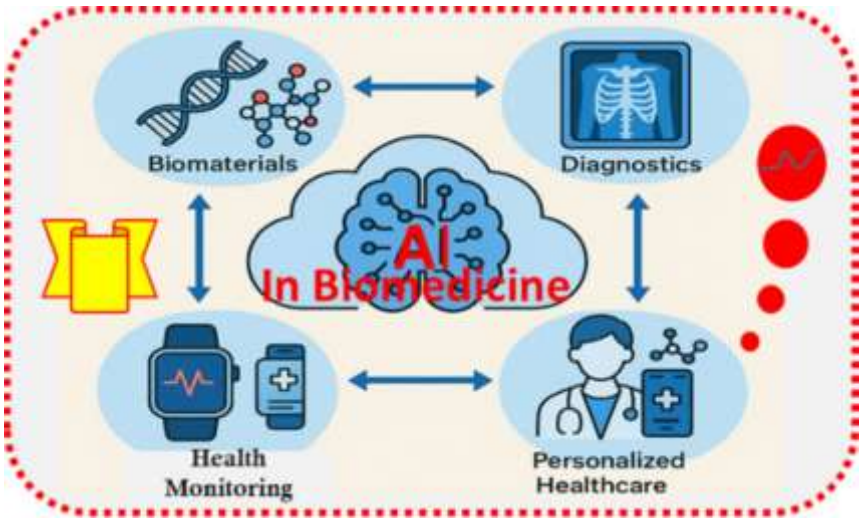

Figure 1. Use of AI in biomedical science [53]

those massive genomic datasets that once overwhelmed researchers suddenly become much more manageable. Hidden patterns begin to emerge, such as how diseases spread and evolve, and

which key genetic targets could lead to effective treatments. This newfound clarity is accelerating everything from monitoring pathogens to designing new antibiotics and vaccines. A similar evolution is happening in cancer research. Genomic profiling is moving away from the outdated one-size-fits-all treatment approach by uncovering the specific mutations that drive tumour behaviou [23]. AI models enhance this by predicting which treatments will be most effective for individual patients and their prognosis. This shift is moving oncology toward a more personalised approach, where treatment decisions are based on an individual's molecular profile rather than broad disease classifications. It's a significant step toward genuine precision medicine. Vaccine science is also advancing rapidly. Traditional vaccine platforms, such as live attenuated and inactivated vaccines, as well as newer mRNA vaccines, each play unique roles in shaping our immune responses [24]. While many vaccines rely primarily on antibody-mediated immunity, the design process has changed dramatically. AI is now taking on some of the most labour-intensive aspects of vaccine development. Early tools like Vaxijen paved the way, and now machine learning models can analyse vast amounts of protein and peptide data to identify promising antigens with remarkable accuracy [25]. This is especially useful for complex pathogens like Helicobacter pylori, where conventional methods often fall short. Predictive immunology adds yet another dimension. AI can simulate how vaccines will perform across diverse populations and model immune responses during co-infection scenarios that are notoriously difficult to replicate in the lab [26]. By doing much of this work in silico, development timelines shrink significantly. The rapid development of COVID-19 mRNA vaccines is a prime example of how quickly things can move when AI-driven modelling and genomic surveillance are used throughout the process. Still, challenges remain. There is an increasing demand for single-shot vaccines, particularly in areas with limited access to healthcare. AI-driven adjuvant discovery platforms aim to address this by identifying new compounds that can enhance immune responses. As these tools continue to evolve, we can expect a shift toward more personalised, precision-based vaccination strategies, an approach that could profoundly transform global immunisation efforts [27]. Meanwhile, technologies focused on the environment are becoming just as critical to public health as laboratory discoveries. Sensors, remote monitoring systems, and AI-driven analytics are now tracking exposures that affect disease risk. Initiatives like carbon capture seek to reduce emissions before they accumulate, and circular economy models encourage industries to rethink how they manage resources. These strategies aren't just about sustainability; they can directly improve health by reducing pollutants that contribute to respiratory diseases, heart conditions, and certain cancers [28]. Understanding the environmental factors behind diseases is increasingly essential. Climate change is altering the habitats of pathogens and their carriers, pollution disrupts microbial communities in our environment, and extreme weather events increase our exposure to harmful contaminants that might have remained hidden. Emerging technologies are helping us map these connections, showing how disruptions in our environment can impact human health. Improved waste management, better emissions controls, and risk-assessment tools are making it easier to identify and address potential health risks before they escalate [29]. Of course, bringing all these technologies together comes with its own set of challenges. Issues like data security, ethical considerations, and the need for stronger collaboration between industry and academia need to be addressed. However, the potential benefits are hard to overlook. When biomedical research, vaccine innovation, environmental monitoring, and AI work in concert, we create a more responsive and predictive system than we've ever had. All these developments are weaving together a connected ecosystem where molecular data, environmental insights, and computational intelligence complement one another [30]. AI speeds up discoveries in every area, genomics provides essential context, and environmental technologies give us the perspective needed to understand health issues in our rapidly changing world (Table 3). The outcome

is a biomedical system that can swiftly adapt, anticipate global health threats, and deliver targeted solutions with a level of precision that was unimaginable just a decade ago.

Table 3. Integration of Environmental Technologies in Public Health Monitoring

Technology	Function	Public Health Application	Reference
Remote Sensing & Satellite Data	Detect climate patterns, pollution, ecological shifts	Predict vector-borne disease expansion	[21]
AI-Driven Environmental Analytics	Correlates environmental exposure with health outcomes	Early alert systems for respiratory and infectious diseases	[17]
Sensor-Based Monitoring Systems	Track water quality, air pollutants, microbial contamination	Real-time risk assessment and outbreak prediction	[22]
Climate-Health Modelling Platforms	Integrate climate and biomedical data	Forecasting disease outbreaks linked to climate change	[30]

4. Discussion

Biomedical science is currently experiencing a remarkable transformation. For years, researchers operated within relatively isolated fields: microbiology on one side, oncology on another, and environmental health in yet another space, while computational science served as a parallel but not fully integrated support system [31]. However, that landscape has changed dramatically. Today, fields such as genomics, artificial intelligence, Machine learning, vaccine technology, cancer biology, and environmental monitoring are intertwining into a cohesive, interconnected framework [32]. This integration is fundamentally altering our understanding of diseases, our preparedness for health threats, and the way we design interventions at both the individual and community levels. What makes this transformation so significant goes beyond merely having access to new tools; it's about how these tools enhance one another. Genomics generates vast amounts of molecular data, while AI interprets these complex datasets at speeds and scales beyond the reach of human analysts alone [33]. Environmental sensors monitor exposures that can have subtle or significant effects on health. Cancer biology depends on all these components for early detection and targeted therapies, while vaccine science uses them to forecast how pathogens might evolve and tailor immune responses accordingly [34]. When these areas work together, they create a biomedical ecosystem capable of detecting, predicting, and responding to health threats with remarkable accuracy. Microbial genomics exemplifies how innovation in biomedical science is changing direction. With the advent of sequencing technologies, we can now decode entire pathogen genomes in mere hours instead of days or weeks. This shift allows researchers to examine complete genetic blueprints rather than isolate individual genes. These comprehensive maps can uncover mutations that impact virulence, antibiotic resistance, and transmission patterns [35]. The detail is astounding: scientists can trace a pathogen's journey across continents, track its evolutionary path, and identify exactly when resistance genes were acquired. However, genomic data by itself isn't sufficient. Even a single outbreak can produce terabytes of sequence data, particularly when metagenomic samples are included. Initially, genomic epidemiology relied on tedious manual analysis, which slowed response time [36]. The introduction of AI has dramatically altered this situation. Machine learning systems can now analyse thousands of genomes simultaneously, detecting subtle shifts that are invisible to human researchers. AI can cluster strains based on their similarities, predict how mutations might affect protein structures or drug resistance, and model transmission dynamics with impressive accuracy [37]. One of the most significant benefits of combining microbial genomics with AI is the identification of conserved targets for therapeutics and vaccines. Although pathogens are constantly mutating, certain regions of their

genomes remain relatively stable because they are essential to survival. These stable regions are ideal candidates for vaccine antigens or drug targets. AI-powered structural prediction tools can determine protein shapes solely from sequence data, speeding up antigen design and narrowing the search for therapeutically important molecules [38]. The shift toward predictive microbiology represents a profound advancement. Instead of merely responding to outbreaks as they arise, we can now anticipate emerging threats based on evolutionary trajectories. Researchers can monitor how environmental factors, such as antibiotic usage or climate-induced ecological shifts, drive pathogens toward new adaptations. This predictive approach not only enhances global biosecurity but also reduces the time lag between detection and intervention. Similarly, cancer biology is undergoing a parallel revolution [39]. Traditionally, cancer classification depended heavily on tissue origin and visual characteristics observed through a microscope. While these methods were clinically useful, they had their limitations. Two tumours that look similar under a microscope can behave very differently due to different molecular drivers [40]. The advent of genomic profiling has dramatically changed this narrative. Next-generation sequencing (NGS) enables clinicians to examine the entire cancer genome, identifying mutations, structural changes, and epigenetic modifications that can influence tumour behaviour. AI models enhance this understanding by integrating genomic, transcriptomic, proteomic, and clinical data into cohesive predictions [41]. These systems can forecast treatment responses, assess the risk of recurrence, differentiate between aggressive and more benign tumours, and suggest personalised treatment strategies for patients. One of the most transformative applications is found in liquid biopsies. Tiny amounts of tumour DNA circulate in the bloodstream long before a tumour becomes detectable by imaging techniques. Identifying this "cell-free DNA" requires sophisticated computational methods to filter out true signals from background noise [42]. AI significantly enhances this ability, facilitating earlier detection and real-time monitoring of treatment effectiveness. This shift minimises the trial-and-error approach that has historically characterised oncology, moving us toward more adaptive, data-driven therapies. Beyond merely detection and treatment, research is also unveiling the role of the microbiome in cancer biology [43]. Intratumoral microbes can influence immune responses and even impact treatment outcomes. Understanding these complex interactions stands to revolutionise how we conceive of cancer treatment and prevention, further exemplifying the rich potential of the convergence of these groundbreaking scientific fields. The collaboration between vaccine science and advanced technologies like genomics and AI is transforming the landscape of public health. Traditionally, vaccine development was a slow and largely trial-and-error process [44]. With computationally guided antigen design, scientists can now minimise guesswork. AI analyses pathogens' genetic material to predict which parts will evoke a strong immune response, ultimately leading to more effective vaccines. This technological advancement is particularly crucial when dealing with rapidly mutating pathogens. Thanks to genomic surveillance, we can quickly identify new variants and understand how genetic mutations affect vaccine effectiveness. If a vaccine needs to be updated, the process can now be completed in months rather than years, as demonstrated by the swift development of mRNA vaccines [45]. In addition to improving antigen design, AI is enhancing our understanding of how diverse populations respond to vaccines. By simulating responses based on varied human leukocyte antigen (HLA) profiles, researchers can ensure that vaccines work broadly and reduce the risk of ineffective coverage in certain demographics [46]. AI also contributes valuable insights into immune reactions when individuals face co-infections, something that traditional methods often overlook. We're also entering an exciting phase in adjuvant discovery, finding elements that can enhance the immune response. Single-shot vaccines are incredibly beneficial, especially in resource-limited settings, but they require effective and sustained immune activation. AI can sift through extensive immunological data to identify promising adjuvant candidates and predict how they might work with specific antigens, paving the way for more efficient and accessible vaccines worldwide. Another critical area is post-licensure surveillance. AI systems can analyse real-time data from electronic health records, wearables, and local reporting networks to monitor vaccine safety and effectiveness [47]. This not only ensures that recommendations can be updated dynamically but also reinforces public trust in vaccination programs. Environmental factors significantly impact global health. Issues like pollution, climate change, and ecosystem disruptions play a crucial role in the appearance of diseases and affect our overall health outcomes. Modern

technologies, such as remote sensors and satellite monitoring, offer unparalleled insights into these environmental factors. AI models are adept at linking environmental exposures with health data, shedding light on connections that were previously tough to uncover. For example, air pollution worsens asthma, heightens the risk of cardiovascular disease, and affects vulnerability to respiratory infections [48]. Climate change alters where disease-carrying vectors live, shifting the locations of diseases like malaria and Lyme disease. Additionally, extreme weather events can increase exposure to contaminated water and damage health infrastructure. Environmental monitoring systems provide ongoing data that feed into predictive models to anticipate outbreaks, pinpoint high-risk locations, and inform public health responses. Nanotechnologies aimed at reducing carbon emissions and waste can also mitigate some health risks, contributing to both environmental preservation and population health [49]. By merging environmental data with biomedical information, we gain a comprehensive understanding of disease dynamics. As climate change continues to reshape our world, this integrated approach becomes crucial for effective health planning. However, challenges like data integration remain significant hurdles. Often, genomic, clinical, and environmental data are in formats that cannot easily interact, making it necessary to develop interoperable systems to enable broad collaboration. Another primary concern is the transparency of AI models. Healthcare professionals and regulatory authorities need to understand how AI systems make decisions, particularly in life-or-death situations such as cancer diagnosis or vaccine safety assessments. Advancements in explainable AI are vital to facilitate the broader acceptance of these technologies. Equitable access to new technological advancements is also a pressing issue [50]. Cutting-edge genomic research tools and advanced diagnostics can be costly. If we don't actively work to democratise access to innovations like cancer treatment, we risk widening existing disparities in global health [51]. Regulatory frameworks also need to evolve to keep pace with the rapid developments driven by AI. It is essential to create adaptable yet stringent guidelines that ensure the safe rollout of these technologies without stifling their innovation potential. The convergence of AI, genomics, vaccine development, cancer research, and environmental technologies is fundamentally changing the future of healthcare [52]. Each of these domains complements and enhances the others: AI accelerates discovery; genomics provides the necessary molecular context, and environmental technologies offer insights into disease drivers. Together, they are forging a new path for public health progress.

5. Conclusion

The fusion of genomics and AI offers unprecedented tools for humanity's most significant health challenges, from resistant microbes and complex cancers to the existential threats posed by environmental change. This transformation promises a future that is data-driven, personalised, and proactive, enabling tailored therapies and sophisticated disease prediction. However, realising this profound potential requires overcoming systemic obstacles. We must dismantle technical silos, ensure model transparency through Explainable AI (XAI), and enforce rigorous ethical standards to combat algorithmic bias. Implementing this paradigm hinges on sustained, interdisciplinary collaboration to improve both human and planetary health through the One Health framework.

Author Contributions

M.S.A.M. conceived the study, designed the overall framework, and prepared the initial manuscript draft. E.A.S. contributed to data interpretation, literature review, and manuscript revision. M.U.P. assisted in methodology development, critical analysis, and final editing of the manuscript. All authors read and approved the final version of the manuscript.

.

REFERENCES

[1] Seifrid M, Pollice R, Aguilar-Granda A, Morgan Chan Z, Hotta K, Ser CT, Vestfrid J, Wu TC, Aspuru-Guzik A. Autonomous Chemical experiments: challenges and perspectives on establishing a self-driving lab. Acc Chem Res. 2022;55(17):2454–66. doi: 10.1021/acs.accounts.2c00220.

[2] Rahman, F., Islam, A., Nashid, S., Akhir, A., Papia, S. K. (2025). "Advancing Healthcare Through Data Analytics Transitioning from Descriptive Insights to Predictive and Prescriptive Solutions", Paradise, 1(1),1-8,10377 https://doi.org/10.25163/paradise.1110377

[3] Sarkar C, Hasnat A, Rahman MM, Maliha M, Singha BC, Tufael. Bacterial Surface Components and Toxins in Cancer Development: Mechanisms of Oncogenesis and Therapeutic Implications. Microb Bioact. 2025;8(1):1–12. https://doi.org/10.25163/microbbioacts.8110174

[4] Abolhasani M, Kumacheva E. The rise of self-driving labs in chemical and materials sciences. Nat Synth. 2023;2:483–92. doi: 10.1038/s44160-022-00231-0.

[5] Jessop-Fabre MM, Sonnenschein N. Improving reproducibility in Synthetic Biology. Front Bioeng Biotechnol. 2019;7:18. doi: 10.3389/fbioe.2019.00018.

[6] Tufael, Siddique MAB. Bioinformatics in Microbiology: Reviewing the Role of Bioinformatics in Studying Microbial Genomics, Metagenomics, and Phylogenetics. Microb Bioact. 2025;8(1):1–11. https://doi.org/10.25163/microbbioacts.8110370

[7] Yegros-Yegros A, van de Klippe W, Abad-Garcia MF, et al. Exploring why global health needs are unmet by research efforts: the potential influences of geography, industry and publication incentives. Health Res Policy Sys. 2020;18:47. doi: 10.1186/s12961-020-00560-6.

[8] Feng YA, Chen CY, Chen TT, Kuo PH, Hsu YH, Yang HI, Chen WJ, Su MW, Chu HW, Shen CY, Ge T, Huang H, Lin YF. Taiwan Biobank: a rich biomedical research database of the Taiwanese population. Cell Genom. 2022;2(11):100197. doi: 10.1016/j.xgen.2022.100197.

[9] Evens R, Kaitin K. The evolution of biotechnology and its impact on health care. Health Aff (Millwood) 2015;34(2):210–9. doi: 10.1377/hlthaff.2014.1023.

[10] Md Iqbal Hossain, Ispita Jahan, Md Sakib Mia, Niladry Chowdhury, Sonia Khan Papia. (2025). "Leveraging Artificial Intelligence for Human Resource Analytics from Recruitment to Retention", Journal of Ai ML DL, 1(1),1-8,10384 https://doi.org/10.25163/ai.1110384

[11] Papanastassiou M, Pearce R, Zanfei A. Changing perspectives on the internationalization of R&D and innovation by multinational enterprises: a review of the literature. J Int Bus Stud. 2020;51:623–64. doi: 10.1057/s41267-019-00258-0.

[12] Aprahamian I. The future of Molecular machines. ACS Cent Sci. 2020;6(3):347–58. doi: 10.1021/acscentsci.0c00064.

[13] Soldatova LN, Clare A, Sparkes A, King RD. An ontology for a Robot scientist. Bioinformatics. 2006;22(14):e464–71. doi: 10.1093/bioinformatics/btl207.

[14] Seyhan AA. Lost in translation: the valley of death across preclinical and clinical divide – identification of problems and overcoming obstacles. Transl Med Commun. 2019;4:18. doi: 10.1186/s41231-019-0050-7.

[15] Bao Z, Bufton J, Hickman RJ, Aspuru-Guzik A, Bannigan P, Allen C. Revolutionizing drug formulation development: the increasing impact of machine learning. Adv Drug Deliv Rev. 2023;202:115108. doi: 10.1016/j.addr.2023.115108.

[16] Dlamini Z, Francies FZ, Hull R, Marima R. Artificial intelligence (AI) and big data in cancer and precision oncology. Comput Struct Biotechnol J. 2020;18:2300–11. doi: 10.1016/j.csbj.2020.08.019.

[17] da Silva RGL, Blasimme A. Organ chip research in Europe: players, initiatives, and policies. Front Bioeng Biotechnol. 2023;11:1237561. doi: 10.3389/fbioe.2023.1237561.

[18] Adir O, Poley M, Chen G, Froim S, Krinsky N, Shklover J, Shainsky-Roitman J, Lammers T, Schroeder A. Integrating Artificial Intelligence and Nanotechnology for Precision Cancer Medicine. Adv Mater. 2020;32(13):e1901989. doi: 10.1002/adma.201901989.

[19] Datta P, Dey M, Ataie Z, et al. 3D bioprinting for reconstituting the cancer microenvironment. npj Precis Onc. 2020;4:18. doi: 10.1038/s41698-020-0121-2.

[20] Datta P, Dey M, Ataie Z, et al. 3D bioprinting for reconstituting the cancer microenvironment. npj Precis Onc. 2020;4:18. doi: 10.1038/s41698-020-0121-2.

[21] Waite AM, McDonald KS. Exploring challenges and solutions facing STEM careers in the 21st Century: A Human Resource Development Perspective. Adv Developing Hum Resour. 2019;21(1):3–15. doi: 10.1177/1523422318814482.

[22] Warr WA. Special issue: computer-aided drug design strategies in pharmaceutical research. J Comput Aided Mol Des. 2017;31(3):245–334. doi: 10.1007/s10822-017-0017-6.

[23] Liu N, Shapira P, Yue X. Tracking developments in artificial intelligence research: constructing and applying a new search strategy. Scientometrics. 2021;126(4):3153–92. doi: 10.1007/s11192-021-03868-4.

[24] Kim HJ, Hopfield J, Brogan L, Khademhosseini A. Terasaki Institute: Innovating Personalized Health through Convergent Science and Bioengineering. Matter. 2020;3(2):324–6. doi: 10.1016/j.matt.2020.07.018.

[25] Ferguson AL, Brown KA. Data-Driven Design and Autonomous Experimentation in Soft and Biological materials Engineering. Annu Rev Chem Biomol Eng. 2022;13:25–44. doi: 10.1146/annurev-chembioeng-092120-020803.

[26] Bari KF, Salam MT, Maliha M, Singha BC, Islam AF, Oni NK, Hossain S, Ullah MS, Islam M, Tufael. Observational Study on the Clinical Manifestations and Features of Dengue Fever. J Primeasia. 2025;6(1):1–9. https://doi.org/10.25163/primeasia.6110203

[27] Frasca M, La Torre D, Repetto M, De Nicolò V, Pravettoni G, Cutica I. Artificial intelligence applications to genomic data in cancer research: A review of recent trends and emerging areas. Discov Anal. 2024;2:10. https://doi.org/10.1007/s44257-024-00017-y

[28] Topol EJ. High-performance medicine: The convergence of human and artificial intelligence. Nat Med. 2019;25:44-56. https://doi.org/10.1038/s41591-018-0300-7

[29] Bibault JE, Giraud P, Burgun A. Big Data and machine learning in radiation oncology: State of the art and future prospects. Cancer Lett. 2016;382:110-117. https://doi.org/10.1016/j.canlet.2016.05.033

[30] Burkett MS. Molecular testing and precision oncology: An overview. Nursing. 2024;54:46-50. https://doi.org/10.1097/NSG.0000000000000106

[31] Esteva A, Robicquet A, Ramsundar B, Kuleshov V, DePristo M, Chou K, Cui C, Corrado G, Thrun S, Dean J. A guide to deep learning in healthcare. Nat Med. 2019;25:24-29. https://doi.org/10.1038/s41591-018-0316-z

[32] PK MMU, Tufael. Artificial Intelligence and Applied Machine Learning to Improve Pre-Analytical and Post-Analytical Processes in Laboratory Medicine. J Ai ML DL. 2025;1(1):1–10. doi:10407. https://doi.org/10.25163/ai.1110407

[33] Holzinger A, Langs G, Denk H, Zatloukal K, Müller H. Causability and explainability of artificial intelligence in medicine. WIREs Data Min Knowl. 2019;9:e1312. https://doi.org/10.1002/widm.1312

[34] Garraway LA, Lander ES. Lessons from the Cancer Genome. Cell. 2013;153:17-37. https://doi.org/10.1016/j.cell.2013.03.002

[35] Islam MR, Akter MF, Siddique MAB, Tufael, Manica AK. Integrating Clinical Data and Molecular Profiling to Predict Antibiotic-Induced Anaphylaxis: A Comparative Study of Ceftriaxone and Meropenem. J Primeasia. 2025;6(1):1–11. https://doi.org/10.25163/primeasia.6110446

[36] Horak P, Griffith M, Danos AM, Pitel BA, Madhavan S, Liu X, Chow C, Williams H, Carmody L, Barrow-Laing L, et al. Standards for the classification of pathogenicity of somatic variants in cancer (oncogenicity): Joint recommendations of ClinGen, CGC, and VICC. Genet Med. 2022;24:986-998. https://doi.org/10.1016/j.gim.2022.01.001

[37] Akter MF, Manica AK, Siddique MAB, Tufael, Islam MR, Nusrat S. Structural Insights into TEM-1 β-Lactamase-Mediated Ceftriaxone Resistance in Escherichia coli: A Molecular Docking and Toxicity Analysis. Microb Bioact. 2025;8(1):1–11. https://doi.org/10.25163/microbbioacts.8110447

[38] Debnath A, Siddique MAB, Nath ND, Biswash MAR, Tufael. Emerging Alternatives to PCR for Efficient Nucleic Acid Amplification. J Primeasia. 2025;6(1):1–11. https://doi.org/10.25163/primeasia.6110167

[39] Richards S, Aziz N, Bale S, Bick D, Das S, Gastier-Foster J, Grody WW, Hegde M, Lyon E, Spector E, et al. Standards and guidelines for the interpretation of sequence variants. Genet Med. 2015;17:405-424. https://doi.org/10.1038/gim.2015.30

[40] Chowdhury N, Mahat NC, Tufael, Siddique MAB. TGF-β1 as a Molecular Target and Vitamin D Interaction in Diabetic Nephropathy: A Bio-clinical Correlation Study. Integr Biomed Res. 2025;9(1):1–8. https://doi.org/10.25163/biomedical.9110450

[41] Sessa C, Balmaña J, Bober SL, Cardoso MJ, Colombo N, Curigliano G, Domchek SM, Evans DG, Fischerova D, Harbeck N, et al. Risk reduction and screening of cancer in hereditary breast-ovarian cancer syndromes: ESMO Clinical Practice Guideline. Ann Oncol. 2023;34:33-47. https://doi.org/10.1016/j.annonc.2022.10.004

[42] Pilarski R. The Role of BRCA Testing in Hereditary Pancreatic and Prostate Cancer Families. Am Soc Clin Oncol Educ Book. 2019;39:79-86. https://doi.org/10.1200/EDBK_238977

[43] Tufael, PK MMU. Machine Learning in Cancer Biology: Transforming Diagnosis, Prognosis, and Treatment in Modern Medical Research. J Ai ML DL. 2025;1(1):1–10. https://doi.org/10.25163/ai.1110405

[44] Calabrese A, Von Arx C, Tafuti AA, Pensabene M, De Laurentiis M. Prevention, diagnosis and clinical management of hereditary breast cancer beyond BRCA1/2 genes. Cancer Treat Rev. 2024;129:102785. https://doi.org/10.1016/j.ctrv.2024.102785

[45] Tufael, Rashid MJ, Amin MS, Rahman A. Unmasking the Dual Threat of mRNA Vaccines: Spike Protein Toxicity, Nanorobotic Vectoring, and the Promise of Signal-Based Medicine. J Precis Biosci. 2025;7(1):1–10. https://doi.org/10.25163/biosciences.7110288

[46] Tufael, Akter, M. F., Islam, M. R., Siddique, M. A. B., Hassan, N., Numan, A. A., Naher, A. A., Shabuj, M. M. H., Manica, A. K., Shaikat, B., Rabbani, T. B. (2025). "Encoded Resistance: Structural Disruption and Signaling Crosstalk Undermine Sorafenib Binding in Mutant VEGFR2-Driven HCC", Paradise, 1(1),1-8,10427. https://doi.org/10.25163/paradise.1110427

[47] Vaz-Drago R, Custódio N, Carmo-Fonseca M. Deep intronic mutations and human disease. Hum Genet. 2017;136:1093-1111. https://doi.org/10.1007/s00439-017-1809-4

[48] Amin MS, Rashid MJ, Tufael, Rahman A. Probiotics as Emerging Neurotherapeutics in Spinal Cord Injury: Modulating Inflammation, Infection, and Regeneration. Microb Bioact. 2025;8(1):1–11. https://doi.org/10.25163/microbbioacts.8110290

[49] Tamanna SF, Noyel M, Fatin M, Rabbi MH, Das DC, Tufael. Nanotechnology in Agriculture and Water Quality Management. Appl Agric Sci. 2025;3(1):1–12. https://doi.org/10.25163/agriculture.3110170

[50] Nagahashi M, Shimada Y, Ichikawa H, Kameyama H, Takabe K, Okuda S, Wakai T. Next generation sequencing-based gene panel tests for the management of solid tumors. Cancer Sci. 2019;110:6-15. https://doi.org/10.1111/cas.13837

[51] Khan MSS, Tufael. Innovations in Cancer Research and Treatment. J Precis Biosci. 2025;7(1):1–11. https://doi.org/10.25163/ahi.7120050

[52] Rashid MJ, Amin MS, Tufael, Rahman A. Unintended Genetic Consequences of mRNA Vaccines: Evaluating Risks of Transcriptional Disruption, HLA Alteration, and Genomic Integration. J Precis Biosci. 2025;7(1):1–11. https://doi.org/10.25163/biosciences.7110287

[53] Parvin, N.; Joo, S.W.; Jung, J.H.; Mandal, T.K. Multimodal AI in Biomedicine: Pioneering the Future of Biomaterials, Diagnostics, and Personalized Healthcare. *Nanomaterials* **2025**, *15*, 895. https://doi.org/10.3390/nano15120895

[54] Jiang X, Ji J, Yang Q, Dou Y, Li Y, Yang X, Liu C, Dou S, Dong L. Key Technologies of Synthetic Biology in Industrial Microbiology. *Microorganisms*. 2025; 13(10):2343. https://doi.org/10.3390/microorganisms13102343

[55] Athanasopoulou K, Michalopoulou V-I, Scorilas A, Adamopoulos PG. Integrating Artificial Intelligence in Next-Generation Sequencing: Advances, Challenges, and Future Directions. *Current Issues in Molecular Biology*. 2025; 47(6):470. https://doi.org/10.3390/cimb47060470